# MEDICON 2026

XVII Mediterranean Conference on Medical and Biological Engineering and Computing

# BOOK OF ABSTRACTS

September 14–17, 2026
Siena, Italy

Edited by
Ernesto Iadanza

Organised by UNIVERSITÀ DI SIENA 1240 BIOENGINEERING LAB Department of Medical Biotechnologies Promoted by EAMBES AIIC associazione italiana ingegneri clinici Proceedings by Springer

Co-Sponsored by IFMBE UNIVERSITY OF WARWICK INBIT MedTech Projects ΕΛΕΒΙΤ Endorsed by COMUNE DI SIENA

# BOOK OF ABSTRACTS

Organised by:

Promoted by:

Co-Sponsored by:

Endorsed by:

Ernesto Iadanza

# COMMITTEES

## LOCAL ORGANIZING COMMITTEE – UNIVERSITY OF SIENA

Prof. Ernesto Iadanza (Conference Chair)
Prof. Tommaso Addabbo
Mr. Alberto Balistreri
Prof. Alessandra Cartocci
Prof. Gabriele Cevenini
Prof. Elisa Frullanti
Prof. Simone Grandini
Ms. Sofia Lo Conte
Dr. Alessio Luschi
Prof. Chiara Mocenni
Dr. Maria Palmieri
Prof. Domenico Prattichizzo
Mr. Ali Salman
Dr. Viola Serio
Ms. Adna Softić
Mr. Alessio Rotelli
Prof. Pietro Rubegni
Prof. Linda Tognetti

## SCIENTIFIC PROGRAMME COMMITTEE

Milos Ajcevic, *University of Trieste*
Riccardo Bellazzi, *University of Pavia*
Stefano Bergamasco, *Associazione Italiana Ingegneri Clinici*
Paolo Bifulco, *University of Naples "Federico II"*
Li Bin, *IFMBE CED*
Fabiano Bini, *Sapienza University of Rome*
Leonardo Bocchi, *University of Florence*
Giacomo Cappon, *University of Padua*
Daniela Cardone, *Università degli Studi "G. d'Annunzio" Chieti – Pescara*
Federico Carpi, *University of Florence*
Filippo Cavallo, *University of Florence*
Andrea Cereatti, *Politecnico di Torino*
Gabriele Cevenini, *University of Siena*
Lorenzo Chiari, *University of Bologna*
Oriana Ciani, *Bocconi University*
Gastone Ciuti, *Scuola Superiore Sant'Anna*
Paulo De Carvalho, *University of Coimbra*
Ugo Della Croce, *University of Sassari*
Carmelo De Maria, *University of Pisa*
Aris Dermitzaki, *University of Patras*

# TABLE OF CONTENTS

## KEYNOTE PRESENTATIONS



## ORAL PRESENTATIONS

### Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 5A)



### Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 5B)



### Digital, Remote, and Wearable Healthcare Technologies (Session 5C)



### Medical Imaging, Simulation, and Immersive Technologies (Session 5D)



### MS From Users to Cocreators (Session 5E)

## Plenary session (Session 7)



## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies (Session 8A)



## MS Cardiomechanical monitoring techniques (Session 8B)



## MS Artificial Intelligence in Lung Cancer Screening (Session 8C)



## MS AI Applications in Clinical Engineering (Session 8D)



## MS IUPESM From Concept to Impact (Session 8E)



## MS Governing Health Technology Innovation: A Subsidiary HTA Approach in Italy (Session 8F)

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 10A)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 10B)



## Digital, Remote, and Wearable Healthcare Technologies (Session 10C)



## Medical Imaging, Simulation, and Immersive Technologies (Session 10D)



## SS Evolving Medical AI (Session 10E)



## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies (Session 12A)

## Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management (Session 12B)



## MS Harmonising BME Education (Session 12C)



## SS Bridging the Gap: A Multi-Stakeholder Dialogue on Essential Skills for the Future Biomedical Engineer (Session 12D)



## SS Next-Generation Neural Interfaces, Motor Control and Neurorehabilitation (Session 12E)



## SS HPC - driven molecular modelling and enzyme dynamics in precision and translational (Session 12F)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 14A)

## Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management (Session 14B)



## Medical Imaging, Simulation, and Immersive Technologies (Session 14C)



## SS Bridging the Innovation Gap (Session 14D)



## SS EAMBES Special Session on recognition of Biomedical Engineers in European hospitals and health institutions (Session 14E)



## SS ICT and Open Data in Healthcare (Session 14F)



## Plenary session (Session 15)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 17A)

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 17B)



## SS Nonlinear Methods for Medical Data Analysis (Session 17C)



## Biomedical Signal Processing and Physiological Systems Engineering (Session 17D)



## IFMBE Scientific Challenge (Session 17E)



## Plenary session (Session 19)

## SS Designing Future Ready BME Programs (Session 21A)



## Biomedical Signal Processing and Physiological Systems Engineering (Session 21B)



## SS Frontiers in Neuroimaging (Session 21C)



## MedTechLabel: A Universal Digital Labelling Framework for MDs and IVDs (Session 21D)



## SS EAMBES: AI in MDs – Bridging BME Innovation and Clinical Practice in Europe (Session 21E)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 22A)



## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies (Session 22B)

## SS IFMBE Students and Recent Graduates (Session 22C)



## SS AI and Shared Decision-Making in Breast Cancer (Session 22D)



## Workshop: Designing Future Ready BME Programs (Session 22E)



## MS Medical Equipment Ageing: Implications for Maintenance Strategies, Lifespan Modelling and Replacement Planning (Session 22F)



## Plenary session (Session 24)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 25A)



## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine (Session 25B)



## Biomedical Signal Processing and Physiological Systems Engineering (Session 25C)

### SS Responsible AI in Healthcare (Session 25D)



## POSTER PRESENTATIONS

# KEYNOTE PRESENTATIONS' ABSTRACTS

**Sergio Cerutti**

Session 3
Monday September 14, 10:00-10:30

### 50 years of Bridge building between Biomedical Signal Processing and Physiological Modelling and what's the Next

Looking back at the history of MEDICON's – Mediterranean Conferences on Medical and Biological Engineering (the first one was held in Sorrento 1977), it is remarkable to notice that since the beginning there has been a significant development in both Biomedical Signal Processing methods and technologies as well as in Physiological Modelling. These two aspects of Biomedical Engineering strongly characterise the research and application achievements. But, which is more important, the two separate research topics have found synergies and common developments which produced an enormous amount of dedicated literature. Just to consider the item of Heart Rate Variability only, which is pivotal in signal processing and physiological applications, actually almost 4M papers refer to this keyword (Google Scholar, 2026), almost in the same time span of 50 years. Many Medical and Biomedical Engineering research groups (with relevant Italian participation, too) introduced and discussed physiology-related and signal processing-driven methods, parametric vs non-parametric and linear vs non-linear methods. Now, the goal for future investigations will be to be able to integrate these findings with proper algorithm of Artificial Intelligence (AI) which could suggest further correlations and connections for prioritarily improving medical and bioengineering knowledge, typical of Human Intelligence (HI).

**Sridevi V. Sarma**

Session 4
Monday September 14, 10:30-11:00

### Measuring Neural Health: An Energetic Signature of the Living Brain

Quantifying neural health before irreversible decline occurs remains one of the central challenges in neuroscience and medicine. Across epilepsy, psychiatric illness, neurodevelopmental disorders, and neurodegeneration, we lack a unifying physiological standard that defines what a "healthy brain" truly is - and how it begins to fail. In this talk, I will introduce the Brain Entropy Index (BEI), a physics-grounded biomarker built on two organising principles of living neural systems: entropy maximisation in spatial energy distributions and tight homeostatic regulation of neural activity. In a healthy resting brain, energy is broadly and efficiently distributed across regions, reflecting high entropy, while remaining remarkably stable and tightly controlled. BEI operationalises neural health through five measurable energetic properties: lognormal energy distributions, balanced regional allocation, statistical independence between regions, low variance, and temporal stability. I will present results from multimodal EEG, fMRI, and MEG datasets comprising over 525 participants across neurological, psychiatric, neurodevelopmental, and neurodegenerative conditions. BEI not only differentiates healthy and clinical populations, but scales with disease severity and generalises across diagnostic categories and imaging modalities. These findings suggest the existence of a disease-agnostic, modality-invariant energetic signature of neural health. By reframing brain function through the lens of energetic organisation, BEI provides a quantitative foundation for early detection, patient stratification, and real-time monitoring of therapeutic response.

**Maria Chiara Carrozza**

Session 11
Tuesday September 15, 11:30-12:00

### Giving Shape to Intelligence: Robotics, Embodiment and the Quest to Understand Natural Intelligence

Recent advances in generative artificial intelligence have demonstrated extraordinary capabilities in language, reasoning, content generation, and knowledge representation. Yet, despite their human-like outputs, these systems remain fundamentally disembodied. Their intelligence emerges primarily from large-scale statistical learning and data-driven optimisation, although generative AI produces human-like outcomes, even though its knowledge is derived from human experience only indirectly, through language and the analysis of human-generated texts, rather than through perception, action, and physical engagement with the world. Robotics offers a complementary perspective. By endowing artificial intelligence with a body, robotics transforms abstract computation into action, perception, and motor behaviour. Even when limited in comparison with biological organisms, a robotic body provides the physical substrate through which intelligence can develop, adapt, and acquire meaning. In this sense, robots can be viewed as a particular form of artificial intelligence: intelligence given shape. This lecture will discuss how the concept of embodiment has become central to the evolution of robotics and how bioinspired design has increasingly guided the development of robots capable of more adaptive, efficient, and robust behaviour. Biological systems demonstrate that cognition, perception, and motor control emerge from the continuous interaction between brain, body, and environment. Inspired by these principles, robotics has evolved from purely engineering-driven approaches toward biologically grounded paradigms that seek to reproduce not only intelligent behaviour but also the mechanisms that generate it.

**Jari Hyttinen**

Session 18
Wednesday September 16, 11:30-12:00

### Multiscale cardiovascular hybrid digital twins for stratification of hypertrophic cardiomyopathy patients

Hypertrophic cardiomyopathy (HCM) is a prime example of cardiac myopathy arising from multiple causal gene mutations, expressing clinical heterogeneity with complex, multiscale manifestations ranging from molecular and cellular function, tissue structure, to cardiac function. Moreover, HCM from heart to the entire cardiovascular system. However, it is diagnosed as just one disease. To address this, a better understanding of the disease is needed, and tools to stratify and treat patients require integration and use of data from molecular and cellular mechanisms, genotypic traits, population-level clinical data, and patients' phenotypic findings. Thus, HCM makes a great target for patient digital twin development. In the talk, I will bring together the methodologies and tools developed within SMASH-HCM, an EU HORIZON-Digital Twin themed project, which aims to develop and validate a digital twin platform to support clinicians with better stratification and patient management strategies, tailored to individual patient pathophysiology, genotype, and phenotype in hypertrophic cardiomyopathy. To develop the HCM patient digital twin, we integrate data from different scales from the molecular manifestation of the disease to patient cellular, tissue, whole-heart, and finally entire cardiovascular systemic level models. The in vitro and in silico model insights into the disease and drug mechanisms form the foundation on which we integrate structured clinical and unstructured data-based models, with emphasis on explainable artificial intelligence towards better understanding of the HCM pathophysiology. All these are being integrated into a three-level decision support solution with deep phenotyping and risk stratification tools to support clinical workflows and decision-making, enabling the development of effective personalised treatment and for the patients for their self-management and possible find new repurposed drugs to mitigate HCM. The SMASH-HCM toolset could offer an exemplar for future application to other cardiac myopathies and comorbidities.

# ORAL PRESENTATIONS' ABSTRACTS

**Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine**

Session 5A

Monday September 14, 11:30-13:00

## The Compromise Between Interpretability and Performance, Or, a Review of Machine Learning Methods for Collective Variable Discovery

*Faruk Bećirović, Adna Ašić, Nejra Merdović, Madžida Hundur Hiyari, Kanita Karađuzović-Hadžiabdić and Lemana Spahić*

Collective variable (CV) identification in biomolecular simulations represents a dimensionality reduction challenge in which high-dimensional molecular configurations must be projected onto low-dimensional representations capable of capturing the key dynamics of the system. Machine learning approaches have emerged as powerful alternatives to traditional physics-based methods; however, their adoption among computer scientists and computational practitioners has remained limited due to literature that often emphasizes chemical intuition over algorithmic considerations. This review provides a computational perspective on ML-based CV discovery by analysing the trade-offs between automation, interpretability, and performance across major algorithmic classes. The findings indicate that automation has largely been resolved across modern methods, leaving interpretability versus performance as the primary remaining trade-off. Linear methods, such as LDA variants and lasso regression surrogate models, offer high interpretability but may sacrifice performance, whereas neural networks achieve substantially greater sampling efficiency, with improvements of up to 200-fold, at the expense of mechanistic understanding. Hybrid approaches, including surrogate models and Bayesian frameworks, demonstrate strong potential to bridge this gap by combining near-optimal performance with improved interpretability. The review further presents a decision-making framework for algorithm selection based on research objectives, discusses transferability limitations, and identifies scalability and the preservation of interpretability as critical challenges for the next generation of methods.

## A Mortality Prediction Study on ICU Patients with Pneumonia

*Hoang Truong, Hoang Vo and Chau Vo*

Background: Pneumonia is a leading cause of ICU mortality, yet existing severity scores have limited accuracy for short-term mortality prediction. Objective: To develop a machine learning model for dynamic 24-hour mortality prediction in ICU patients with pneumonia. Methods: We analyzed 29,847 clinical snapshots from 17,648 pneumonia patients in the eICU database (200+ US hospitals). Snapshots were triggered at critical events (ICU admission, ventilation start, vasopressor start, lactate elevation). We proposed the Soft Voting ensemble which combined LightGBM and XGBoost as our primary solution, compared it with other models via the hold-out validation scheme, and assessed performance against an APACHE-only baseline. Results: The Soft Voting ensemble (LightGBM + XGBoost) achieved the highest PR-AUC of 0.372 (95% CI: 0.265–0.484) and ROC-AUC of 0.855 (95% CI:0.817–0.888), with Platt-calibrated calibration (Brier 0.0422, ECE 0.0107). The Soft Voting ensemble achieved a high PR-AUC improvement over APACHE-only logistic regression. SHAP analysis identified age, APACHE score, and maximum lactate as top predictive features. Conclusions: The Soft Voting ensemble substantially outperformed APACHE-based prediction, suitable for early warning applications. Nonetheless, external validation is required before clinical deployment.

## Digital Twins for Regulatory Testing of $CO_2$ Rebreathing in Continuous Positive Airway Pressure Masks

*Hossein Shamohammadi, Alice R. Harvey, Andrew Sims, Tejas Canchi and Declan G. Bates*

Regulatory requirements for safe levels of $CO_2$ rebreathing in continuous positive airway pressure (CPAP) masks used to treat obstructive sleep apnoea are specified in the ISO 17510:2015 Annex F protocol. Satisfaction of these requirements is currently mandated using physical bench testing on custom-built rigs. We used a previously validated cardiopulmonary simulator to develop physiologically informed digital twins that could facilitate in-silico assessment of $CO_2$ rebreathing. The digital twins were shown to be capable of closely matching the outputs of an industrial bench testing rig. Several enhancements to the digital twins were also introduced and evaluated: (1) replacement of the sinusoidal breathing profile with a subject-specific, asymmetric breathing waveform; (2) personalisation of tidal volume (VT), anatomical dead space (VDanat), and oxygen consumption ($VO_2$) using anthropometric data; (3) incorporation of a layered and conal mixing gas dynamics model in the CPAP mask; and (4) introduction of a CPAP jet-flow module capturing inlet mixing effects. Simulations were performed at baseline and at CPAP pressures of 3, 4, 5, and 10 $cmH_2O$ under two pathways: constant tidal volume at different CPAP pressures, replicating ISO 17510:2015 bench test conditions, and constant inspiratory effort at different CPAP pressures, replicating spontaneous breathing patterns typically observed in patients. Under constant inspiratory effort, end-tidal $CO_2$ pressure ($PexpCO_2$) increased monotonically with CPAP, with the largest relative increase of 18.8% remaining within the ISO-defined 20% safety threshold. The conal mixing model revealed physiologically plausible mask washout behaviour consistent with computational fluid dynamics literature, including jet-driven $CO_2$ clearance at higher pressures. Collectively, these results demonstrate that digital twins can replicate bench test outcomes and also potentially provide more patient-specific and more physiologically realistic testing than standardised physical bench tests, advancing the case for their incorporation into the regulatory assessment of CPAP and other non-invasive respiratory support systems.

## Classification-Guided Multi-Organ Segmentation in Abdominal Ultrasound via Feature Injection

*Simone Kresevic, Alberto Bortolotto, Mauro Giuffrè, Lisa Fusaro, Marco Gulotta, Marco Sartori, Francesca Orbosuè, Aleksandar Miladinovic, Lory Saveria Crocè and Milos Ajcevic*

Automated hepatorenal index (HRI) computation from abdominal ultrasound requires organ segmentation that remains reliable across all frames of a routine examination, including liver-only views where no renal cortex is visible.

Standard deep learning segmentation models fail silently on these out-of-distribution inputs, producing anatomically implausible masks that corrupt HRI estimates. In this study we developed a novel single-network architecture that replicates the clinician's cognitive process: first confirming the view type, then delineating organ boundaries. A shared ResNet34 encoder drives both a classification branch and a U-Net-like segmentation decoder augmented with explicit feature injection points at every upsampling stage. Two complementary injection mechanisms were evaluated (Feature-wise Linear Modulation (FiLM) for channel-wise conditioning and spatial attention gating) alongside a six-level progressive ablation study. On a multi-platform dataset of 801 patients, the combined model achieved mean organ DSC=0.91 and IoU=0.84 on hepatorenal views, with 94.3% balanced view-classification accuracy. Critically, on acoustically challenging frames where the segmentation-only baseline yields implausible masks (DSC=0.714), the proposed model recovers accurate predictions (DSC=0.965). Classification-guided feature injection is an effective and practical strategy to improve segmentation robustness across the distributional variability of routine abdominal ultrasound, providing a reliable foundation for automated multi-image HRI computation in MASLD screening.

### Edge Computer Vision for Arboviruses Vectors and Global Health Surveillance

*Mattia Muraro, Luca Bacco, Mario Merone, Leandro Pecchia and Filippo Crispino*

Vector-borne diseases pose a serious threat to global health, but traditional entomological surveillance is constrained by the slow, costly bottleneck of manual taxonomic identification. To overcome these barriers, we propose a rigorous pipeline for the development and validation of highly optimized Edge Computer Vision models designed for automated, in-the-field mosquito identification using ultra-low-cost, general-purpose hardware (Raspberry Pi 5). The methodology evaluated four distinct convolutional architectures through comprehensive ablation and data scalability studies, directly comparing standard transfer learning against deep fine-tuning strategies to effectively address severe class imbalance. Subsequently, the models underwent Full Integer Quantization, mapping floating-point parameters to an 8-bit discrete domain (INT8) to bypass the computational limitations of edge devices. Experimental validation revealed two striking operational achievements. First, prioritizing the epidemiological necessity to minimize false negatives, the fine-tuned MobileNetV2 architecture emerged as the optimal solution by achieving an exceptional recall of 95.65% on the target vector class. Second, the INT8 software optimization drastically compressed inference latency on the edge device's standard ARM CPU from 99.37 ms to a record 2.11 ms. This extraordinary 47-fold acceleration effectively matches the throughput of expensive dedicated AI hardware accelerators, laying a technologically robust and economically sustainable foundation for a highly scalable global IoT surveillance network.

### Design and Validation of a frugal, low-cost spirometry device for resource- constrained settings

*James Wallace*

Introduction: Respiratory diseases account for a substantial proportion of global deaths, disproportionately affecting populations in low- and middle-income countries (LMICs). In many low-resource settings (LRS), access to reliable diagnostic equipment such as spirometers remains limited due to cost, infrastructure requirements, and contextual constraints. Conventional medical devices are typically designed for high-income contexts and do not adequately address these challenges. This study presents the design and preliminary validation of a frugally engineered, low-cost spirometry device intended to support respiratory assessment in LRS using 3D printing, low-cost electronics, and data-driven processing. Materials and Methods: The spirometer's flow tube and casing was designed using CAD on fusion 360 and manufactured with 3D printing. The airflow modelling was based on Bernoulli's principles, relating volumetric flow rate and differential pressure in a constricted tube. Differential pressure across the tube was measured using a low-cost pressure sensor and interfaced with an Arduino-based microcontroller. Signal acquisition and processing were carried out using custom MATLAB routines, incorporating data processing techniques such as low pass filtering to compute standard spirometry variables. Bench validation was conducted using a handpump with a 2 L volume, while early-stage usability and performance were assessed through expiratory tests conducted by 30 participants, with results compared against a commercially available CE-marked spirometer. Results: The fabricated spirometry tube generated consistent and measurable differential pressure signals, which were successfully converted into airflow waveforms. Across 30 handpump trials, the device demonstrated a mean percentage error of 1.53%. During the usability evaluation, participants produced spirometry results within expected normal ranges and when compared to the CE-marked reference device, it achieved high reliability and consistency with this device. For FEV1 it achieved r= 0.97 and an ICC value of 0.97, indicating very high consistency between devices. Discussion: The proposed device demonstrated accuracy comparable to commercially available spirometers while remaining significantly lower in cost, with an estimated small-scale manufacturing cost of approximately £60. These results indicate strong potential for the device to contribute to improved respiratory diagnostics in LRS. Future work will focus on expanding functionality through the integration of machine learning techniques and further clinical validation.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 5B
Monday September 14, 11:30-13:00

### AIM-LRS: Integrated system workflow for Artificial Intelligence-assisted Microscopy-Based Screening of high-impact diseases in Low-Resource Settings

*Harold Angeles Gavidia, July Galeano and Sandra Pérez-Buitrago*

High-impact diseases, such as cervical cancer and Leishmaniasis, result in high morbidity and mortality rates, especially in low-resource settings due to a shortage of specialists and the centralization of diagnostic services. In Perú, rural healthcare providers face these challenges, known as structural gaps, which significantly delay conventional screening. This study proposes the AIM-LRS scheme as a three-hierarchical workflow to improve diagnostics of these diseases through the use of artificial intelligence and telemedicine. Methodology: The three layers proposed are defined as, Layer 1 describes the telemedicine workflow and the integration of processing via Convolutional Neural Networks. Layer 2 includes process monitoring using the Lean Healthcare methodology, and Layer 3 features a Store-and-Forward model for deferred data transmission. Results: Evaluation of the Value Stream Map revealed that Total Lead Time decreases from 25 days and 2.5 hours to just 7 hours and 10 minutes. Furthermore, the preliminary proposed architecture model for Layer 1-step 3, demonstrated an accuracy of 0.991 in detecting host cells and 0.993 in detecting nuclei. This validates the system’s ability to generate early alerts and optimize workflows in rural areas.

### A Phantom Dataset for Frame-Wise Registration Annotation in RAPN

*Anna Emilia Candela, Elisa Iovene, Laura Cruciani, Matteo Magnani, Sara Martuscelli, Federica Ferraguti and Elena De Momi*

Reliable augmented reality (AR) guidance in robot-assisted partial nephrectomy (RAPN) is still limited by the difficulty of accu- rately aligning preoperative models with the intraoperative scene in the presence of tissue deformation, manipulation, partial occlusions, and viewpoint changes. To support research on this problem, we present a patient-specific deformable kidney phantom dataset together with a proof-of-concept workflow for frame-wise reference alignment annotation in simulated RAPN. The dataset comprises 21 stereo recordings acquired from 7 participants across 3 difficulty levels and 4 representative RAPN task phases, for a total of 158,520 synchronized stereo pairs. Stereo en- doscopic videos were acquired on the da Vinci Research Kit (dVRK) during simulated tasks performed on a CT-derived deformable phantom. Phantom segmentation, stereo 3D reconstruction, and offline annotation- oriented rigid registration were used to associate the visible reconstructed phantom surface with the corresponding phantom model. A subset of 563 frames was manually annotated with validated frame-wise rigid reference alignments. Preliminary results indicate that the proposed workflow can recover plausible rigid alignments while also highlighting the limitations of a purely rigid formulation. Overall, the proposed framework provides a realistic reference dataset and a practical first step toward future de- formable annotation and registration studies for AR-guided RAPN.

### ACE and ACTN3 Polymorphisms in Bosnian and Herzegovinian Athletes Potential Implications for Personalised Sports Performance Profiling

*Ana Lalovic, Adna Ašić, Merima Smajlhodžić-Deljo, Amra Džuho, Neven Meseldžić, Tamer Bego, Adna Softić, Selena Hadžić, Sara Deumić, Ilma Hasanbegović, Jasminka Prguda-Mujić and Lejla Gurbeta Pokvić*

Genetic factors contribute to inter-individual variability in athletic performance, yet their practical relevance in heterogeneous athlete populations remains underresearched. This study investigated the distribution of angiotensin-converting enzyme (ACE) I/D and alpha-actinin-3 (ACTN3) R577X polymorphisms in 85 athletes from Bosnia and Herzegovina and explored their associations with sex and sport type. Genotyping was performed using real-time PCR, and genotype and allele frequencies were analysed using descriptive and inferential statistics. The ACE ID genotype (43.5%) and ACTN3 RX genotype (47.1%) were the most prevalent, and both polymorphisms were in Hardy-Weinberg equilibrium. No statistically significant associations were observed between genotype distribution and sex or sport type, although descriptive trends suggested a somewhat higher prevalence of power-oriented profiles in athletes from power disciplines. These findings indicate limited predictive value of individual polymorphisms in this cohort and support a polygenic and multifactorial model of athletic performance. The results provide initial insight into the genetic structure of athletes from Bosnia and Herzegovina and highlight the need for integrative approaches in personalised sports performance profiling.

### Knee Osteoarthritis as a Multi-Tissue Disease: Multivariate Analysis of Cartilage, Bone, and Muscle on CT imaging

*Federica Kiyomi Ciliberti, Ida Maruotto, Simona Correra and Paolo Gargiulo*

Knee osteoarthritis (KOA) is increasingly recognized as a multi□tissue disease involving articular cartilage, subchondral bone, and surrounding musculature. However, most imaging studies still focus on individual tissues, limiting insight into joint□level degeneration. In this study, we propose a multi□tissue imaging framework to investigate coordinated structural alterations across cartilage, bone, and muscle in KOA. Quantitative morphological and densitometric features were extracted from cartilage segmented on MRI and projected onto co□registered CT scans, as well as from subchondral bone and knee muscles segmented directly on CT. Canonical Correlation Analysis (CCA) was used to characterize multivariate associations between cartilage and bone, and between cartilage and muscle, with statistical significance assessed via permutation testing. Strong and significant multivariate coupling was observed for both tissue pairs. The first canonical correlation reached r=0.80 for cartilage–bone and r=0.95 for cartilage–muscle, indicating particularly strong shared variation with muscle tissue. Loadings analysis revealed that density□related features dominated cross□tissue associations, with subchondral bone density variability and intramuscular adipose tissue (IMAT) properties emerging as key contributors. Classification analyses further demonstrated the added value of a multi□tissue approach: combining cartilage features with CCA□selected bone or muscle features improved discrimination between degenerative and control knees, achieving F1 scores up to 0.82 ± 0.09, compared to 0.72 ± 0.17 using cartilage alone. Overall, these findings support a system□level view of KOA and highlight the potential of multi□tissue quantitative imaging biomarkers for improved disease characterization.

### Gender-Aware Digital Twins for Cognitive Decline

*Ankica Babic*

Digital twins are increasingly proposed as patient-specific, dynamically updated computational representations that integrate multimodal data to support prediction, monitoring, and personalized care. In cognitive decline and dementia, their potential is considerable because disease progression is slow, heterogeneous, and shaped by biological, cognitive, clinical, and social factors. However, digital twins will remain clinically incomplete unless they capture sex- and gender-related differences in disease burden, symptom presentation, testing performance, care pathways, treatment exposure, and support needs. Women carry a disproportionate burden of Alzheimer's disease and related dementias and often show better early verbal-memory performance, which can mask disease and delay diagnosis. The objective of this paper is to define a gender-aware digital-twin perspective for cognitive loss and to translate the literature into design requirements for an integrative IT framework. Electronic health records (EHRs), natural language processing (NLP), digital cognitive assessment, gamified testing, and longitudinal monitoring apps together provide an important technological basis for such a framework. The paper argues that the digital twin should be understood not as a single tool or as a conventional electronic health-record platform, but as a modular, continuously updated patient model that links interoperable assessment, prediction, follow-up, and support components. Such systems should be co-developed with patients, caregivers, relatives, and clinicians to better address women's diagnostic and long-term care needs across the care continuum

## Digital, Remote, and Wearable Healthcare Technologies

Session 5C
Monday September 14, 11:30-13:00

### Development of a Novel Lactation Phantom and Measurement Device for Breast Milk Expression

*Hailey Jones, Owen Kingstedt and Edoardo Battaglia*

Accurate, practical measurement of milk intake during breastfeeding remains a major unmet need, as existing methods are limited by cost, inconvenience, or lack of suitability for routine use. Motivated by this gap in maternal and infant care, we developed a flexible sensing technology for live tracking of milk expression from the breast. To support development of this approach, we modified a silicone-based breast phantom to produce controlled internal volume changes representative of lactation-related deformation and suitable for repeatable benchtop testing. Using this platform, we evaluated multiple attachment methods for Velostat-based strain sensors, including adhesives, fabrics, and tapes, to determine their ability to reliably track phantom deformation. The phantom produced repeatable displacement fields with peak surface displacements on the order of millimeters, and when the internal volume was increased by 50 mL, DIC-based surface reconstruction estimated a volume change of 45.49 mL, corresponding to a 9% error. Among the attachment methods tested, medical tape-based approaches, particularly kinesiology tape and transparent film medical dressing, showed the most reliable sensor performance, while glue- and bra-based attachments were less effective and more difficult to implement consistently. These results support the use of the phantom as a benchtop testbed for lactation sensing and indicate that surface-mounted Velostat-based sensors are a promising approach for future wearable device development.

### Multimodal Physiological Response Profiles in Robot-Assisted Gait Training: A Comparative Case Study in Cerebral Palsy

*Elena Campilii, Paola Giancaterino, Francesco Romano, David Perpetuini, Teresa Paolucci, Emanuele Francesco Russo, Maria Teresa Gatta, Marta Di Nicola, Giovanni Morone, Irene Ciancarelli, Antimo Moretti, Francesca Gimigliano, Sara Moccia, Arcangelo Merla and Daniela Cardone*

Robot-assisted gait training (RAGT) is widely used in paediatric neurorehabilitation for children with cerebral palsy (CP), yet the physiological mechanisms underlying individual rehabilitation response remain insufficiently characterized. This study investigates the relationship between multimodal physiological adaptations and clinical outcomes through a comparative case analysis of two children with CP characterized by different levels of motor impairment (Case A: GMFCS II; Case B: GMFCS V). A multimodal framework integrating heart rate variability (HRV), facial infrared thermography (IRT), and exoskeleton-derived symmetry indices was employed. Physiological features were expressed as changes between baseline and post-intervention (ΔT2–T0) and analysed alongside clinical outcomes, including GMFM, MAS, WeeFIM, and PedsQL. Both cases exhibited clinical improvements, although with different domain-specific patterns. Case A showed moderate gains in motor function and autonomy, while Case B demonstrated larger improvements in quality of life and functional independence, associated with distinct physiological adaptation profiles. Case A exhibited a pronounced modulation of autonomic activity, whereas Case B showed a more consistent increase in thermal high-frequency components and improvements in biomechanical symmetry. These findings suggest that rehabilitation response is characterized by subject-specific physiological patterns and cannot be described by a single biomarker. Multimodal monitoring may support the development of personalized rehabilitation strategies.

### Detection of Pressure-induced Faults in Continuous Glucose Monitoring Sensors using a Dynamic Time Warping-based Approach

*Francesco Prendin, Elena Idi, Andrea Facchinetti, Giovanni Sparacino and Simone Del Favero*

Continuous Glucose Monitoring sensors (CGMs) are portable, minimally invasive devices that are transforming the management of Type 1 Diabetes (T1D). Pressure-induced sensor attenuations (PISAs) are artifacts that can lead to false low glucose readings, compromising the reliability of the sensors. This study investigates the application of Dynamic Time Warping (DTW) algorithm, a pattern recognition technique to assess the similarity between time-series data, for the retrospective identification of these faults. DTW algorithm is employed for detecting a sequence with a specific shape (associated to a PISA episode) in a larger signal and has the ability of handling variations in the duration and timing of the events through a non-linear alignment of the time-series considered. The algorithm is tested using a dataset generated by a state-of-the-art T1D patient simulator. Results show that DTW achieves a recall of 0.87 with an average of 2 false alarms during the monitoring period (10 days). These findings highlight the potential of DTW to enhance CGM reliability, providing a robust method for detecting sensor faults and contributing to the development of more accurate diabetes monitoring technologies.

### PillsGuard: An IoT-Based System for Safe Medication Administration and Error Reduction in

### Clinical Environments

*Cristina Aldana Palomino, Eisel Pinado and Luis Vilcahuamna*

Medication administration remains a critical and error-prone process in healthcare systems, with significant implications for patient safety and clinical outcomes. This study presents PillsGuard, an Internet of Things-based platform designed to enhance the safety and accuracy of medication administration through automated verification and real-time alert mechanisms. The proposed system integrates barcode identification, a microcontroller-based architecture, and multimodal feedback interfaces to validate the correspondence between patient, medication, dosage, and administration schedule. The platform includes modules for data acquisition, processing, visualization, and automated medication dispensing using servo-controlled mechanisms. Additionally, the system provides visual and auditory alerts to support healthcare personnel during decision-making. The solution was developed following structured design methodologies and evaluated in a simulated clinical environment. Results demonstrate the feasibility of the system and its potential to reduce medication errors and improve workflow efficiency. PillsGuard represents a scalable and cost-effective approach for strengthening patient safety by integrating real-time validation and automation into medication management processes, with future applicability in real clinical settings.

### Inspiratory Power-Controlled Ventilation – A New Option To Reduce Ventilator-Induced Lung Injury Risk

*Marek Darowski, Barbara Stankiewicz, Krzysztof Jakub Pałko, Raman Pasledni, Krzysztof Zieliński, Maciej Kozarski and Tomasz Urbankowski*

This study evaluated whether inspiratory power–controlled ventilation (IPCV) produces distinct mechanical loading patterns compared with volume-controlled (VCV) and pressure-controlled ventilation (PCV), with respect to Ventilatory-Induced lung injury (VILI). A hybrid respiratory simulator connected with a novel IPCV ventilator was used to reproduce lung conditions: normal adult mechanics and Acute Respiratory Distress Syndrome (ARDS). Ventilatory modes: VCV, PCV, and IPCV were tested at respiratory rates (RR) of 10, 15, and 20 breaths/min. Airway pressures, inspiratory and expiratory flows, ventilator-delivered work of breathing, and inspiratory mechanical power were analysed. Simulations proved that ventilation modes significantly affected all analysed variables. The biggest differences between IPCV, VCV and PCV were observed in maximal inspiratory mechanical power (MPmax), peak inspiratory flow (PIF), and work of breathing (WOB). For example, in IPCV mode at 15 breaths/min, MPmax, PIF, and WOB were 81.26, 29.36, and 7.32% lower, respectively, than in PCV ($P<0.001$). MPmax was also higher (12.74%; $P<0.001$) in VCV, compared to IPCV. However, PIF and WOB in VCV were lower by 24.49 and 5.86%, respectively, than in IPCV ($P<0.001$). In conclusion, the IPCV represents a distinct strategy for organising inspiratory energy delivery that can significantly diminish MPmax and consequently the risk of VILI, with effects influenced by RR and respiratory system mechanics. Conflict of Interest: All authors have no conflicts of interest. Acknowledgement: This research was fully funded by the National Science Centre, Poland, under Grant No. 2023/50/A/ST7/00498.

## Medical Imaging, Simulation, and Immersive Technologies

Session 5D
Monday September 14, 11:30-13:00

### Analysis of landmark-based coordinates for mouse intracerebroventricular surgery using in vivo X-ray microtomography

*Mattia Humbel, Christine Tanner, Hans Deyhle, Marta Girona Alarcón, Britta Bausch, Willy Kuo, Petr Pleskač, Arash Panahifar, Sergey Gasilov, Britta Engelhardt, Steven Proulx, Vartan Kurtcuoglu and Bert Müller*

Stereotaxic surgery on rodents is a delicate procedure essential for research on central nervous system physiology and pathology. Surgeons generally rely on post-mortem-based atlases that only represent the cerebrospinal fluid spaces in collapsed state. This synchrotron radiation-based in vivo tomography study with 12-week-old C57BL/6J mice enabled the extraction of the cerebrospinal fluid space and relevant stereotaxic landmarks to optimize the intracerebroventricular infusion. For this purpose, we injected a contrast agent into the right lateral ventricle. Its temporal distribution could be followed by a series of tomograms acquired at the BMIT-ID beamline of the Canadian Light Source. The segmented cerebrospinal fluid spaces and the semi-automatically determined stereotaxic landmarks were rigidly aligned to an anatomically oriented reference frame. For 14 mice, the 3D coordinates within the left lateral ventricle with the maximum distance to its surface were correlated to the animal's weight and sex. The stereotaxic coordinate frame showed an overlapping volume of 0.85 $mm^3$ of the left lateral ventricles. The optimized coordinates were 90 µm deeper for males with respect to females. Therefore, separate sets of stereotaxic coordinates for ventricular infusion should be considered for female and male mice with the aim to improve the success of the procedure.

### Quantitative assessment of Crossed Cerebellar Diaschisis in ischemic stroke using a CT Perfusion normalization framework

*Andrea Bonini, Katerina Iscra, Marcello Naccarato, Giovanni Furlanis, Edoardo Ricci, Paolo Manganotti and Milos Ajcevic*

CT perfusion can be applied to detect CCD in acute stroke by analysing cerebellar perfusion abnormalities. This study presents a method for CCD assessment in the acute phase of ischemic stroke, enabling detailed characterization of cerebellar asymmetry through a novel perfusion normalization framework applied to CTP maps. CT Perfusion images were registered to standard space using an ad hoc procedure and global and regional asymmetry indices in Sensorimotor, Cognitive and Vestibular areas, were derived from standardized MTT maps. Voxel-wise analysis was performed to characterize the spatial distribution of cerebellar perfusion asymmetries using a seed-based region-growing algorithm. Patients were stratified according to admission stroke severity. Global and regional asymmetry indices were compared. Associations between asymmetry intensities and neurological deficit at admission and clinical outcome were investigated.

Global asymmetry was observed in 76.5% of patients. Voxel-wise analysis revealed specific spatial patterns reflecting cerebrocerebellar organization. Patients with more severe stroke showed higher global and regional asymmetry, particularly in Sensorimotor cerebellar region, which represented the most affected territory. Increasing asymmetry was associated with worse neurological status and lower odds of favourable outcome. This study advances the characterization of CCD in acute ischemic stroke by introducing an approach allowing comprehensive assessment of cerebellar perfusion abnormalities.

### Design and Preliminary Testing of an Event-Triggered Mixed Reality System for Ataxia Assessment

*Alessia Finti, Michela Franzò, Giovanni Pasini, Francesca De Maio, Begido Doda, Mariano Serrao, Franco Marinozzi and Fabiano Bini*

Objective assessment of upper limb function remains a critical challenge in monitoring cerebellar ataxia, as traditional clinical scales often lack the sensitivity required to detect subtle changes in fine motor control. This work introduces an innovative Mixed Reality (MR) framework that integrates an ecological functional task—inspired by gardening activities—with an automated kinematic analysis pipeline. Developed for the Microsoft HoloLens 2 platform, the system employs event- triggered data acquisition to segment the task into three distinct operational phases: digging, sowing, and watering. This approach enables the extraction of granular metrics for each step, allowing for a clear distinction between motor planning latency and executive efficiency. Preliminary results from two healthy subjects demonstrated the system's capability to map specific error patterns, such as apical trajectory deviations and proximal-distal coordination instability during rotational movements. The extracted metrics (RMS accuracy, target stability, and drift) confirm the robustness of the pipeline and its capacity to generate interpretable quantitative indicators. The framework is designed to complement standard clinical scales, providing therapists with objective data to personalize rehabilitation interventions and support the longitudinal monitoring of motor performance in patients with coordination disorders.

### Study of Nuclear Eccentricity and Gene Expression in MC3T3 During Osteogenic Commitment

*Luigi Manzo, Karina Ovejero Paredes and Joseph Lovecchio*

Osteogenic commitment is a complex and tightly regulated process that involves coordinated changes at both the morphological and transcriptional levels. As cells progressively acquire an osteoblastic phenotype, they undergo structural and transcriptional rearrangements that reflect the activation of lineage-specific programs, which are critical for proper bone formation and tissue homeostasis. The aim of this study is to determine whether nuclear eccentricity correlates with transcriptional activation during osteogenic commitment, providing a potential quantitative marker to monitor early differentiation events. Among the most evident morphological alterations is the variation in nuclear shape and spatial organization, which mirrors chromatin reorganization associated with differentiation and may reflect underlying cytoskeletal remodeling and mechanical adaptations. Nuclear architecture is increasingly recognized as a sensitive indicator of cell fate transitions, as it integrates mechanical cues, chromatin dynamics, and transcriptional activity within a dynamic three-dimensional nuclear environment. In this project, nuclear eccentricity will be analyzed in MC3T3 cells, a well-established preosteoblastic cell line widely used as an in vitro model of osteogenesis. These cells represent a reliable system to investigate both early and late events associated with osteogenic differentiation, providing insights into cellular behavior during lineage commitment. Cells will be cultured for 21 days under osteogenic induction conditions using a differentiation medium containing specific osteoinductive supplements such as ascorbic acid, β-glycerophosphate, and melatonin, and will be compared with undifferentiated control cells maintained in standard growth medium. This experimental design will allow a comprehensive assessment of both morphological and molecular changes associated with the progression of osteogenic commitment. Nuclear morphology will be evaluated through DAPI staining followed by fluorescence microscopy imaging, enabling clear visualization of nuclear contours and overall nuclear organization. A quantitative morphometric analysis will be performed to determine nuclear eccentricity as a descriptive parameter of nuclear remodeling. Acquired images will be analyzed using ImageJ software to calculate eccentricity values, allowing objective, reproducible, and precise quantification of nuclear shape. This approach will allow discrimination between more rounded nuclei (characterized by low eccentricity values) and more elongated nuclei (characterized by high eccentricity values), providing a measurable indicator of structural adaptation and cellular remodeling. In parallel, gene expression analysis of major osteogenic markers, including both early and late differentiation genes (RUNX2, Alkaline phosphatase, Osteocalcin, Osteopontin, Osteonectin, Osterix, Collagen type I) will be performed using qRT-PCR. This combined evaluation of morphological and molecular parameters will provide insight into the relationship between nuclear remodeling and osteogenic transcriptional activation. Overall, this project aims to establish nuclear eccentricity, together with osteogenic gene expression, as complementary and reliable parameters for monitoring osteogenic commitment and assessing whether cellular differentiation is effectively progressing toward the correct lineage fate in a controlled in vitro system.

### Advanced Deep Learning Framework for Otosclerosis Detection in Computed Tomography Scans Using Vision Transformers

*Gustavo J. Meschino, Virginia Laura Ballarin, Nicolas Nieto Arias and Carlos Capiel Jr.*

Otosclerosis is a complex middle-ear pathology characterized by subtle bone remodeling that can lead to severe hearing loss if not detected early. Although Computed Tomography (CT) is the gold standard for clinical evaluation, diagnosing early-stage otosclerosis remains highly challenging due to low radiological contrast and high operator dependency, particularly for non-specialist clinicians. Building upon prior convolutional neural network (CNN) benchmarks that achieved an initial baseline accuracy of 81%, this study aims to develop and validate an enhanced diagnostic framework designed to improve classification performance and robustness in clinical decision support. The primary contribution of this research is the integration of multi-head self-attention mechanisms and

Vision Transformers (ViTs) specifically optimized for high-resolution temporal bone CT patches. Unlike traditional CNN approaches that focus strictly on local pixel-level features, this hybrid architecture captures long-range spatial dependencies and global contextual changes across complex ear anatomy, thereby drastically minimizing false negatives in early fenestral and retrofenestral lesions. The expanded framework was trained and evaluated using an enriched dataset of temporal bone CT images from patients with confirmed otosclerosis. We implemented a hybrid CNN-ViT architecture in which convolutional layers serve as feature extractors and transformer blocks process the embedded tokens to model macro-structural relationships. Model validation was performed using a multi-cycle hold-out strategy. Furthermore, gradient-weighted class activation mapping (Grad-CAM) was integrated into the interface to ensure diagnostic explainability for radiologists. Preliminary evaluations of the transformer-based framework demonstrate a substantial performance leap, achieving 89% predictive accuracy in discriminating pathological states from normal cases. This represents an 8% improvement over our previous CNN-only baseline. Expert radiological validation confirmed that the model's self-attention maps accurately align with true hypodense otosclerotic foci, enhancing both diagnostic precision and clinician trust. The proposed AI framework offers a highly accurate, explainable, and non-invasive tool for automated otosclerosis screening. By shifting from local convolutions to global attention mechanisms, this system will provide reliable diagnostic support, potentially democratizing access to specialized otological expertise and facilitating timely surgical or medical interventions to preserve patients' hearing.

## MS From Users to Cocreators

Session 5E
Monday September 14, 11:30-13:00

### Methods for Co-Designing eHealth Technologies: The Usability Room Approach

*Francesco Tessarolo, Alice Ravizza, Catalina Salome Hinojosa Lopez, Stefano Cimignolo, Michela Masè and Giandomenico Nollo*

The Usability Room, developed within the iNEST – Spoke 2 Digital Health initiative, is a hybrid physical–virtual infrastructure supporting IEC 62366 1–compliant usability engineering for eHealth technologies. It integrates user needs analysis, iterative formative testing, and summative evaluation across realistic simulations of homes, pharmacies, clinics, and hospital wards. Task analysis and scenario based sessions revealed usability barriers such as ambiguous instructions and environmental constraints. Formative studies showed that simplified graphical guides "significantly improved user comprehension and reduced task completion time," while summative evaluations confirmed increased accuracy and reduced errors. A Delphi process validated user profiles, scenarios, and evaluation criteria, providing a replicable model for safe, user centred digital health innovation.

### Measuring Patients' Digital Fragility: A Proposal for a Rapid Multidimensional Assessment Tool

*Alice Ravizza*

The growing adoption of telemedicine highlights the need to assess patients' ability to engage safely with digital health technologies. Existing tools address digital literacy but do not capture the combined cognitive, technological, and psychological factors influencing digital autonomy. To fill this gap, a rapid multidimensional Digital Fragility Questionnaire was co designed with healthcare professionals, patient representatives, and usability experts. The tool comprises 12 items across three domains—understanding and managing information, interaction with technology, and motivation and acceptance—and can be administered in five minutes. Preliminary results confirmed the relevance of these dimensions and informed refinements to improve clarity, usability, and clinical applicability.

### Co-design as a Practical Advocacy Tool for Patients in Medical Technology

*Mauro Grigioni*

Co design offers a practical advocacy tool for patients facing cognitive, communicative, and technological barriers in digital health. Existing frameworks typically address sensory and motor accessibility, but significant gaps persist for users with complex communication needs, older adults, and individuals with language barriers. The text highlights how participatory design enables multimodal interaction, Augmentative and Alternative Communication (AAC) integration, and personalised interfaces that reduce cognitive load and improve communication accuracy. Evidence shows that early involvement of vulnerable users reveals hidden barriers and drives technical adaptations. Embedding co design and usability practices strengthens patient autonomy and supports equitable, person centred medical technology development.

### Demonstrating the Conformity of Medical Devices: the Impact of the Usability and the Role of the Notified Body in the Evaluation Process

*Sara Crocetti*

Demonstrating conformity under the MDR requires manufacturers to show that medical devices meet the General Safety and Performance Requirements, with Notified Bodies assessing compliance for higher risk classes. Usability plays a central role by addressing risks arising from user interaction and supporting risk control measures aligned with ISO 14971 and IEC 62366 1. The Notified Body verifies that usability evidence is systematically integrated into design, risk management, and PMS. Formative and summative evaluations ensure safe and effective use of the final interface, while post market data confirm assumptions and trigger updates. Usability thus becomes a continuous, lifecycle wide contributor to safety, effectiveness, and regulatory transparency.

### CoDesign a Digital Health Platform with Clinicians and Patients: the Pausetiv Case Study

*Silvia Sciamanna*

The Pausetiv case study illustrates how clinical co design and usability engineering can be integrated from the earliest stages of developing a SaMD for menopause assessment. PauseTest translates multidisciplinary clinical guidelines into a self administered questionnaire structured into four clusters and supported by algorithmic logic incorporating staging rules, Red Flags, and cross cluster interactions. Specialists co constructed scoring matrices and decision rules, while usability engineering, according to IEC 62366-1, guided interface design for lay users and risk mitigation strategies for safety critical items. Iterative formative evaluations with clinicians and intended users ensured clinical accuracy, comprehensibility, and safe operation in real world self assessment contexts.

## Plenary session

Session 7
Monday September 14, 14:30-16:00

### Neural Pathway Similarity Analysis for Efficient Glycemic Event Prediction

*Alberto Maria Di Giacinto, Luca Bacco, Leandro Pecchia and Mario Merone*

Predictive models for continuous glucose monitoring in Type 1 Diabetes are often developed under a global paradigm, although recent work increasingly recognizes substantial inter-subject heterogeneity in glycemic dynamics and the benefits of personalized or patient-specific modeling. In this work, we investigate whether personalization can emerge through sparse, patient specific neural pathways within a shared architecture, opening the way to more parameter efficient and personalization oriented adaptive glucose prediction models. To test this hypothesis, we formulate a three class prediction task on the OhioT1DM dataset, targeting 30 minute ahead transitions toward hypoglycemia, normoglycemia, and hyperglycemia, and extract class specialized subnetworks through an iterative pruning strategy inspired by the Lottery Ticket Hypothesis. Beyond predictive performance, we analyze the resulting subnetworks through complementary structural and functional similarity measures, based respectively on spectral similarity and Gromov-Wasserstein distance. The results show that substantial sparsification can be achieved while preserving, and even improving, predictive performance, with optimal sparsity often concentrated around moderate pruning levels and reaching much higher reductions in favorable subjects. Structurally, hypoglycemia exhibits the strongest inter subject variability and the greatest deviation from cohort level behavior, whereas normoglycemic and hyperglycemic transitions remain more architecturally shared. Functionally, hyperglycemia emerges as the most subject dependent class, indicating that shared structural substrates may still support individualized processing. These findings suggest that personalization in glucose prediction may be more effectively achieved through a selective combination of shared sparse pathways and class specific subject dependent specialization, rather than through fully individualized models.

### Toward a Patient-Specific Model of Protein-Bound Uremic Toxin Kinetics during Online Hemodiafiltration

*Marcello Miceli, Nicolò Migliore, Niccolò Morisi, Silvia Giovanella, Marco Ferrarini, Daniele Goldini, Giulia Ligabue, Luigi Rovati, Gabriele Donati, Umberto Morbiducci and Giuseppe De Nisco*

Protein-bound uremic toxins (PBUTs), such as indoxyl sulfate (IS) and p-cresyl sulfate (pCS), are poorly removed by conventional hemodialysis because of their strong affinity for plasma proteins, which reduces the effective diffusive driving force across the dialyzer membrane. Existing mechanistic models of PBUTs kinetics during hemodialysis rely on population-averaged parameters, thereby limiting their predictive capability at the individual patient level. In this work, a patient-specific extension of a previously validated mechanistic model is proposed. The model couples a three-compartment representation of the patient (plasma, interstitial, and intracellular compartments) with a one-dimensional dialyzer model, accounting for convection, diffusion, and reversible protein binding kinetics. Model parameters were individualized by integrating clinical data with in vitro measurements. The model was applied to a cohort of 20 hemodialysis patients treated with two different dialyzers, Solacea 21H and Cordiax FX100 with the online hemodiafiltration technique. Predicted total IS and pCS plasma concentrations showed good agreement with clinical measurements collected at multiple time points during dialysis sessions. Predictive performance was stable across patients, toxins, and treatment conditions, with absolute prediction errors below 20 mg/L and no significant differences between dialyzers or across time points. Overall, the proposed framework accurately reproduces patient-specific PBUTs kinetics and highlights the value of integrating experimental and clinical data for personalized modelling. This approach represents a step toward precision dialysis and may support the optimization of treatment strategies based on individual patient characteristics.

### A digital twin-based evaluation of corrective insulin bolus algorithms in type 1 diabetes

*Elisa Pellizzari, Francesco Prendin, Giacomo Cappon, Giovanni Sparacino and Andrea Facchinetti*

Type 1 diabetes (T1D) is a chronic disease characterized by elevated blood glucose (BG) levels caused by the absence of endogenous insulin secretion. In T1D management, corrective insulin bolus (CIB) strategies are particularly important to reduce hyperglycemia without leading to hypoglycemia. Most existing approaches for determining their timing and dosing remain reactive and rely on fixed heuristics that do not account for individual glucose–insulin dynamics. In this work, we leverage the ReplayBG digital twin (DT) framework to compare three recent literature-based CIB rules with three proactive and personalized algorithms that incorporate a patient-specific inter-bolus timing, and prediction-based triggers: drCORRECT, rAR-CIB, and LSTM-CIB. All methods are evaluated in a unified DT-based in-silico environment using real-world free-living data from 30 adult patients, including continuous glucose monitoring data, meal logs, and insulin administrations. Performance is assessed using standard glucose control metrics, including time in range (TIR), time above range (TAR), and glycemia risk index (GRI). The results show that all CIB strategies improve glycemic control compared to baseline (TIR: 52.29%, TAR: 46.57%, GRI: 52.71), with the highest benefits obtained for proactive approaches. In particular, LSTM-CIB achieves the best overall performance (TIR: 65.29%, TAR: 33.26%, GRI: 33.64) while maintaining low hypoglycemia exposure. Compared to the literature-based methods, the considered proactive strategies consistently yield a higher TIR and a lower GRI. Overall, integrating personalized timing with predictive triggers improves glycemic outcomes compared to baseline and rule-based literature approaches, highlighting the value of DT–enabled personalization for next-generation CIB strategies in T1D.

### Development of a RAG-Powered Chatbot for Assistive Technologies Benchmarking

*Aya Mahboub, María Teresa Arredondo Waldmeyer and María Fernanda Cabrera-Umpiérrez*

Access to digital healthcare remains a persistent barrier for older adults and individuals with disabilities, a challenge the Red Cross and TECSOS directly address through Orientatech, a curated assistive technology (AT) platform designed to foster independent living. Despite the availability of life-changing tools such as screen readers, cognitive support aids, and communication devices, people with disabilities frequently struggle to identify solutions matching their health and functional needs, risking exclusion from essential digital healthcare services. This paper presents Ori, a web-integrated conversational agent designed to promote independent living and improve quality of life, grounded exclusively in curated platform resources via a Retrieval-Augmented Generation (RAG) pipeline. Ori ingests platform data in PDF format, segments content into semantically coherent chunks, encodes them using SentenceTransformer embeddings (all-MiniLM-L6-v2), and retrieves context through a ChromaDB vector store. Retrieved content is passed to a locally hosted Ollama LLM, preserving data privacy and eliminating dependency on external cloud services. The system was evaluated across four task categories, product explanation, needs-based discovery, fallback handling, and personalized recommendation, achieving an average retrieval precision of 88.1%, response consistency of 93.7%, and mean latency of 1.85 s. A System Usability Scale (SUS) study with ten participants (ages 30–63, including users with visual, cognitive, and motor impairments) yielded an overall score of 88.7/100, with 90% rating the system as intuitive. Domain-specific design choices, including a constrained knowledge scope, multi-turn context accumulation, and accessibility-first interface principles, distinguish Ori from generic RAG deployments and align it with EN 301 549, WCAG 2.1, and digital accessibility requirements.

### Radiomics-based identification of subjects with cardiovascular diseases from retinal images

*Ilaria Bottini, Anna Corti, Riccardo Tatoni, Benedetta Grossi, Letizia Perri, Mario Romano, Gianluigi Condorelli, Valentina Corino and Luca Mainardi*

Cardiovascular diseases (CVDs) remain the primary cause of global mortality, highlighting the need for improved early detection strategies. While conventional risk calculators rely on standard clinical parameters, growing evidence suggests associations between retinal microvascular alterations and cardiovascular pathologies. Retinal imaging has emerged as a promising, non-invasive tool for cardiovascular risk assessment. In this study, we investigated the diagnostic utility of optical coherence tomography angiography (OCTA) combined with radiomics to identify individuals with CVDs, including congestive heart failure, stroke, and vascular diseases. The publicly available RASTA dataset was used, comprising 814 OCTA images from 491 participants. Multiple feature selection techniques and machine learning classifiers were evaluated to optimize performance. The final model, based on correlation filtering, elastic net regularization and logistic regression, achieved a balanced accuracy of 0.782 and an area under the receiver operating characteristic curve (AUC) of 0.808 on the test set. The model demonstrated high sensitivity (0.941) and successfully identified all cases of congestive heart failure and stroke. These findings support the potential of OCTA-based radiomics as a non-invasive screening approach for CVD detection, warranting further validation in larger cohorts.

### Multimodal Phenotyping of Sleep Apnea: Integrating SpO2 and HRV through Subject-Based Correlation Networks

*Javier Gomez-Pilar, Adrián Martín-Montero, Fernando Vaquerizo-Villar, Carla de León-Morán, María Fernández-Vaquerizo, Máximo Domínguez-Guerrero, Lidia Enríquez-Meijome, Daniela Ferreira-Santos, Pedro Pereira-Rodrigues, Daniel Álvarez, David Gozal, Roberto Hornero and Gonzálo César Gutiérrez-Tobal*

Abstract. Obstructive sleep apnea (OSA) is a highly prevalent and heterogeneous sleep-related breathing disorder still primarily characterized using global severity indices derived from polysomnography, such as the apnea-hypopnea index (AHI). However, these indices only partially capture the underlying physiological variability across subjects. This study proposes a multimodal phenotyping framework based on subject-based correlation networks constructed from physiological features derived from pulse oximetry (SpO2) and heart-rate variability (HRV). Data from 2,641 subjects from the Sleep Heart Health Study were analyzed using a novel pipeline combining bootstrap resampling and consensus clustering for stable phenotype identification, and community detection based on modularity optimization for phenotypic discovery. Four clinically and physiologically distinct phenotypes were identified: (1) younger, lean individuals with mild OSA and preserved autonomic function; (2) older subjects with intermediate severity and a hyperreactive, potentially compensatory autonomic response; (3) younger, obese patients with severe hypoxia but paradoxically blunted autonomic activity; and (4) older, obese individuals with extreme hypoxic burden, high comorbidity, and maladaptive autonomic patterns. These phenotypes showed significant differences across 43 of 73 clinical variables and were predicted with a Cohen's kappa of 0.878 on an independent test set. These results demonstrate that integrating SpO2- and HRV-derived features enables the identification of clinically relevant and highly separable OSA phenotypes.

## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies

Session 8A
Monday September 14, 16:30-18:00

### An event-based approach to estimate motor engagement during Robot-Assisted Gait Training via gaze-related features

*Ornella Marino, Elena Campilii, Francesco Romano, David Perpetuini, Teresa Paolucci, Alice Cichelli, Emanuele Francesco Russo, Maria Teresa Gatta, Marta Di Nicola, Giovanni Morone, Irene Ciancarelli, Arcangelo Merla and Daniela Cardone*

Motor engagement during robot-assisted gait training (RAGT) is a key factor influencing rehabilitation outcomes, yet its objective and quantitative assessment remains challenging. Traditional evaluation approaches are mainly based on motor performance and provide limited information about the patient's level of participation. In this study, we propose a non-invasive method to estimate motor engagement by combining visual behavioral features and biomechanical signals acquired during RAGT sessions. Joint torque data were collected from a Lokomat system, while gaze direction was extracted from frontal video recordings using computer vision techniques. An event-based framework was adopted, defining events as time windows in which gaze orientation exceeded a given threshold, indicating attention toward the task. Results showed that task-oriented gaze was associated with lower joint torque values, suggesting higher levels of active participation. This relationship was consistently observed across sessions. These findings support the use of simple video-based features combined with robotic measurements as a practical and objective proxy for engagement during RAGT.

### Reverse Osmosis Membranes in Medical Applications: Focus on Water Purification for Hemodialysis

*Achraf El Allaoui, Wafaa Dachry and Hassan Gziri*

Reverse osmosis (RO) membranes are extensively employed in medical water purification systems, particularly for hemodialysis, where the production of ultrapure water is key to patient safety. This paper provides a comprehensive analysis of RO applications in dialysis facilities, describing the multistage purification process and evaluating its effectiveness in removing chemical and microbiological contaminants. A case study from a dialysis unit in Morocco demonstrates the system's stable performance. Current challenges encompass membrane fouling, high energy consumption, and complex maintenance requirements. To mitigate these issues, the integration of Internet of Things technologies enables real time monitoring and predictive maintenance, while renewable energy can be used to power high-pressure pumps. These strategies support the development of resilient, efficient, and sustainable dialysis infrastructures, especially in regions facing water scarcity. The paper underscores the importance of continued advancements in membrane technology and system optimization to meet the growing demand for safe and environmentally responsible dialysis treatment.

### HIFU (High Intensity Focused Ultrasound) for biomedical and dentistry application

*Boo Cheong Khoo*

Abstract: In this work, we study the physical phenomena and the application of HIFU (High Intensity Focused Ultrasound) using both simulation and experiment. The experiment was done with a bowl-shaped focused ultrasound system. High speed videos of the generation of cavitation bubbles at the focal point of the HIFU are captured. We observed interesting bubble cloud structures, bubble movements and stationary bubble oscillations. The system is then applied for dentistry applications. Firstly we use the HIFU to drive antibacterial nanoparticles into dentinal tubules for disinfection in root canal treatment. Initial results show delivery of these nanoparticle deep into the dentinal channels which are a few microns in size. Next we cultivate E. Faecalis biofilm, a common bacteria colony found in the mouth and teeth, on petri dish and in human tooth. Then we subject them for removal under strong HIFU for a period of time. We obtain positive results in the biofilm removal with the increasing HIFU sonification time. Separately, we simulate the interaction of a bubble with pulsed ultrasound and in an ultrasound field near bio-materials such as fat, muscle and bone. The simulation shows extreme growth and collapse of the bubble under certain conditions. It is found that the formation and direction of the water jet during bubble collapse is highly dependent on the properties of the bio-materials nearby. These studies provide a foundation for better understanding of HIFU and its uses in medical treatment.

### Building a National Medical Equipment Inventory in Greece: Field Registration Process and AI-Assisted Data Entry across 129 Public Hospitals

*Aris Dermitzakis, Spilios Zisimopoulos, Anastasia Daskalaki and Nicolas Pallikarakis*

A reliable, continuously updated medical equipment (ME) inventory is the foundation of any modern Healthcare Technology Management (HTM) system. The WHO 2022 Global Atlas of Medical Devices reports that most countries lack such inventories at national scale. We describe the implementation of a Unified Medical Equipment Management System (MEMS) covering the Greek public healthcare sector, delivered as part of a national digital transformation programme. The work covers two coupled processes: a standardised on-site registration of every electrically powered, maintenance-relevant device (room-by-room tagging, photographic documentation, mobile data capture), and a structured data-entry workflow that converts image-based field records into clean inventory entries on the web-Praxis platform. To accelerate data entry we developed an AI-assisted matching tool that proposes manufacturer–model–GMDN "Triplets" directly from device photographs, with a three-tier human review pyramid for quality control. The project covered 129 public hospitals, registering 170,860 devices, and assigned GMDN codes to 26,156 distinct models drawn from 1,143 GMDN Terms (197 Collective Terms). The approach is reproducible and scalable, and provides an evidence base for centralised contracting, harmonised maintenance and equipment redistribution.

### Design of a Video System for Training Clinical Engineering Personnel

*Cristina Aldana Palomino, Eisel Pinado, Luis Vilcahuamna and Walter Rios*

Medical device maintenance is essential to ensure patient safety and the continuity of healthcare services; however, in developing countries such as Peru, it is often affected by fragmented technical information, lack of structured training processes, and high turnover of biomedical interns. These limitations reduce learning efficiency and increase the risk of operational errors. This study presents the design and preliminary evaluation of a digital training platform aimed at improving knowledge transfer in clinical engineering environments. The proposed system integrates structured audiovisual modules and centralized access to technical documentation, organized according to the institutional inventory of biomedical equipment. A pilot implementation was conducted in a real clinical setting, focusing on ultrasound equipment as a case study. The evaluation involved biomedical interns and assessed usability, access to information, and perceived support for learning. Results indicate a positive user perception, with all participants reporting that the platform is accessible and easy to use. These findings support the feasibility of the proposed approach as a tool for structuring training processes and improving access to technical knowledge. Although the results are limited to a preliminary evaluation, the platform provides a foundation for future studies aimed at assessing its impact on learning outcomes and operational performance.

### Innovative Design of an Automated Ventilator for Emergency Respiratory Care

*Mercy Adusei Boatemaa, Harriet Yaa Amoako, Rose Amewonyo and Charles Dorcoo Kwesi*

Mechanical ventilation is a cornerstone of advanced critical care, providing essential respiratory support to patients experiencing respiratory failure, severe pulmonary conditions, or neurological impairment. Despite its clinical significance, access to ventilatory support remains severely limited in resource-constrained healthcare settings, particularly in low- and middle-income countries. Conventional mechanical ventilators are prohibitively expensive, bulky, and require specialized infrastructure and trained personnel, rendering them inaccessible in district hospitals, ambulances, rural health centers, and during mass casualty events. The COVID-19 pandemic further exposed a critical global shortfall of approximately 880,000 ventilators, underscoring the urgent need for affordable and portable alternatives. This study presents the design and development of a low-cost automated ventilation system intended for emergency respiratory support in resource-limited environments. The system employs a motor-driven mechanism to automate the compression of an Ambu bag (self-inflating resuscitation bag), thereby eliminating reliance on manual bag-mask ventilation, which is inherently imprecise and operator-dependent. The design prioritizes portability, affordability, and scalability through the integration of lightweight, readily available, and cost-effective components, making the device suitable for deployment across a broad range of clinical and pre-hospital settings. Performance testing demonstrated the system's capability to deliver controlled breaths through precise timing mechanisms and current regulation. The device is designed to be adaptable for future upgrades, including the integration of patient monitoring modules. Performance testing was conducted to validate the system's functionality and reliability as an emergency ventilatory aid. The outcomes of this project demonstrate the feasibility of producing a portable, automated ventilation device that significantly reduces production costs while maintaining clinical efficacy. This system has the potential to bridge the critical gap between the high demand for emergency ventilatory support and the limited availability of conventional ventilators in under-resourced healthcare systems, including those in sub-Saharan Africa. The scalability of the design further positions it as a viable solution for mass production in response to public health emergencies.

## MS Cardiomechanical monitoring techniques

Session 8B
Monday September 14, 16:30-18:00

### Applications of Forcecardiography sensors in cardiovascular and respiratory health monitoring

*Paolo Bifulco, Jessica Centracchio, Raffaele Izzo, Salvatore Parlato, Eliana Cinotti and Emilio Andreozzi*

Forcecardiography (FCG) is a novel cardiomechanical monitoring technique based on a non-invasive, small monolithic force sensor that captures respiration, heart walls motion, infrasonic heart valves vibrations, and heart sounds, all simultaneously from a single contact point onto the chest. This work presents an overview of the principles, performance, and clinical significance of FCG. It also discusses the relationship between FCG and other well-established cardiomechanical signals. Forcecardiography could pave the way for a comprehensive evaluation of cardiac mechanics via wearable devices for continuous long-term monitoring of many clinical indices like cardiac time intervals, stroke volume, cardiac output, ejection fraction, myocardial contractility, heart valves performance. Therefore, FCG could provide critical improvements in patients follow-up for a variety of chronic cardiovascular and pulmonary diseases, especially in non-clinical settings.

### Applications of Heart Rate Variability Analysis from Mechanocardiographic Signals: A Narrative Review

*Szymon Sieciński*

Heart rate variability (HRV) has traditionally been analyzed from electrocardiograms, but recent progress in microelectromechanical (MEMS) sensors and signal processing has made it increasingly feasible to estimate HRV from mechanocardiographic signals, including ballistocardiograms, seismocardiograms, and gyrocardiograms. This narrative review discusses 18 studies in which cardiomechanical signals were used for HRV-based health- and state-related assessment. The reviewed literature was grouped into four main areas: cardiovascular diseases, posture and activity, music-related effects, and alcohol-related impairment assessment. The most mature evidence focuses on cardiovascular applications, especially atrial fibrillation detection, where arrhythmia is directly reflected in mechanically derived beat-to-beat timing series. Mechanocardiographic HRV was also informative for distinguishing healthy subjects from patients with valvular heart disease, although more specific disease phenotyping generally required additional morphology-based or multimodal features. In posture-, activity-, and sleep-related applications, interval-derived HRV indices appeared more robust than raw morphology-sensitive descriptors, particularly under low-motion or controlled conditions. Music- and alcohol-related studies suggest that mechanocardiographic HRV can also reflect subtler physiological or behavioral state changes, but the evidence in these areas remains preliminary. Overall, HRV analysis based on mechanocardiograms is a feasible extension of conventional ECG-based HRV analysis, but broader adoption will require more reliable ECG-independent heartbeat detection, larger and better-balanced cohorts, public benchmark datasets, standardized processing pipelines, and stronger external validation.

### Morphic sensors for respiratory and cardiac ubiquitous monitoring

*Gaetano Gargiulo, Ganesh Naik, Benjamin Brandwood, Titus Jayarathna and Paul Breen*

Morphic sensors based on electro-resistive bands (ERBs) represent a robust and viable solution for ubiquitous, non-invasive physiological monitoring. These sensors, which function as distributed strain-gauges, can be easily integrated into standard wearable garments providing continuous surveillance of cardio-respiratory signals without the need for direct skin contact or obtrusive electrode arrays. Our design tested against medical gold standards show that clinically relevant parameters like tidal volume, heart rate and respiratory rate can be extracted with sufficient precision during sleep as well as light physical activity

### Forcemyography: an effective alternative to EMG for muscle monitoring and Human–Machine Interface

*Daniele Esposito*

Forcemyography (FMG) has recently emerged as a promising technique to monitor muscle activity level by sensing the mechanical changes related to contraction. Traditionally, surface electromyography (EMG) has been widely adopted for such applications; however, this technique requires reliable electrical contact and is subject to various issues, such as electrode stability, electromagnetic interference, and the need of raw EMG data processing to extract the envelope. This study presents a comprehensive overview of the evolution of FMG, from muscle contraction monitoring to its application in real-time Human–Machine Interfaces (HMIs). The FMG signal is typically obtained using force or pressure sensors placed on the skin near the muscle. During contraction, the muscle cross-section increases and the tendons tighten, exerting a radial force that can be recorded onto skin surface. Several investigations demonstrated a strong correlation between FMG and the EMG linear envelope. Although electrical phenomena always precede mechanical contraction, the FMG signal does not exhibit a noticeable delay relative to the EMG envelope, which requires processing that inevitably introduces a time delay in real-time applications. Obviously, FMG cannot capture the complexity of individual motor unit recruitment but generates an overall signal of muscle contraction. Many real-time applications, such as HMI control, rely exclusively on this overall signal and can benefit from the FMG technique, which offers the advantages of extreme ease of use, the availability of very thin sensors, immunity to electromagnetic interference, and a signal that requires minimal or no processing. Novel experiments on isometric contractions have further demonstrated that the FMG is capable of accurately estimating muscle force through regression models. Finally, the applicability of FMG in HMIs is reviewed through representative implementations, including gesture recognition interfaces, prosthetic hand control, and wearable hand exoskeletons. Overall, FMG demonstrates significant potential as a robust, low-cost alternative to EMG, particularly suited for real-time interfaces.

## MS Artificial Intelligence in Lung Cancer Screening

Session 8C
Monday September 14, 16:30-18:00

### Designing and validating AI pipelines for lung cancer screening: challenges and pitfalls

*Giulia Raffaella De Luca, Christian Di Buò, Chiara Marzi, Edoardo Cavigli, Mario Mascalchi and Stefano Diciotti*

Designing reliable AI pipelines for lung cancer screening requires addressing reproducibility, scalability, and methodological pitfalls. Variability due to non-deterministic training, heterogeneous computing environments, and differences in data handling can substantially affect model performance, making results difficult to replicate. Moving from single-server experimentation to high-performance computing —combined with containerization and dataset versioning—enables controlled, scalable, and more reproducible workflows. At the same time, computational efficiency remains a limiting factor in large-scale CT analysis, and data leakage can artificially inflate reported performance if not rigorously controlled. We present experimental results on reproducibility and computational efficiency using the Sybil deep learning model on the National Lung Cancer Screening Trial (NLST) dataset (train: 9,646 patients, 28,053 samples [26,621 negative, 1,432 positive]; test: 2,203 patients, 6,277 samples [5,978 negative, 299 positive]). We observe high robustness to class imbalance on the negative class: using only 20% of negative samples reduces training time by over 50% with negligible performance loss. In contrast, reducing positive samples degrades performance without computational benefits due to oversampling effects. We further analyze Sybil's predictive behavior across clinically relevant factors. While risk estimates are consistent across reconstruction kernels, performance varies significantly with cancer visibility: at a 3-year prediction window, AUC reaches 0.936 for prevalent nodules, decreasing to 0.758 for pseudo-incident and 0.508 for incident cases, with similar trends up to 6 years. Overall, this work emphasizes that achieving clinically meaningful AI systems requires treating reproducibility and scalability as design objectives, rather than retrospective checks, integrating them directly into pipeline development and validation.

### Towards Robust and Generalisable AI for Lung Cancer Screening

*Margarida Gouveia, Hélder P. Oliveira and Tania Pereira*

Lung cancer screening using low-dose computed tomography (LDCT) has been shown to reduce mortality significantly. Furthermore, integrating automated artificial intelligence (AI) models for classifying lung nodule malignancy can provide radiologists with valuable second opinions faster than histopathologic malignancy confirmation. However, these deep learning (DL) models frequently struggle to generalise across different datasets and clinical institutions due to domain shift caused by differences in scanners, acquisition protocols, hospitals, and patient demographics. In addition to limited access to data for model training, challenges originate from heterogeneous data sources, with inconsistent annotation practices, label semantics, and limited harmonisation of protocols across datasets. In this talk, we examine how these challenges manifest in real-world settings, drawing on examples from both public and private datasets, and show how inconsistent annotations and heterogeneous data sources further degrade model performance. Additionally, we will discuss the importance of data harmonisation and domain-generalisation strategies in creating generalisable, robust, and scalable AI solutions well-suited to the realities of lung cancer screening using LDCT scans.

### Data and anatomy standardization in lung cancer screening: drawing from neuroimaging*

*Giulia Raffaella De Luca*

The clinical implementation of artificial intelligence (AI) in low-dose computed tomography (LDCT) lung cancer screening is frequently hindered by heterogeneous data and the absence of standardized reference space. While neuroimaging has long benefited from established spatial templates and rigorous data standards, thoracic imaging has historically lacked these foundational tools. This presentation explores the strategic adaptation of proven neuroimaging best practices in lung cancer screening. First, we addressed data standardization by introducing a proof-of-concept extension of the Brain Imaging Data Structure (BIDS) to CT imaging, applying it to the National Lung Screening Trial (NLST) dataset, and developing a BIDS-App. Second, we tackle anatomical standardization by constructing a high-resolution, 3-D lung template and probabilistic lobar atlas derived from the NLST cohort, utilizing the Advanced Normalization Tools (ANTs) ecosystem and FSL, a staple in neuroimaging. This atlas enabled voxel-wise analysis to map specific deformation patterns associated with varying emphysema severities. Furthermore, it facilitated the creation of a lung nodule atlas, highlighting the distinct spatial locations of malignant versus benign pulmonary nodules within the cohort. By bridging the gap between neuroimaging methodologies and thoracic AI, we introduce robust, open-source tools to advance and standardize lung imaging research.

### Mitigating Label Noise and Concept Shift in LIDC-IDRI for Domain Generalisation in Lung Nodule Malignancy Classification

*Margarida Gouveia, Hélder P. Oliveira and Tania Pereira*

Lung cancer screening programs can leverage Deep Learning (DL) models as a supplementary tool for radiologists to detect and classify lung nodules. Various studies in the literature have applied high-performance DL models to the LIDC-IDRI dataset; however, the robustness of these models is affected by the quality of the dataset annotations. This study seeks to deepen our understanding of how label noise and concept shift affect the cross-dataset generalisation of DL models for lung nodule malignancy classification. The focus was on using LIDC-IDRI, which was labelled by radiologists with a "likelihood of malignancy" ($Y_{rad}$) rather than biopsy-confirmed labels ($Y_{bio}$), and which presents annotations with high interobserver variability. The findings revealed that models trained on $Y_{rad}$ labels struggle to generalise to datasets with $Y_{bio}$ labels. To address this issue, we propose a model-driven relabelling strategy for LIDC-IDRI that uses an ensemble of 2.5D~\textit{ResNet-18} trained on the LUNA25 dataset with biopsy-confirmed labels. This strategy demonstrated a notable improvement in cross-dataset generalisation for the classification models, achieving a 10\% increase in AUC on an external dataset while also improving performance on the internal dataset. In summary, the results underscore the critical importance of addressing annotation quality and developing strategies to enhance the generalisation of DL models across diverse clinical data sources in the context of lung cancer screening.

## MS AI Applications in Clinical Engineering

Session 8D
Monday September 14, 16:30-18:00

### Artificial Intelligence (AI) Applications in Clinical Engineering (CE) Overview & Use Cases

*Thomas Judd*

"AI" refers to applied, system-level use of machine learning in healthcare environments, where it intersects with the following: • Medical devices • Hospital infrastructure • Data systems • Safety and compliance 1. Intelligent Health Technology Management (HTM) • Predictive Maintenance of Medical Equipment o AI is used to monitor and predict equipment failures. □ Inputs: Sensor data (temperature, voltage, usage cycles) □ Outputs: Alerts before breakdowns happen • HTM Workflow & Operational Tools o Digital systems that improve hospital efficiency. □ Asset tracking (RFID, RTLS) □ Maintenance management systems (CMMS) □ Post-market device surveillance (PMS) 2. Distributed Care • Telehealth & Remote Care Platforms o Digital tools that deliver care outside the hospital. □ Video consultations, remote diagnostics, e-prescriptions □ Integration with hospital systems (EHR, PACS) o Remote Patient Monitoring (RPM) & Wearables □ Connected devices that continuously collect patient data. • Vital signs: heart rate, SpO□, ECG, blood pressure • Chronic disease monitoring (diabetes, cardiac conditions) o Examples of device types (not brands): □ Smartwatches with ECG □ Home-use pulse oximeters □ Connected glucose monitors o Mobile Health (mHealth) Applications □ Patient-facing apps for health management. • Medication reminders • Rehabilitation tracking • Mental health monitoring 3. Clinical Applications • Cancer a) Health promotion, i.e., keeping people healthy and therefore preventing cancer b) Early detection & diagnosis before the presence of clinical signs, via screening and biomarker-based technologies c) Treatment of cancer and its follow-up d) Support if cancer is no longer curable • Imaging AI models (often deep learning) analyze: o CT, MRI, X-ray images o Ultrasound scans • Use cases: o Tumor detection o Fracture identification o Stroke diagnosis (rapid triage) o Mammography o Colonoscopy o Pancreatic cancer • Clinical Decision Support Systems (CDSS) o AI assists clinicians in making decisions. • Examples: o Sepsis prediction o Drug interaction alerts o Risk scoring for ICU patients iv. Digital Diagnostics o Software tools that assist in diagnosis or care planning. o Symptom checkers o AI-assisted triage systems o Scheduling and bed management tools 4. Digital Health (DH) Tools and Interoperability • Electronic Health Records (EHR) & Data Integration Core digital infrastructure for managing patient data. o Centralized patient records o Integration across departments (lab, imaging, pharm.) • Workflow Optimization & Hospital Operations AI helps optimize hospital efficiency. o Patient flow prediction o Operating room scheduling o Resource allocation • Smart Medical Devices & IoMT (Internet of Medical Things) AI is embedded directly into devices. A network of connected medical devices and systems. Examples: o Smart infusion pumps o Wearables (heart rate, oxygen monitoring) o AI-enabled ventilators o Bedside monitors, imaging systems o Real-time data sharing across hospital networks “Digital Health” refers to the ecosystem of connected technologies that support care delivery, including: • Devices (hardware) • Platforms (software) • Networks (infrastructure) • Data systems (integration & analytics) Cybersecurity & Data Privacy AI + Cybersecurity in Healthcare Systems • Since dataset explicitly links AI with cybersecurity, this is important. • AI is used to: o Detect unusual network/device behavior o Identify potential cyberattacks on medical devices o Digital health greatly expands the attack surface. o Protection of patient data o Securing connected devices and networks o Compliance with regulations (HIPAA, FDA guidance) 6. Regulatory, Risk, Safety and Forensics • Regulatory, Safety, and Quality Issues A major theme in CE publications: o Ensuring AI systems meet standards (e.g., FDA, IEC) o Validating algorithms on real-world data o Managing risks (false positives/negatives) with embedded AI and System of Systems

### Beyond Clinical AI: Artificial Intelligence for Clinical Engineering, Healthcare Operations and Medical Device Management

*Leandro Pecchia*

Artificial Intelligence (AI) is rapidly transforming healthcare, with most attention focused on clinical applications such as diagnosis, decision support, precision medicine, and predictive analytics. While these developments are undoubtedly important, they represent only part of the value that AI can generate within healthcare systems. A less explored, yet equally impactful domain concerns the application of AI to clinical engineering, healthcare operations, and medical device management. Healthcare organizations are increasingly challenged by growing complexity, resource constraints, workforce shortages, and the need to manage large fleets of interconnected medical technologies. Clinical engineers play a pivotal role in ensuring the safety, effectiveness, availability, and sustainability of medical devices and healthcare infrastructures. However, many of the processes supporting these activities remain labor-intensive, fragmented, and reliant on manual decision-making. This presentation will explore how AI can support clinical engineering functions beyond traditional clinical applications, highlighting real-world proof-of-concept (PoC) solutions developed within European research and innovation projects. These initiatives demonstrate how AI can enhance operational efficiency, improve resource allocation, support decision-making, and contribute to safer and more resilient healthcare systems. The first group of applications focuses on process mining and healthcare workflow optimization. By combining AI techniques with data extracted from hospital information systems, it becomes possible to identify inefficiencies, bottlenecks, and deviations from intended workflows, enabling evidence-based redesign of clinical and technical processes. A second area concerns crowd management and patient-flow optimization. AI-driven models can analyze movement patterns, predict congestion, and support dynamic allocation of resources in complex healthcare environments. Such approaches have demonstrated potential to improve patient experience, increase operational efficiency, and enhance preparedness during periods of high demand. The presentation will also discuss AI-supported infection prevention and control strategies. Machine learning algorithms can integrate heterogeneous data sources to identify risk patterns, support surveillance activities, and provide early warning mechanisms that contribute to reducing healthcare-associated infections and improving patient safety. Another important application area involves the micro-logistics of third-party managed medical devices. Hospitals increasingly rely on externally owned or managed devices, creating challenges related to traceability, availability, utilization, and inventory management. AI-based solutions can support real-time monitoring, demand forecasting, and optimized allocation of these resources, reducing waste and improving service continuity. The role of AI in advanced document management will also be presented. Clinical engineering departments manage large volumes of technical documentation, maintenance records, regulatory evidence, procurement documents, and manufacturers’ information. Recent advances in natural language processing and large language models enable intelligent document retrieval, automated knowledge extraction, compliance support, and enhanced decision-making throughout the device lifecycle. Finally, the presentation will examine emerging applications of AI for workforce training and competency development. Intelligent tutoring systems, adaptive learning platforms, and AI-powered simulation environments can support continuous education of healthcare professionals and clinical engineers, facilitating knowledge transfer and improving training effectiveness. Drawing on practical experiences and lessons learned from European projects, this presentation aims to broaden the discussion on AI in healthcare by highlighting the significant opportunities that exist outside the traditional clinical domain. The examples presented demonstrate how AI can become a strategic enabler for clinical engineering, contributing not only to technological innovation but also to operational excellence, sustainability, and resilience across healthcare systems.

## MS IUPESM From Concept to Impact

Session 8E
Monday September 14, 16:30-18:00

### Forty Years of International Biomedical Engineering Projects: The Evolution of a Field Through Personal Experience

*Nicolas Pallikarakis*

A presentation reviewing major developments in Biomedical Engineering over the past forty years through the perspective of personal participation in international projects and initiatives spanning research, education, regulation, clinical engineering, and health technology assessment. From the early European policy initiatives of the 1980s, including the “New Approach” that paved the way for the Medical Devices regulatory framework, to the growth of transnational Biomedical

Engineering education from the 1989 European postgraduate MSc program in BME, to the application of AI in BME education, and from the strengthening of IFMBE structures in Clinical Engineering and HTA, to the establishment of EAMBES and more recently the GCEA, the field has progressively expanded into a globally connected, multidisciplinary domain. The presentation links these milestones with direct experience in European and international activities, including participation in the European Commission Medical Devices Committee, leadership roles in IFMBE, the creation of INBIT in 1991 that has been designated this year (2026) as a WHO Collaborating Centre for Medical Equipment Management and Assessment. The aim is to illustrate how the evolution of Biomedical Engineering has been shaped not only by scientific and technological progress, but also by international collaboration, educational innovation, institutional development, and policy engagement.

### EMITEL Project for Development of Medical Physics Encyclopaedia and Scientific Dictionary and its Collaboration with IFMBE

*Slavik Tabakov and Magdalena Stoeva*

The second edition of the *Encyclopaedia of Medical Physics* aims to provide free, high-quality educational resources for medical physics students and educators worldwide through an open-access website. Building on its 2010 first edition, the updated Encyclopaedia expands its scope with substantial new material on Clinical Engineering for imaging and radiotherapy equipment, developed in collaboration with IFMBE specialists. Between 2019 and 2021, the entire online content underwent major revision, incorporating about 25% new material reflecting technological advances since 2010. The current edition includes 3,300 peer-reviewed, cross-referenced articles, over 600 abbreviations, around 1,000 updated entries, and approximately 2,000 illustrations across more than 4,000 printed pages. Contributions came from 150 experts across 30 countries, supported by a dedicated Clinical Engineering subgroup. The Encyclopaedia serves both as a graduate-level teaching resource and a comprehensive reference, with strong emphasis on CE–MP collaboration throughout the equipment lifecycle. Its multilingual Scientific e-Dictionary translates 4,000 terms into 32 languages, supporting global education. The redesigned website, accessible on mobile devices, offers advanced search modes and has attracted up to 40,000 monthly global enquiries. The project represents the first freely available, large-scale educational platform of its kind in medical physics.

### Publishing Biomedical Engineering and Medical Physics: Navigating a Rapidly Moving Environment

*Christoph Baumann*

This presentation will examine how large language models and other AI tools are reshaping the creation and evaluation of scholarly content in Biomedical Engineering and Medical Physics. It will map where AI now enters the research and publishing cycles, highlight the implications for article and book development, and identify the emerging challenges for quality control, originality, and accountability.

### The role of Biomedical Engineering to achieve impact in health and wellbeing: perspectives from EAMBES

*Giuseppe Fico*

As the "trusted link" between disruptive laboratory innovation and resilient clinical care, Biomedical Engineering (BME) has evolved into the essential pillar of European healthcare modernization and strategic autonomy. No longer confined to a purely technical background role, the profession now stands at the decisive intersection of medicine and technology, guiding innovation to ensure it serves humanity ethically, safely, and sustainably. This talk will explore the trajectory of the European Alliance of Medical and Biological Engineering and Science. Representing half of the global BME community within the IFMBE, EAMBES has successfully positioned the profession as a vital interlocutor in European policy-making. Key achievements to be discussed include the establishment of the European Parliament Interest Group on BME (EPIG BME) and the alliance's proactive role in shaping landmark regulations such as the Medical Device Regulation (MDR), the AI Act, and the European Health Data Space (EHDS). Special focus will be given to "Concept to Impact" through EAMBES projects, including but not limited to, the EMBE Innovation Consortium (EMBEic): Accelerating the internationalization of BME research through expert matchmaking. The TRUST Project: Leveraging trustable AI to automate regulatory compliance for medical research, reducing the administrative burden on biobanks and clinical units. Professionalization Mandates: The urgent EAMBES-led initiatives for the formal certification of BME as a regulated profession and the harmonization of clinical engineering curricula across European hospitals to ensure patient safety and technical authority. By leveraging the Quintuple Helix model—linking science, industry, policy, society, and the environment—EAMBES is defining a future where BME serves as the central nervous system of healthcare, translating scientific discovery into practical, sustainable, and universally accessible well-being.

### Advancement in the Technological Development of Diagnostic Radiology: Insights from the New Edition of the IAEA Diagnostic Radiology Physics Handbook

*Magdalena Stoeva, Chris Boyd, Natasa Brasik, David Hintenlang, Renato Padovani and Virginia Tsapaki*

The rapid evolution of diagnostic imaging technologies continues to reshape modern healthcare, demanding comprehensive professional guidance and harmonized educational curricula. The new edition of the IAEA Diagnostic Radiology Physics - a Handbook for Teachers and Students provides updated content covering both classical and advanced resources for medical physicists, radiologists, technologists, and related disciplines. The second edition of the handbook extends beyond the classical applications and imaging modalities like radiography, mammography, interventional, computed tomography, dental, ultrasound and magnetic resonance imaging. Enhanced coverage of emerging technologies, advanced imaging systems, image quality assessment, radiation protection, information technology, and equipment management. The handbook also expands on digital technologies, reconstruction algorithms, and the integration of artificial intelligence into imaging workflows, reflecting the field's shift toward data driven and automated solutions. Additionally, the handbook provides practical insights into clinical implementation and foundation of diagnostic radiology, and the basics of imaging anatomy, bridging the gap between physics principles and diagnostic practice. In general, the new edition of the Diagnostic Radiology Physics handbook serves as a timely and forward looking reference that encapsulates the technological progress, safety frameworks, and clinical application related to the contemporary diagnostic radiology.

## MS Governing Health Technology Innovation: A Subsidiary HTA Approach in Italy

Session 8F
Monday September 14, 16:30-18:00

### Regulatory Frameworks for Medical Devices: European and Italian Perspectives

*Stefano Bergamasco*

The European regulatory landscape for medical devices has undergone profound transformation with the full application of Regulations (EU) 2017/745 (MDR) and 2017/746 (IVDR), which introduced more stringent requirements on safety, clinical evidence, performance evaluation, post-market surveillance, and traceability through the UDI system. In parallel, Regulation (EU) 2021/2282 on Health Technology Assessment (HTAR), applicable since January 2025, has introduced a European coordination mechanism through Joint Clinical Assessments (JCAs), progressively extending from oncology drugs and advanced therapies to class IIb/III medical devices and class D in vitro diagnostics from 2026. This presentation will illustrate the regulatory frameworks of medical devices and the new related challenges to obtain the CE marks. The speaker will also discuss how Italy has transposed this evolving framework through Legislative Decrees 137/2022 and 138/2022, redefining national governance of medical devices by introducing new obligations regarding vigilance, traceability, and multidimensional assessment of health technologies.

### European Approaches to HTA: Challenges, Solutions, and Transferable Lessons

*Martina Andellini*

Health systems across Europe have developed markedly different approaches to the assessment of health technologies, each shaped by distinct institutional traditions and governance priorities. This presentation will provide a comparative analysis of consolidated European HTA systems, examining NICE in the United Kingdom, the dual G-BA/IQWiG model in Germany and the HAS in France. The speaker will highlight shared features underpinning these mature systems, over two decades of operational continuity, high productive capacity, robust integration of HTA into reimbursement and procurement decisions, scientific independence, and methodological transparency, while also discussing their structural differences, from NICE's pragmatic cost-per-QALY thresholds to the German model's rapid hospital access pathways. Drawing transferable lessons from these European experiences, the speaker will examine Italy's current position with the National HTA-MD Programme (PNHTA-DM), discussing its governance architecture and funding mechanism, and identify which elements of these European systems, in terms of institutional design, evaluator plurality, and integration with procurement, could inspire a more responsive and scalable Italian HTA model.

### Decision-Making for Innovative Health Technologies: Key Features of a Subsidiary HTA System

*Giandomenico Nollo*

Faced with a growing structural gap between the demand for HTA of medical devices and Italy's current evaluative capacity, SIHTA has developed a novel governance model, the Subsidiary HTA system, designed to complement and strengthen the current national PNHTA-DM framework. This presentation will discuss the five founding pillars that guide the definition of the Subsidiary HTA model: subsidiarity with respect to the public governance system, institutional authority guaranteed by central accreditation and oversight, timeliness aligned with medical device life cycles, a liberal approach based on regulated competition among accredited evaluators, and accountability towards all stakeholders. The speaker will then present the new Subsidiary HTA system based on the strategic distinction between HTA Doers, the new Subsidiary Bodies for HTA of medical devices responsible for producing HTA assessments, operating under the strategic supervision of the Ministry of Health and the technical coordination of AGENAS, and the HTA Users, namely, healthcare organizations, contracting authorities, and other decision-making entities that use HTA assessments for appraisal and adoption decisions. The presentation will outline the rationale, objectives, operational mechanisms, system architecture, roles, responsibilities, and functional relationships among the key actors of the HTA-MDs ecosystem and expected benefits of the proposed model.

### Value based procurement and adoption and monitoring of Health Technologies the HTA Users perspectives

*Matteo Ritrovato*

Once HTA evidence has been produced, its value depends on how effectively it is translated into procurement, adoption, and monitoring decisions at national, regional, and local level. This presentation will focus on the perspective of HTA Users within the Subsidiary HTA system proposed by SIHTA. The speaker will illustrate how validated HTA reports inform technical evaluation criteria in public tenders under Legislative Decree 36/2023, enabling value-based procurement models in which clinical outcomes, organisational impact, and total cost of care are translated into objective scoring criteria, moving decisions beyond price alone. The presentation will further address the adoption phase, in which Regions and healthcare organisations plan procurement volumes and integrate HTA evidence into care pathways, and the subsequent monitoring phase, where real-world clinical, organisational and economic outcomes feed back into national information systems coordinated by the Ministry of Health. The speaker will discuss how this real-world data supports periodic reassessment of technologies, including the review of disruptive innovation status, and will argue for strengthening HTA appraisal capacity within healthcare organisations as a prerequisite for translating national evidence into responsive, context-sensitive local decisions.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 10A
Tuesday September 15, 09:30-11:00

### A View-Controllable CT-Based Pipeline for Generating Synthetic Echocardiographic Images with Aligned Anatomical Labels

*Marco Perra, Edoardo Spairani, Francesco Podda, Giovanni Magenes and Giulia Matrone*

In this work, we propose an integrated pipeline for generating synthetic transthoracic echocardiographic (TTE) images from computed tomography (CT) volumes, together with spatially aligned segmentation masks. The framework combines multi-label anatomical segmentation (Total Segmentator), tissue-classbased echogenicity modelling, geometry-aware plane extraction, scatterer-based ultrasound simulation (MUST simulator), and CycleGAN-based image refinement within a unified workflow. Unlike approaches based on simplified anatomical models, the proposed method exploits patient-specific CT data to preserve anatomical variability and maintain spatial consistency across all generated outputs. The simulation stage produces physically grounded B-mode images, while the subsequent domain adaptation step reduces the visual gap between synthetic and real echocardiographic data. In addition to qualitative assessment, preliminary proof-ofconcept experiments were conducted to evaluate the use of the generated data for training a semantic segmentation network in a low-data regime. The progressive addition of synthetic images to a limited set of real annotated samples improved segmentation performance, supporting the feasibility of the proposed framework as a source of annotated synthetic data. Although the present implementation focuses on TTE image generation, the modular structure of the pipeline could be extended to other anatomical regions, enabling the generation of synthetic ultrasound images from CT-derived anatomical information in different body districts. Overall, the proposed framework provides a flexible and controllable approach for generating synthetic echocardiographic datasets, with potential applications in training, validation, and benchmarking of AI-based image analysis algorithms, while reducing the dependence on manually annotated clinical datasets.

### Antimicrobial Activity of Three Rationally Selected L-Series Synthetic Peptides Against Clinically Relevant Bacterial Strains

*Natalia Beltrán Fernández, Fabiola Hernández Rosas and Tushar Janardan Pawar*

Antimicrobial resistance has intensified the need for alternative anti-infective strategies, particularly against clinically relevant bacterial pathogens. In this study, three short synthetic peptides from the L-series—L1, L2, and L3—were rationally selected based on high predicted antimicrobial peptide probability and evaluated against Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Enterococcus faecalis. Peptides were synthesized by solid-phase peptide synthesis, purified, and tested using a broth microdilution-associated alamarBlue assay and minimum inhibitory concentration (MIC) determination. In parallel, computational docking was used to explore peptide interaction with the transglycosylase domain of E. coli penicillin-binding protein 1b (PBP1b), a relevant target in bacterial cell-wall biosynthesis. Experimental results showed distinct strain-dependent antibacterial profiles for the three peptides despite their closely related amino acid composition. L1 exhibited the broadest and most balanced activity, with its strongest effect against E. faecalis (MIC 4 μg/mL), whereas L2 showed preferential activity against E. coli (MIC 8 μg/mL) and L3 was most active against P. aeruginosa (MIC 8 μg/mL). Docking analysis supported the experimental findings by indicating sequence-dependent differences in predicted target recognition. Overall, the study demonstrates that subtle residue rearrangements within short cationic peptides can substantially influence antibacterial spectrum and potency, supporting the integration of computational prioritization and experimental screening as an efficient strategy for early-stage antimicrobial peptide discovery.

### AI-Assisted Triage in Screening Mammography: Multi-Center Validation of a Transformer-Based System for Workload Reduction at High Sensitivity

*Luca Piano, Domenico Ficili, Giovanni Maimone, Giovanni Serra, Elena Galeasso, Giulia Rotunno, Simone Mazzetti, Valentina Giannini, Daniele Regge and Francesca Caumo*

Mammography-based breast cancer screening, while clinically effective, remains highly resource-intensive due to the low prevalence of malignancy among screened populations and the widespread reliance on independent double reading to ensure diagnostic accuracy. Deep learning systems have shown considerable promise in providing support to radiologists; nevertheless, several obstacles persist, including the inherent class imbalance arising from low cancer rates, the computational demands of handling very high-resolution imaging data, and the complexity of integrating complementary information across the multiple views acquired in a standard examination. In this paper, we develop and evaluate a transformer-based AI triage system for screening mammography, designed to reduce clinical workload while preserving high sensitivity. The model was trained on a large dataset comprising more than 2.5 million images and assessed on two independent test sets including out-of-distribution vendors and women of different nationalities, to evaluate its generalization capabilities across heterogeneous clinical settings. The proposed architecture builds on an improved TinyViT backbone to efficiently process the four standard mammographic views at high resolution, subsequently combining view-level representations into a single exam-level prediction. The model achieved AUROC values ~97%, with standalone sensitivities of ~98%. When combined with human readers, the model reduced the workload of the second reader by approximately 75%, while simultaneously improving positive predictive value and lowering recall rate relative to standard double reading. Benchmarked against two reference multi-view architectures, the proposed model demonstrated superior overall discrimination, supporting transformer-based AI triage as a promising tool for workflow optimization in mammography screening programs operating across diverse clinical environments.

### PPARGC1A, FTO, and MC4R: integrating metabolic genetics with sport performance, training adaptation, and metabolic risk

*Merima Smajlhodžić-Deljo, Ana Lalović, Amra Džuho and Adna Ašić*

The functions of PPARGC1A, FTO, and MC4R as metabolic genes that connect training adaptation, athletic performance, and metabolic health are examined in this narrative review. The rs8192678 polymorphism of PPARGC1A, which codes for PGC-1α, a master regulator of mitochondrial biogenesis and oxidative metabolism, has been linked to aerobic performance and endurance capacity, even though, the effects vary depending on the sport and ethnicity. In turn, MC4R and FTO are essential for controlling adiposity and energy balance. MC4R helps regulate hunger and activity-behavior, while FTO variations affect how the body responds to exercise. Exercise and training load can alter their phenotypic expression, and evidence suggests that polygenic models integrating these and related loci increase prediction of obesity and metabolic characteristics beyond single-gene effects. The need for more detailed, longitudinal, and genome-integrated research is highlighted by methodological limitations, such as limited sample numbers, heterogeneous phenotyping, and a lack of standardized training-intervention studies in athletes. PPARGC1A, FTO, and MC4R together demonstrate how genetic diversity interacts with lifestyle, nutrition, and training to shape athletic potential and metabolic resilience. This suggests a future in precision sports medicine that combines functional and metabolic phenotyping with genetic profiling.

### A quantitative virtual profile for 3D bone extracellular matrix mineralization

*Joseph Lovecchio, Beatrice Del Prete, George Mihail Vlasceanu, Mariana Ionita, Pietro Furlani, Emanuele Giordano, Ólafur Eysteinn Sigurjónsson and Paolo Gargiulo*

Biohybrid engineered tissues (BET) hold great promise in the pursuit of generating functional biological tissues for either research and/or clinical applications. These constructs involve biologically active material, therefore a high variability in the progress of their in vitro maturation process is expected. Traditionally, the evaluation of tissue engineered constructs relied on a multitude of specific metrics tailored to the tissue type being engineered. While these metrics can be highly informative, they have limitations, including a lack of generalizability and comparability across different constructs, leading to an incomplete reference values that make difficult to compare results across different studies and laboratories. Starting from this paradigm, a quantitative virtual profile (qVP) based on histological and metabolomic parameters was developed for an advanced monitoring of 3D in vitro bone extracellular matrix mineralization. This approach revealed a specific pattern during the maturation process of a bone tissue engineering-based product, suggesting that integrating data from various analytical techniques can yield a reliable tool for establishing unambiguously when a BET construct has reached a state of maturity. In this context, machine learning algorithms can be employed to uncover patterns, correlations, and trends that may not be apparent via traditional statistical analysis, enabling the development of a dimensionless predictive index. This idea new work is expected to unleash the full potential of tissue engineering, marking a groundbreaking advancement in the evaluation of TEed constructs and a significant milestone in the field. As the use of dimensionless indices becomes more widespread, the potential for innovative breakthroughs will bring us closer to the realization of the promise of TE in clinical applications.

### A Trasfer Learning approach for Localization of Molars and Dental Apices in Pediatric Panoramic Radiographs

*Francesca Angelone, Parisa Soltani, Homa Baninajarian, Amirhossein Vedae, Alessia La Rocca, Mario Sansone, Maria Romano, Francesco Amato and Alfonso Maria Ponsiglione*

Accurate assessment of dental apices in pediatric panoramic radiographs is a fundamental pillar for proper endodontic treatment planning. The integration of artificial intelligence is transforming radiographic analysis, offering crucial diagnostic support tools even in pediatric dentistry. This study analyzes the effectiveness of a transfer learning approach using the YOLOv8 model for identifying mandibular first permanent molars and their root apices. The primary objective is to test the model's accuracy in identifying root apices, a critical step for subsequent apical classification and a discriminating parameter between apexogenesis and apexification processes during clinical assessments. The system was validated using spatial accuracy, segmentation, and image quality metrics, including the Dice coefficient, mean precision (mAP), and structural similarity index (SSIM). The obtained data confirm the high performance of YOLOv8, which achieved a Dice score of 0.93 ± 0.06 for molars and 0.81 ± 0.08 for apices, and a mAP@50 of 0.93 and 0.90 for molar and apical detection tasks, respectively. The SSIM results also highlight a remarkable ability to preserve the finest anatomical details. Overall, the study demonstrates the validity of single-stage detection models in processing thin, low-contrast structures, typical of apical regions.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 10B
Tuesday September 15, 09:30-11:00

### ECG-Based Non-Invasive Glycaemic Estimation in Type 1 Diabetes

*Claudia Ferraro, Flavia Pasquali, Luca Bacco, Mario Merone and Leandro Pecchia*

Non-invasive glucose monitoring remains a key challenge in Type 1 diabetes mellitus. Among emerging alternatives to subcutaneous continuous glucose monitoring (CGM), electrocardiogram (ECG)-based approaches have shown potential, although existing studies are largely limited to fully subject-specific models. This study evaluates ECG-based continuous glucose estimation with particular focus on the role of personalization, leveraging a newly collected paediatric T1DM dataset acquired in real-life conditions. A two-stage feature extraction framework was applied to 6-second ECG windows preceding each CGM measurement, generating 160 statistical descriptors derived from beat-level morphological features. Three modelling strategies based on multilayer perceptron networks were compared: subject-specific (SS), subject-independent (SI), and subject-independent with fine-tuning (SI+FT). Performance was assessed using Clarke Error Grid analysis, distinguishing between subjects monitored with CGM devices sampling every 5 minutes and those sampling every 15 minutes. In the 5-minute sampling group, SS and SI+FT achieved comparable clinical accuracy (97.33% ± 3.16 vs 97.01% ± 4.27 in Zones A+B), while SI showed lower performance (90.63% ± 11.86). In the 15-minute sampling group, performance decreased across all strategies. These results indicate that fine-tuning enables performance comparable to fully personalized models while supporting scalable ECG-based glucose estimation.

## Performance of Different Wearable Sensor Configurations in Sleep/Wake Classification with and without Apnoea Events

*Daniele Sasso, Claudia Ferraro, Mario Merone, Luca Bacco and Leandro Pecchia*

Wearable devices enable large-scale and non-invasive sleep monitoring by continuously capturing physiological signals in real-world settings. However, the relative contribution of different sensing modalities and the impact of apnoea-related variability on model performance remain insufficiently understood in wearable sleep/wake classification. In this work, we present a controlled experimental study to investigate the role of multimodal wearable signals and apnoea-related variability. We evaluate multiple modality configurations, ranging from accelerometry alone to combinations with additional physiological signals, and assess robustness under different training and testing conditions defined by the presence or absence of apnoea events. A lightweight 1D convolutional neural network is adopted and kept fixed across experiments to isolate the effect of input configurations. Experiments on the DREAMT dataset show that combining accelerometry with heart rate consistently improves performance over both single-modality and full multimodal configurations, reaching an F1-score of 0.766, outperforming both single-modality and full multimodal configurations. In addition, results reveal a significant impact of apnoea-related variability, with performance degradation under mismatched training/testing conditions, where apnoea events are present in only one of the two datasets, indicating the presence of distribution shifts. These findings highlight the importance of modality selection and physiological variability in wearable sleep analysis, and show that simple models can achieve competitive performance when paired with appropriate input representations.

## Education 4.0 in Vocational Biomedical Engineering: Integrating AI, VR, and 3D Printing to Strengthen Digital and Practical Competencies

*Madžida Hundur Hiyari and Adna Softić*

In the context of rapid technological advancement and the emergence of Industry 4.0, education systems are undergoing a profound transformation, particularly within vocational education and training (VET). The increasing demand for a workforce equipped with both theoretical knowledge and practical, technology-driven skills has accelerated the adoption of Education 4.0 approaches, especially in interdisciplinary fields such as biomedical engineering, where engineering principles are directly applied to healthcare challenges. This paper explores the integration of key enabling technologies, including artificial intelligence (AI), virtual reality (VR), and 3D printing, alongside Massive Open Online Courses (MOOCs) and Open Educational Resources (OER), as tools for enhancing learning outcomes and strengthening digital competencies in vocational education. The study highlights how these technologies facilitate experiential, flexible, and personalized learning environments, enabling students to acquire hands-on skills aligned with real-world industry requirements. In the context of biomedical engineering, such approaches are particularly relevant for the development of competencies related to medical device design, simulation of clinical procedures, and analysis of biomedical data. Special attention is given to the role of 3D printing and immersive VR environments in bridging the gap between theoretical instruction and practical application, while AI-driven tools support adaptive learning and data-informed educational processes. Furthermore, MOOCs and OER contribute to increased accessibility and scalability of high-quality educational content, including specialized topics in healthcare technologies. Despite the significant potential of these technologies, the paper also identifies key challenges related to infrastructure, institutional readiness, and pedagogical adaptation, which continue to limit their widespread implementation. The findings suggest that a strategic and integrated approach to Education 4.0 is essential for modernizing vocational education systems and ensuring their alignment with the evolving demands of the digital economy, particularly within the rapidly advancing biomedical engineering sector.

## Quantitative Assessment of Skin Tone Bias in Photoplethysmographic Signal Processing and Feature Analysis

*Estella Himona, Ling Li and Panicos A. Kyriacou*

Photoplethysmography (PPG) has become a foundational sensing modality in both clinical monitoring and wearable health technologies. Beyond pulse oximetry, PPG waveforms are increasingly utilised for pulse wave analysis (PWA) and morphology-based feature extraction in applications such as cuffless blood pressure estimation, vascular ageing assessment, arterial stiffness evaluation, and cardiovascular risk modelling. As reliance on PPG-derived biomarkers expands, an important question arises: are waveform-derived features consistent across individuals with diverse skin tones? Emerging evidence suggests that device performance may vary systematically with skin pigmentation, raising concerns regarding potential bias in PPG-based technologies. However, whether skin tone is associated with differences in waveform morphology itself remains insufficiently understood. In this study, we extracted features from signals observed from the Open Oximetry dataset and analysed them to explore potential differences across skin tone groups. Initial statistical analysis suggested differences in several temporal features, indicating possible variation in waveform morphology. When accounting for multiple comparisons, these differences did not survive statistical robustness. Effect size analysis nevertheless revealed small to moderate trends across a subset of features, suggesting that any underlying variation may be subtle and distributed rather than strongly pronounced. These findings emphasize the need for careful statistical treatment and appropriate units of analysis when studying physiological signals and highlight the importance of further investigation using larger and more diverse datasets.

### Predicting Response to Neoadjuvant Chemotherapy in Ovarian Cancer from CT Baseline Using Multi-Loss Deep Learning

*Francesco Pastori, Francesca Fati, Marina Rosanu, Luigi De Vitis, Lucia Ribero, Gabriella Schivardi, Giovanni Damiano Aletti, Nicoletta Colombo, Jvan Casarin, Francesco Multinu and Elena De Momi*

Ovarian cancer is the most lethal gynecologic malignancy: around 60% of patients are diagnosed at an advanced stage, with an associated 5-year survival rate of about 30%. Early identification of non-responders to neoadjuvant chemotherapy remains a key unmet need, as it could prevent ineffective therapy and avoid delays in optimal surgical management. This work proposes a non-invasive deep learning framework to predict neoadjuvant chemotherapy response from pre-treatment contrast-enhanced CT by leveraging automatically derived 3D lesion masks. The approach encodes axial slices with a partially fine-tuned pretrained image encoder and aggregates slice-level representations into a volumetric embedding through an attention-based module. Training combines classification loss with supervised contrastive regularization and hard-negative mining to improve separation between ambiguous responders and non-responders. The method was developed on a retrospective single-center cohort from the European Institute of Oncology (Milan, IT), including 280 eligible patients (147 responder, 133 non-responder). On the test cohort, the model achieved a ROC-AUC of 0.73 (95% CI: 0.58–0.86) and an F1-score of 0.70 (95% CI: 0.56–0.82). Overall, these results suggest that the proposed architecture learns clinically relevant predictive patterns and provides a robust foundation for an imaging-based stratification tool.

### Lightweight Multimodal Deep Learning for Continuous Respiratory Rate Estimation from ECG and PPG

*Edoardo Caporin, Luca Bacco, Leandro Pecchia and Mario Merone*

Continuous Respiratory Rate monitoring is an important early indicator of clinical deterioration. Although non-invasive sensors—such as wearable Holters and smartwatches—can acquire electrocardiogram and photoplethysmogram signals, reliably extracting respiratory modulations remains challenging due to artifact corruption and intrinsic morphological variability. To bridge the gap between clinical accuracy and edge-device constraints, we propose UT-RespNet, a lightweight multimodal deep learning architecture. Combining 1D U-Net feature extractors with a Transformer-based late-fusion mechanism, UT-RespNet processes 32-second multimodal windows. The U-Net encoders capture high-resolution local morphologies via skip connections, while the Transformer attention mechanism learns long-term global temporal dependencies, dynamically weighting the most reliable modality. To ensure unbiased clinical validation, UT-RespNet was evaluated on the public BIDMC dataset (53 critically ill patients) using Leave-One-Patient-Out CrossValidation. Setting a new State-of-the-Art performance, our approach achieved a Mean Absolute Error (MAE) of 1.16 ± 2.59 Breaths Per Minute (BPM) on clean data, maintaining a MAE of 1.24 ± 1.88 BPM under out-of-distribution noise on the test sets. UT-RespNet achieves this accuracy while requiring 1.2M parameters and 2.21 ms of inference time, demonstrating its viability for continuous Respiratory Rate monitoring on resource-constrained ambulatory devices.

## Digital, Remote, and Wearable Healthcare Technologies

Session 10C
Tuesday September 15, 09:30-11:00

### A Wearable Closed-Loop EEG-Guided Mindfulness System for Chronic Tinnitus Intervention: A Randomized Controlled Study

*Bao Xiaoyu, Minhao Gao, Xueji Feng, Yinfei Liang, Zhicheng Li, Kaixiu Jin, Xiaofeng Lin, Ruichuan Lu, Junhao Lin, Canjian Huang, Qiyun Huang, Xiangli Zeng and Yuanqing Li*

Chronic tinnitus is commonly accompanied by sleep disturbance, emotional distress, and impaired attentional regulation, yet effective non-pharmacological interventions remain limited. We developed a wearable closed-loop EEG-guided mindfulness system for home-based tinnitus intervention and evaluated its feasibility and preliminary efficacy in a randomized controlled study. Sixty patients with chronic tinnitus were enrolled, and 57 completed the protocol. Participants were assigned to an experimental group receiving real-time EEG-contingent feedback or to a control group receiving sham feedback during daily 20-min mindfulness training over 1 month. Linear mixed-effects modeling showed a significant group-by-time interaction for Tinnitus Handicap Inventory (THI), indicating a greater reduction in tinnitus-related handicap in the experimental group than in the control group. Within the experimental group, tinnitus severity and anxiety decreased, mindfulness level increased, and subjective sleep improved. EEG measures in the experimental group further showed a reduced theta/beta ratio and an increased decoded mindfulness score after intervention, suggesting improved attentional regulation. These findings support the feasibility of wearable closed-loop EEG-guided mindfulness training as a home-based, non-pharmacological intervention for chronic tinnitus and suggest potential benefits for tinnitus-related burden, sleep, and brain-state regulation.

### Pressure Distribution in Supine Postures: Full-Body and Region of Interest Analysis

*Stefano Cimignolo, Damiano Fruet, Michela Masè and Giandomenico Nollo*

Pressure injuries represent one of the main complications in individuals forced to remain in the same position for prolonged peri- ods. Frequent repositioning has been shown to reduce the incidence of pressure ulcers. This work evaluated how five different supine postures influenced pressure distribution using the public PoPu dataset. For each configuration, median pressure and contact area were computed on sen- sors exceeding a 5 mmHg threshold. The analysis was performed by com- paring global (full-body) metrics with a regional evaluation focused on the torso (Region of Interest (ROI)), an area particularly exposed to overload risk. The results showed that global metrics provided an over- all characterization of pressure distribution, while the ROI analysis was significantly more discriminative. Notably, the posture with arms behind the head exhibited the highest pressure concentration in the torso area (21.06 mmHg) despite a large global contact area.

Sensitivity analysis (3, 5, 10 mmHg), conducted on the full–body configuration, showed that increasing the threshold reduced noise but also led to the loss of a rel- evant portion of the pressure distribution. These results suggested that regional pressure monitoring was crucial for effective pressure injury pre- vention and that approaches of this type could support existing clinical guidelines for patient repositioning.

### A Digital Calibration Management Framework for Medical Equipment in Low-Resource Healthcare Settings

*Mary Kalekye Mulu*

Effective calibration of medical equipment is critical for patient safety and clinical accuracy. However, hospitals in low-resource settings often face challenges such as limited technical personnel, inconsistent calibration schedules, and inadequate documentation systems, which compromise equipment performance and regulatory compliance. This paper proposes a digital framework for full-cycle medical equipment calibration management, encompassing planning, execution, verification, and reporting. The framework integrates digital tracking tools, automated alerts, and dashboards to monitor calibration status, prioritize high-risk devices, and ensure adherence to international standards. By leveraging digital systems, the framework enhances operational efficiency, reduces human error, and supports sustainable resource utilization. Its design considers scalability, accessibility, and adaptability to resource-constrained healthcare environments, promoting equitable and reliable management of biomedical assets. The proposed solution intersects clinical engineering, digital health technologies, and regulatory compliance, addressing Topics 2, 3, and 6 of the IFMBE conference. The framework is presented conceptually with illustrative workflows, demonstrating its potential to improve equipment reliability, patient safety, and compliance monitoring in diverse healthcare settings.

### An explainable Hybrid Symbolic-Deep Learning Architecture for Real-Time Sleep and Behavior Monitoring in Ambient Assisted Living Environment

*Simone Kresevic, Aleksandar Miladinović, Agostino Accardo, Marco Vascotto, Cristiano Gomiselli and Milos Ajcevic*

Ambient Assisted Living (AAL) technologies can support independent living through unobtrusive monitoring of daily behavior, yet real-world deployment remains constrained by limited robustness across heterogeneous home environments and the lack of transparent, caregiver-interpretable decision support. This study aims to develop an explainable hybrid symbolic-learning framework in which a symbolic module provides interpretable behavioral states, while a deep-learning-based one characterizes resident behavior through sleep-activity analysis, used here as the prototypical behavioral dimension to capture long-range temporal dependencies. The system was developed across eight independent real-world residential environments involving older adults, each spanning one-to-two months of continuous operation. Integrating symbolic behavioral representations with deep learning consistently outperforms raw-sensor learning across all evaluated model families. The Transformer-based configuration achieves the strongest performance on held-out test scenarios, reaching F1-score of 0.96, MCC of 0.94, and PR–AUC of 0.99 —an approximate 10% relative improvement over its raw-sensor counterpart. By reframing sleep monitoring from a dichotomous rule-based decision to a probabilistic estimation problem, the proposed approach reduces the false-negative rate for sleep detection from 9.2% to 3.9%, enabling more reliable real-time monitoring. The proposed system supports real-time, edge-compatible deployment while preserving traceability through explanation-aware alarms, providing a practical and auditable solution for scalable AAL deployments.

### Digital and AI□Enabled Screening Methods for Diabetic Neuropathy: a Systematic Review

*Pedro Checa Rifa, Davide Piaggio, Paramjit Gill, Daniel Fox, Kamben Vyapooree, Hannah Kobia-Amanfi and Jinjian Jiang*

Diabetic neuropathy (DN) is one of the most prevalent and disabling complications of diabetes mellitus, affecting up to half of patients over their lifetime and contributing substantially to ulcers, amputations, and mortality. Despite this burden, existing DN screening methods remain resource□intensive, often invasive, and poorly suited for large□scale or community□based deployment. Recent advances in digital health and artificial intelligence (AI) offer opportunities to improve early detection, monitoring, and accessibility through mobile and point□of□care (POC) solutions. This systematic literature review aims to identify and evaluate DN screening methods that have been integrated with digital health technologies, assess their diagnostic performance, usability, and feasibility for non□specialist use, and identify gaps to inform the design of an AI□enabled mHealth screening toolbox. A structured search was conducted across four databases, namely PubMed, Scopus, Web of Science, and Embase, covering publications from 2011 to the present. Eligible studies involved digital or mobile health solutions applied to DN screening, diagnosis, or monitoring, including smartphone applications, wearable or POC devices, and AI□assisted systems. Screening methods of interest included vibration, thermal, pressure, sudomotor, pupillometry, and validated questionnaires. Invasive methods and non□digital tools were excluded. Following duplicate removal, 1,920 records were identified. After title and abstract screening, 78 records were retained, and approximately 50 studies met the inclusion criteria after full□text assessment. Included studies demonstrated substantial heterogeneity in screening modalities, digital architectures, and validation strategies. Multimodal approaches combining subjective questionnaires with objective sensory testing were common, with several studies reporting integration into smartphone□based platforms. Diagnostic performance metrics were variably reported, and only a subset of studies included external validation, usability assessments, or non□specialist deployment. AI and machine learning techniques were increasingly used for classification and risk stratification, though transparency, explainability, and regulatory considerations were inconsistently addressed. Digital health solutions for DN screening show promising diagnostic accuracy and potential for scalable, non□invasive deployment; however, evidence gaps remain in clinical validation, usability, and real□world implementation. These findings highlight key design requirements and research priorities for developing frugal, user□centred, and regulatorily compliant mHealth tools for DN screening and monitoring.

### Decoupling of Spectral and Network EEG Features in Drug-Resistant Epilepsy

*Sara Mecozzi, Lorenzo Ricci, Biagio M. Sancetta, Marco Sferruzzi, Giovanni Assenza, Leandro Pecchia and Margherita A.G. Matarrese*

Purpose: Relative power spectral density (rPSD) and functional connectivity (FC) are widely used quantitative EEG (qEEG) features in computational neuroscience and epilepsy research, yet they are often analyzed independently. How their relationship varies across frequency bands and between physiological and pathological conditions remains unclear. We investigated how the rPSD–FC correlation varies across frequency bands in healthy controls (H) and people with focal epilepsy, with a specific focus on differences between responders (R) and non-responders (non-R). We also evaluated whether correlations between channel-wise rPSD and nodal graph metrics, including centrality and segregation measures, could improve discrimination between H, R, and non-R. Methods: We retrospectively analyzed scalp 19-channels EEGs from 284 people with focal epilepsy with at least 2 years of follow-up and 109 healthy controls. For each frequency band, we computed rPSD and estimated FC using multiple phase- and amplitude-based connectivity measures. From these, we derived global and nodal graph-theoretical metrics and inter-hemispheric asymmetry indices. The rPSD–FC correlation within each frequency band was quantified using Spearman's rank correlation coefficient. Results: In H, only 23/918 global FC features were significantly correlated with rPSD ($\rho>0.4$, $p<0.05$), exclusively in the α frequency band. In contrast, people with epilepsy showed 15 correlated features overall, mainly distributed in the δ band (14 features), with only one in the α band. These moderate correlations predominantly involved FC matrices not corrected for volume conduction, i.e. phase locking value (PLV), amplitude envelope correlation (AEC), and magnitude-squared coherence. At the nodal level, α-band correlations between rPSD and closeness centrality progressively decreased from H to R and non-R for both wPLI (median values H: 0.028; R: –0.035; non-R: –0.11) and ImCOH (H: 0.09; R: 0.01; non-R: –0.08), with significant differences between H and non-R, and between R and non-R ($p<0.05$). In contrast, correlations between α-rPSD and clustering coefficient increased from H to epilepsy groups for both wPLI (H: 0.11; R: 0.22; non-R: 0.28) and ImCOH (H: –0.02; R: 0.10; non-R: 0.18). Clustering coefficient showed significant differences between H and both epilepsy groups, and across all ImCOH group comparisons ($p<0.05$). Conclusions: rPSD and FC capture complementary rather than interchangeable qEEG information. The structured α-band spectral–network coupling observed in H is disrupted in focal epilepsy, indicating a pathological reorganization of brain network dynamics. In particular, nodal correlations between spectral and topological features differentiated H, R, and non-R groups, suggesting their potential utility as multimodal EEG biomarkers for drug-response characterization and classification pipelines.

## Medical Imaging, Simulation, and Immersive Technologies

Session 10D
Tuesday September 15, 09:30-11:00

### An Experimental MIMO Ultrasound Tomography Dataset for Benchmarking Imaging Algorithms

*Michele Ambrosanio, Stefano Franceschini, Francesca Bifulco, Roberta Diana, Giuseppe Cesarelli and Fabio Baselice*

Ultrasound tomography (UST) is a promising imaging modality for biomedical and non-destructive testing applications, as it enables the reconstruction of spatially distributed mechanical properties in an operator-independent manner. Despite significant methodological advances, the validation and comparison of tomographic and data-driven imaging approaches remain hindered by the limited availability of publicly accessible experimental datasets acquired under controlled conditions. This work addresses this gap by presenting a two-dimensional experimental ultrasound tomography database acquired using an in-house multiple-input–multiple-output (MIMO) circular array system. The dataset comprises a wide range of acquisition scenarios involving targets of different sizes, shapes, materials, and spatial configurations. By providing coherent multistatic measurements together with a well-documented acquisition protocol, the proposed database is intended to serve as a benchmark platform for the development, testing, and validation of conventional, learning-based, and ultrasound imaging algorithms.

### Feasibility of a Mixed Reality Framework for Balance Assessment in Multiple Sclerosis

*Alessia Finti, Michela Franzò, Giovanni Pasini, Martina Fioretti, Gemma Vizzaccaro, Edoardo Covelli, Franco Marinozzi and Fabiano Bini*

Multiple Sclerosis (MS) significantly impairs sensory integration, leading to balance disturbances that often go undetected by conventional clinical tests due to limited sensitivity. This study introduces a Mixed Reality (MR) framework designed to objectively assess postural instability through an immersive overground walking task. Developed in Unity for the HoloLens 2, the protocol utilizes four virtual labyrinths with increasing sensory and cognitive loads, including dynamic obstacles and visual-vestibular conflicts. A key contribution of this work is the Lateral Variability Index (LVI), a metric specifically defined to capture rapid micro-corrections and episodic instability that traditional indices, like sway%, often fail to detect. Preliminary validation on healthy volunteers demonstrated that the protocol effectively elicits scenario-dependent gait behaviors, with LVI proving highly responsive to localized challenges. These findings suggest that LVI could serve as a sensitive digital biomarker for the early identification of subtle MS-related balance impairments. Future developments will focus on clinical validation and leveraging high-fidelity devices like the Apple Vision Pro to further enhance diagnostic reliability.

### Beyond Overlap Metrics: A Multi-Domain Evaluation Framework for Hepatic Vascular Segmentation

*Enrico Franzoi, Alberto Morelli, Cosimo Aliani, Leonardo Bocchi and Francesca Uccheddu*

Evaluation and validation of hepatic vascular segmentations remain an open methodological challenge: traditional volumetric overlap metrics fail to cap-ture the geometric fidelity and topological integrity of highly branched, clini-cally critical structures. This limitation undermines comparability across segmentation methods and hinders the assessment of their actual clinical suitability. This paper proposes a multi-domain evaluation framework de-signed as a reusable comparative protocol for hepatic vascular segmentation: rather than evaluating a single algorithm in isolation, it provides a structured methodology for benchmarking multiple segmentation methods against a common Ground Truth, producing method-specific diagnostic profiles across three complementary and non-redundant evaluation dimensions, volumetric (DSC, IoU, MCC), geometric (MSD, RMS, HD95), and topological (clDice). The framework is independent of the segmentation technique used and in-cludes a rank aggregation system for comparing heterogeneous methods. To demonstrate its discriminative capability, the framework was applied to five multi-scale vesselness filters and an nnU-Net v2 model on the 3D-IRCADb-01 dataset. Results show that methods with comparable volumetric perfor-mance can exhibit significantly different behaviour in terms of geometric ac-curacy and topological continuity, revealing differences invisible to DSC alone. The proposed framework constitutes a generalisable methodology for vascular segmentation evaluation and provides a solid foundation for the de-velopment of advanced approaches oriented towards clinical application.

## Development and Evaluation of Alignment Fixtures for Precision Airflow Velocity Profiling in Biosafety Cabinets

*Lok Him Tse, Hiu Ching Poon, Cheuk Hin Man and Yuk Yin Li*

Standardised certification and preventive maintenance of Biosafety Cabinets (BSCs) require precise airflow measurements. Manually placing an anemometer leads to errors due to operator influence, angle misalignment, and airflow disturbances. To eliminate these confounding variables, this study developed and evaluated mechanical alignment fixtures designed to enforce fixed spatial positioning and stable angular orientation during testing. Two prototypes were fabricated: a Polyamide 12 (Nylon PA12) model via Selective Laser Sintering (SLS) and a Grade 316L stainless steel model via Selective Laser Melting (SLM). Both designs were experimentally validated within a Class II Type B2 BSC across a standardised measurement grid. The results demonstrate that both fixtures significantly enhanced measurement consistency and accelerated sensor stabilisation compared to manual deployment, with the stainless steel design exhibiting optimal structural rigidity. Furthermore, while the 3D-printed nylon prototype provides an effective platform for rapid prototyping, its inherent micro-porosity subjects it to long-term chemical degradation, swelling, and dimensional warping when exposed to aggressive clinical sterilising agents. Conversely, Grade 316L stainless steel demonstrated absolute chemical immunity, making it the superior material for clinical field deployment. Although current prototypes are limited by model-specific geometries, the proposed way forward involves developing an adjustable telescopic framework with indexed locking tracks to achieve universal adaptability across diverse cabinet profiles.

## Design and development of a perfusion bioreactor for in-line and real-time measurement of metabolic patterns

*Cristiana Ragozzino, Tamara Boscarino, Pierpaolo Fucile and Joseph Lovecchio*

Dynamic cell culture systems represent promising tools for the in vitro study of osteogenesis, as they overcome the limitations of traditional static cultures. Bone cells respond not only to biochemical signals but also to physical and mechanical stimuli, including medium flow, shear stress, and the convective transport of nutrients and metabolites. These factors activate mechanotransduction pathways regulating cell proliferation, differentiation, and mineralized extracellular matrix deposition. In this context, dynamic bioreactors recreate a more physiologically relevant microenvironment, promoting more homogeneous and functionally mature cell cultures. Among the available configurations, perfusion bioreactors are particularly effective for three-dimensional (3D) cultures on porous scaffolds. Controlled medium flow improves oxygen and nutrient distribution while generating mechanical cues associated with osteogenic differentiation. However, most current dynamic culture systems still rely on end-point analyses or discrete sampling of the culture medium to evaluate cell activity. This approach provides limited information and does not capture the dynamic evolution of cellular metabolism. To address these limitations, this project focuses on the development of a perfusion bioreactor integrated with electrochemical biosensors capable of continuously monitoring key metabolites involved in cell proliferation and osteogenic differentiation. The bioreactor consists of two main functional units: a perfusion unit responsible for generating controlled medium flow and a control unit regulating the operating conditions of the system. The platform also includes modular multiwell systems in which cells are cultured on biomimetic scaffolds under controlled flow conditions, enabling reproducible modulation of fluid dynamic parameters and the mechanical microenvironment. This approach combines dynamic 3D culture with in-line monitoring of the culture medium, allowing real-time tracking of cellular metabolic evolution and providing sensitive information on biological responses. The proposed platform may support advanced in vitro models for osteogenesis studies and biomaterial screening, contributing to the development of physiologically relevant tissue engineering systems.

## The Shift Toward Non-Planar Biofabrication

*Pierpaolo Fucile, Vivek Cherian David, Maria Kalogeropoulou and Lorenzo Moroni*

Recent advances in Regenerative Medicine (RM) are enabling increasingly high degrees of biomimicry. These kinds of innovations must be supported by adequate structures in terms of biomimetic design and responses. Limitations in Additive Manufacturing (AM) technologies are evident when it comes to the fabrication of complex architectures (i.e. anisotropic structures and specific fibres disposition). We have developed many solutions to overcome these limitations and provide useful and powerful tools for researchers in the field of RM and biofabrication. We tackled the issue of complex pores designs availability, and printing path optimization by developing GIPPO (Graph-based Iterative Printing Path Optimization). It is an open-source and user-friendly platform for designing complex porous scaffolds while improving 3D printing outcomes. GIPPO can generate ad hoc bio-inspired designs and optimize the printing path, thus boosting the final performances of the devices. This resulted in enhanced printing resolution and mechanical performances which were tested through tensile and out-of-plane deformation assessments. We demonstrated that lattices performances can be enhanced by overcoming software-inherent limitations. To unlock the full potential of GIPPO as non-planar lattices generator and optimizer, we combined it with RAVEN (Robot-Assisted Volumetric ExtrusioN), a hardware-agnostic platform for robotic printing in small-scale RM applications. RAVEN is based on ROS2 (Robot Operating System) and enhanced by AI for real-time control and adjustment of extrusion flow and positioning. Our open-source platform consists of a neural network-based computer vision algorithm which identifies printed filaments, and a high precision inertial measurement unit that can accurately measure the 3D orientation of the extruder. This control on the non-planar printing process allowed us to fabricate complex “in air” and unit-cell based designs, by combining custom-made algorithms for generative 3D lattices design and automatic orientation calculation. The integration with GIPPO was successfully tested by optimising complex 3D lattices and comparing them with non-optimized ones.

## SS Evolving Medical AI

Session 10E
Tuesday September 15, 09:30-11:00

### Augmented Clinical Intelligence: Human-Centered AI Supporting and Enhancing Medical Practice

*Gabriele Cevenini*

The rapid integration of artificial intelligence (AI) and digital technologies into clinical environments has prompted a fundamental reconceptualization of the physician–patient–technology triad. Rather than operating as autonomous decision-makers, modern digital solutions must be designed as human-centered tools that function within a shared care ecosystem, prioritizing explainability and the humanization of healthcare. This presentation introduces the framework of Augmented Clinical Intelligence, a paradigm in which AI serves to support, amplify, and refine, rather than disrupt, traditional clinical practices, actively strengthening the foundational bond of trust and comfort between doctors and patients. To demonstrate the efficacy of this collaborative approach, we highlight two long-standing, model-driven clinical applications developed to seamlessly integrate into established medical workflows. First, in obstetrics, an interactive multinormal probability model paired with artificial neural networks allows real-time checking and correction of human errors during fetal echobiometry, significantly improving the accuracy of fetal weight estimations. Second, in cardiac surgery, a machine-learning clinical model optimizes preoperative blood resource allocation, radically reducing blood bag waste while safeguarding patient safety. Both examples demonstrate that state-of-the-art AI systems achieve their full clinical potential when they are transparent, interpretable, and subordinate to medical judgment. By acting as a robust "second opinion," these technologies reduce cognitive burdens and minimize clinical errors without altering the relational integrity of medical care. Ultimately, this work posits that the future of medical engineering lies not in the replacement of human expertise, but in its deliberate, harmonious, and ethically grounded technological augmentation.

### Deep Learning in Medical Imaging: From Detection to Clinical Integration

*Alessandra Cartocci*

Medical imaging has been fundamentally transformed by the advent of deep learning architectures, particularly convolutional neural networks (CNNs) and, more recently, vision transformers (ViTs). This presentation provides a comprehensive overview of the trajectory from algorithmic detection to full-scale clinical integration, examining both the technical underpinnings and the translational challenges inherent in deploying image-based AI in real-world healthcare settings. We review state-of-the-art performance benchmarks across key imaging modalities, including radiology, pathology, ophthalmology, and cardiology where deep learning models have demonstrated diagnostic accuracy comparable to or exceeding specialist-level performance. Particular attention is devoted to the methodological rigor required for clinical validation: prospective study design, external cohort testing, and the construction of demographically representative training datasets. A central focus of this session is the growing body of real-world deployments in which AI imaging tools have achieved full clinical integration. In chest radiology, AI-assisted triage systems are now operational in multiple European hospital networks, automatically flagging critical findings such as pneumothorax and pulmonary embolism to reduce reporting delays. In ophthalmology, deep learning platforms for diabetic retinopathy screening have received regulatory clearance and are deployed at population scale in national programmes across several State. Pathology has seen the emergence of AI-powered whole-slide image analysis for cancer grading, with several tools embedded directly into pathology workstation software. These examples illustrate how imaging AI, when designed around established clinical workflows and validated on representative populations, transitions successfully from research prototype to standard of care. Case studies from European hospital networks are used to illustrate successful integration pipelines, and a phased implementation model is proposed in which deep learning tools are introduced as augmentative instruments within structured quality-assurance frameworks.

### AI-Based Diagnostic Algorithms: Clinical Applications in Dermatology

*Linda Tognetti*

Dermatology represents one of the most advanced clinical domains for the deployment of AI-based diagnostic algorithms, owing to the inherently visual and pattern-dependent nature of skin disease classification. This presentation systematically reviews the current landscape of machine learning tools applied to dermatological diagnosis, with a focus on their clinical utility, performance characteristics, and translational potential. The recognition of cutaneous malignant melanoma at the early stage rests a critical issue for dermatologists worldwide. Early diagnosis based on dermoscopic examination rest the first tool to decrease MM mortality rate. However, this non-invasive diagnostic method is largely influenced by the dermatologists' experience and by the subjectivity in visual perception of dermoscopic features inside melanocytic skin lesions. Moreover, standard dermoscopy fails to reach adequate diagnostic accuracy in differentiating the early melanomas from the atypical nevi with overlapping clinical and biological features. More recently, the medical imaging field drew its attention to convolutional neural network, deep learning models that remind the neurons connections of the human visual cortex. In the last few years, DCNNs became of interest as decision support systems for dermoscopic analysis of MM and skin lesions in general, and different CNNs models competed in international challenges on large datasets. Promising results have been reported overall, but adequate comparison was hard due differences in the composition of the training and of the testing set, beside the intrinsic differences in the DCNN architecture. We here aim to summarize the status of the art of DCNN in melanoma diagnosis and present the newly proposed hybrid DCNN models integrated with clinical data. Based on the current encouraging results, future architectures should consider to incorporate some additional clinical data of lesions and patients to improve their diagnostic accuracy in difficult MSL detection. Moreover, we report on our recent studies concerning the use of DL models in the non-invasive diagnosis of squamous cell carcinoma and basal cell carcinoma with line-filed confocal optical coherence tomography, a new imaging device of dermatologic use able to give an in vivo tridimensional overview of the skin at cellular resolution. Finally, we illustrate a series of experiments on the use of GAN-generative adversarial network in the generation of synthetic images of melanomas and atypical nevi for educational purposes of dermatologists and implementation of defective datasets useful for the training of future diagnostic models

### Generative AI in Healthcare: Clinical Reporting, Decision Support, and Knowledge Sharing

*Alessio Luschi*

The talk presents a multimodal generative AI pipeline for structured dermoscopic reporting, combining CNN-based classification of melanocytic lesions with LLM-driven clinical report generation. The framework builds on a prior validation study of synthetic dermoscopic images, assessed through a visual Turing test with expert dermatologists, which confirmed their perceptual quality and value for model training. Implications for reliability, reproducibility, and governance of generative models as decision support systems in clinical practice will be discussed.

### The Limits of AI in Medicine: Bias, Safety, Ethics, and Clinical Responsibility

*Pietro Rubegni*

As artificial intelligence systems become increasingly embedded in clinical practice, a rigorous examination of their limitations is both scientifically necessary and ethically imperative. This presentation offers a critical appraisal of the structural, epistemic, and normative constraints that define the boundaries of AI applicability in medicine, with particular emphasis on algorithmic bias, patient safety, and the distribution of moral responsibility. We begin with a taxonomic analysis of bias sources across the AI pipeline — from data curation and annotation to model training and deployment — demonstrating how systematic underrepresentation of minority populations, atypical presentations, and low-prevalence conditions generates discriminatory error gradients that may exacerbate existing healthcare inequalities. Documented case studies across imaging, risk stratification, and clinical triage are presented to ground theoretical concerns in empirical evidence. Safety considerations are addressed through the lens of failure mode analysis: we characterize the conditions under which AI systems produce high-confidence erroneous outputs, and argue for mandatory adversarial testing as a prerequisite for clinical certification. The ethical framework is developed around the concepts of non-maleficence, accountability, and informed consent in AI-mediated care. We critically interrogate the diffusion of clinical responsibility in human–AI hybrid decision systems and propose a structured model of shared accountability. The session concludes with a set of evidence-based recommendations for governance bodies, clinical institutions, and AI developers committed to the safe and equitable integration of AI into medicine.

## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies

Session 12A
Tuesday September 15, 12:00-13:30

### Real-Time Indoor Positioning of Critical Medical Devices: A Hybrid BLE Pilot under Greece's Unified Medical Equipment Management System

*Georgios Papadoulis, Emil Valchinov and Aris Dermitzakis*

Critical medical devices in modern hospitals – infusion pumps, defibrillators, patient monitors, ventilators, ECG carts, mobile beds – move continuously between wards, leading to misplacement, accelerated wear, delays in patient care, and a substantial hidden workload for nursing and biomedical engineering staff. This paper presents a pilot subsystem for real-time indoor positioning of critical medical devices, developed and deployed under Greece's national project Horizontal Digital Transformation Interventions for Supervised Bodies of the Greek Ministry of Health – Section 3: Unified Medical Equipment Management System. The pilot is implemented by INBIT as a specialised subcontractor and integrates with the National Medical Equipment Inventory and Vigilance platform, which covers 129 public hospitals and an approximately 170,000 medical assets. The proposed architecture combines two complementary positioning tiers within a single platform: a high-precision tier based on Bluetooth Low-Energy (BLE) Angle of Arrival (AoA) for clinically critical areas, with typical accuracy of 0.1–0.5 m, and a lower-cost tier based on BLE beacons for general areas. Switching between tiers is transparent to operators. The system displays the live position of tagged devices on hospital floor plans, records movement history for analytics, and triggers real-time alerts based on configurable geofences. Beyond device tracking, the same infrastructure is designed to support broader smart-hospital services, including patient and personnel guidance, accessibility services for visually impaired visitors – building on the previously published HOSP4ALL pilot at the University General Hospital of Patras – and operational analytics. We describe the system architecture, the deployment approach, expected operational benefits, and open challenges for hospital-wide and nation-wide adoption.

### Pull Procurement and Institutional Networking Among Teaching Hospitals to Restore MRI Functionality in Ghana

*George Boadu*

Access to advanced diagnostic imaging remains a challenge in many low- and middle-income countries due to high acquisition and maintenance costs. In Ghana, a national effort to standardize Magnetic Resonance Imaging (MRI) systems across teaching hospitals was initially successful, but maintenance issues later rendered many machines non-functional. This paper presents a successful case of institutional networking among teaching hospitals to restore MRI functionality at the Komfo Anokye Teaching Hospital (KATH). Through a collaborative agreement facilitated by the Ministry of Health, essential spare parts were sourced from other institutions with decommissioned MRI units. This initiative restored diagnostic capacity at KATH, improved access to imaging services, and highlighted the strategic value of coordinated institutional partnerships and resource pooling.

### Additive Manufacturing of Biocompatible Oculopalpebral Prostheses: A Workflow for Personalized Design Approach to Reduce Clinical Time

*Fabiola Hernández Rosas, José Rafael Alanis Gómez, Enrique Hidalgo Peña, Arantxa García Aldana, Sebastián Cendejas Fong, Junin González Martínez and Renata Carmona González*

Oculopalpebral defects caused by congenital conditions, oncologic disease, or severe trauma led to major esthetic, functional, and psychosocial impairment. Although biomaterials, imaging, and computer-aided design tools have progressed substantially, clinical fabrication of facial prostheses still relies heavily on conventional artisan workflows that demand repeated patient visits and prolonged production times. This study describes and preliminarily validates a standardized digital workflow for patient-specific oculopalpebral prostheses based on computed tomography, 3D reconstruction, CAD modeling, and additive manufacturing. A cross-sectional clinical case with technological intervention was conducted in a 62-year-old woman with ocular loss and facial defect secondary to mucormycosis. Anatomical data were acquired by computed tomography and 3D facial scanning, segmented in 3D Slicer, and modeled in Blender. A physical facial model and anatomical negative were fabricated to decouple fitting from patient presence. Prototypes were produced by 3D printing and cast with a biocompatible silicone resin. The proposed workflow generated high-fidelity anatomical models with deviations below ±0.25 mm, reduced the need for repeated in-person fitting sessions, and shortened total manufacturing time to approximately 90 days. In vitro testing in NIH-3T3 fibroblasts showed cell viability above 80%, consistent with non-cytotoxic behavior under ISO 10993-5 criteria. These findings support the clinical feasibility of a transferable digital workflow for facial rehabilitation that improves reproducibility and patient-centered care.

### Design of a Patient-Specific Mandibular Graft for Reconstruction Planning Using Medical Image Processing

*Jonathan Pimienta Castillo, Sarah Julieta Mendez Hernandez, Fabiola Hernández Rosas, Cintia Yvette López Ruíz and Enrique Hidalgo Peña*

Segmental mandibular resection following oral squamous cell carcinoma can produce complex bone defects that compromise mastication, swallowing, speech, and facial symmetry. Accurate reconstruction planning is therefore essential to support anatomical restoration and improve surgical decision-making. This study presents the design of a patient-specific mandibular graft for reconstruction planning using medical image processing. Computed tomography (CT) images in DICOM format from a patient with a segmental mandibular defect were processed to generate a three-dimensional model of the mandible. Bone tissue segmentation was performed in 3D Slicer, followed by mesh optimization, defect delimitation, and graft modeling in Blender. The personalized graft was designed using the contralateral healthy mandibular segment as an anatomical reference through mirror-based reconstruction and was adapted to the resection margins to achieve virtual restoration of mandibular continuity. The proposed design enabled detailed visualization of the defect and generation of a geometrically consistent patient-specific graft model for reconstruction planning. These findings support the feasibility of medical image processing as a practical approach for personalized mandibular graft design. Further work should incorporate quantitative fit assessment, finite element analysis, additive manufacturing, and mechanical or biological validation.

### Health Technology Assessment as a Bridge Between Biomedical Engineering and Public Health Policy

*Fabiola Martinez-Licona and Raul Molina-Salazar*

Health care systems are increasingly expected to make sure that decisions on the adoption, purchase, and disinvestment of technologies are supported by robust, multidimensional evidence. Biomedical engineering departments can provide detailed operational data on technologies, which are directly pertinent to such decisions. However, this type of information is seldom used in the formulation of public health policies. Health Technology Assessment (HTA) is recognized as a structured, multidisciplinary process for assessing different implications of health technologies, although the connection with biomedical engineering is limited. This paper presents a study on HTA as a translational architecture that can bridge biomedical engineering and public health policy. A structured approach was used to undertake a systematic domain analysis, and a comparative structural analysis that focused on differences in the unit of analysis, time horizon, evaluation logic, and accountability. Then, a translational integration approach comprising three layers, with HTA as a formal intermediary, was proposed. The findings reaffirm the premise that the disconnect between engineering and health policy is organizational, where the metrics of the former are inherently compatible with the existing evaluation domains of HTA, but the pathways to integration are lacking. The approach illustrates the potential role of the clinical engineer as a 'translational agent,' providing operational evidence to support procurement, capital investment, and disinvestment decisions through the HTA process. The improvement in integration between biomedical engineering and HTA has significant implications for transparency, sustainability, and equity in the governance of health technology, and indicates the need for curricular reform in biomedical engineering.

## Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management

Session 12B
Tuesday September 15, 12:00-13:30

### Dual-Crosslinked Pectin-Based Hydrogels via Thiol–Ene Michael Addition and Photopolymerization for Tunable Cell–Material Interactions

*Sonali S Naik*

Engineering hydrogels with independently tunable network architectures is critical for understanding and directing cell behavior in 3D microenvironments. In this study, we develop a dual-crosslinking strategy using thiolated pectin and pectin methacrylate to fabricate hydrogels with controllable physicochemical and biological properties. The system leverages thiol–ene Michael addition for rapid, spontaneous network formation under mild conditions, followed by photocrosslinking of methacrylate groups to further stabilize and modulate the network. By varying the ratio of thiol to methacrylate functionalities and the extent of photoexposure, we systematically tailor gelation kinetics, crosslinking density, mechanical stiffness, and degradation behavior. This modular platform enables decoupling of initial cell encapsulation conditions from subsequent network reinforcement. Encapsulated cells are evaluated for viability, proliferation, morphology, and mechanosensitive responses to elucidate how sequential crosslinking influences cell–matrix interactions. Our results demonstrate that the interplay between thiol–ene and photoinitiated crosslinking governs matrix elasticity and ligand presentation, which in turn regulate cell spreading and function. This study provides a versatile framework for designing pectin-based bioadhesive hydrogels with spatiotemporal control over material properties, with potential applications in tissue engineering, wound healing, and injectable therapeutics.

### Multifunctional Magnetofluorescent Carbon Dots for Magnetic Hyperthermia in Breast Cancer Models

*Chi-Ju Chuang and Wen-Tyng Li*

This study evaluated the therapeutic efficacy of hyaluronic acid (HA) and folic acid (FA)-doped magnetofluorescent carbon dots (MFCDs) against breast cancer in a murine model. Red-emissive MFCDs doped with FA and HA were synthesized via a microwave-assisted method, designated as FMCD and HMCD, respectively. In vitro cell viability assays using 4T1 murine breast cancer cells indicated that FMCD and HMCD exhibited negligible cytotoxicity. Under radiofrequency (RF)-induced hyperthermia, FMCD and HMCD suspensions achieved a temperature increase of 16.7 °C, resulting in a 4T1 cell viability reduction of 87% and 75%, respectively. To study the cellular heat-shock response, Western blot analysis of exosomal markers showed upregulated expression of CD63, GAPDH, and HSP70 following hyperthermia treatment. In vivo studies demonstrated that mice receiving four cycles of magnetic hyperthermia following tail vein injection showed the most significant tumor growth inhibition, whereas RF treatment alone failed to suppress progression. These multifunctional nanoprobes show great potential for targeted dual-modal imaging and minimally invasive hyperthermia therapy.

### Computational Design, Mechanical Homogenization, and Additive Manufacturing of a Porous Scaffold for Trabecular Bone Regeneration

*Fabiola Hernández Rosas, Emilio Carnaya Bustamante, José Rafael Alanis Gómez, Araceli Zapatero-Gutiérrez, Jaime Peña Soloache, Josué García Avila and Andrés Tobias González*

Trabecular bone regeneration requires a scaffold architecture that combines pore interconnectivity, structural continuity, and direction-dependent mechanical behavior. In this work, a porous scaffold for trabecular bone regeneration was developed through a workflow that integrated mathematical design, mechanical homogenization, and resin-based additive manufacturing. A custom unit cell was generated in nTop 5.0 from an implicit trigonometric formulation and periodically replicated to construct the complete scaffold. The geometry was parameterized to evaluate the effect of thickness on the apparent mechanical elastic response. Mechanical homogenization was performed on a representative unit cell using a linear elastic isotropic material model in order to estimate the effective stiffness distribution arising from the architecture. The resulting stiffness matrices showed direction-dependent behavior and progressive changes as scaffold thickness increased, suggesting that the proposed topology can be tuned toward a more uniform or more porous structural response depending on design requirements. After numerical evaluation, the full scaffold was fabricated as a single prototype by high-resolution resin-based additive manufacturing using a Q-touch HALOT-X1 16K printer and Tough 1500 Resin. The printed construct was successfully obtained and UV-cured, demonstrating the feasibility of translating the computational design into a physical porous structure. Although no geometric metrology, experimental mechanical testing, or biological validation was performed at this stage, the proposed workflow establishes a preliminary platform for future biofabrication and experimental studies aimed at trabecular bone tissue engineering.

### Multisource Intelligence for Early Sepsis Prediction: An Ensemble Modeling Approach

*Javier Camacho, Isis Bonet and Bladimir Gil*

Sepsis is a critical illness characterised by elevated mortality rates and significant financial strain on healthcare systems. Due to the problems in detection and treatment, it is considered as one of the most serious global public health challenges. Early identification of sepsis and initiation of timely and effective treatment are crucial for patient survival. This research presents a novel model named Intelligent Sepsis Predictor (iSP) for the early prediction of sepsis development in patients admitted to intensive care units. We present a machine learning ensemble using the XGBoost algorithm and k-nearest neighbours with a Dynamic Time Warping distance metric. The suggested model calculates static and time series data from vital signs and laboratory results. We trained our suggested model utilising MIMIC IV and a proprietary database from a hospital in Colombia, adhering to the sepsis-3 definition. The results of the study demonstrate that the iSP model generates more reliable predictions than conventional scores, providing an area under the characteristic receiver curve (AUROC) for MIMIC IV: (0.88, 0.89, 0.78, 0.84) and for the private database (0.88, 0.86, and 0.86) for 1 hour, 2 hours, and 3 hours prior to sepsis onset, respectively. Sepsis syndrome can be anticipated by integrating physiological and laboratory test findings inside a machine learning framework.

## MS Harmonising BME Education

Session 12C
Tuesday September 15, 12:00-13:30

### Harmonising Biomedical Engineering Education in the Age of AI: Is a Common European Framework Still Realistic?

*Nicolas Pallikarakis*

Biomedical Engineering has become one of the most multidisciplinary and rapidly evolving fields in higher education. In addition to its traditional foundations in engineering, biology and medicine, the field now includes artificial intelligence, digital health, medical devices, health data science, robotics, regulatory frameworks and health technology assessment. These developments create new opportunities, but also place increasing pressure on curricula, as emerging subjects compete for space within already crowded programmes. Since the early 1990s, several initiatives have attempted to harmonise Biomedical Engineering education, including IFMBE-related activities, BIOMEDEA and European projects such as TEMPERE, CRH-BME and BME-ENA, developed under ERASMUS, TEMPUS and related EU programmes. These efforts although aligned with the Bologna Declaration aiming to facilitate student and staff mobility, ECTS and mutual recognition of degrees, necessitated reconsideration every ten years. Today, the situation is more complex. A recent survey identified more than 550 active Biomedical Engineering programmes, representing an approximate 60% increase compared with the 2020 baseline. Bachelor-level Biomedical Engineering programmes have become increasingly prominent, while the field itself is becoming more specialised and diverse. This growth intensifies longstanding challenges related to curriculum comparability, student mobility, ECTS recognition and professional competence alignment. This mini-symposium will take the form of a round table discussion and will address the central question: Is there still room for harmonisation of Biomedical Engineering education, and if so, how should it be achieved? The session will explore whether harmonisation should continue to focus on curricula, or whether a more flexible model is needed, based on common core competences, learning outcomes, specialisation tracks, modular mobility and micro-credentials. Emphasis will be placed on open discussion with the audience, inviting proposals and positions on the advantages and disadvantages of renewed harmonisation efforts. The expected outcome is to initiate a broader dialogue on a possible Biomedical Engineering education framework for the coming decade, capable of supporting quality, mobility and professional identity while preserving curricular flexibility and innovation.

### Biomedical Engineering Education at UL-FE: From Curriculum Harmonization to the Age of Artificial Intelligence

*Tomaž Jarm*

The origins of Biomedical Engineering (BME) at the University of Ljubljana, Faculty of Electrical Engineering (UL-FE), date back to the late 1960s, while BME was formally introduced into the undergraduate curriculum in 1977. Three decades later, the European Tempus project CRH-BME coincided with the establishment of the Department of Biomedical Engineering and the Bologna reform of first- and second-cycle study programs at UL-FE. Building on these developments, a Master's-level specialization in Biomedical Engineering within the Electrical Engineering program was launched in the 2012–2013 academic year. The curriculum was rooted in earlier educational activities while also incorporating recommendations developed within the CRH-BME project, including the balance of credit allocation across course categories and the inclusion of courses considered at the time part of the essential BME core. The project thus provided an important framework for harmonizing the curriculum with contemporary European BME educational guidelines while preserving local research strengths and expertise. Since its inception, the curriculum has remained a living framework that continuously integrates developments emerging from BME research groups at UL-FE. Over the past fourteen years, the BME specialization has established itself as a stable component of the Master's program in Electrical Engineering and is currently one of seven available study tracks. Apart from a small number of shared electives, it maintains a dedicated curriculum and course portfolio. While most students enter from the first-cycle Electrical Engineering program at UL-FE, the specialization also attracts graduates from Physics, Mechanical Engineering, Chemical Engineering, and the Biotechnical Faculty. Although the overall course structure has remained largely unchanged, course contents are continuously updated to reflect advances in biomedical technologies, data science, and artificial intelligence. AI is increasingly shaping both biomedical engineering practice and engineering education, creating new opportunities in areas such as signal and image processing, medical decision support, and personalized healthcare. At the same time, it raises important questions regarding curriculum design, teaching methods, assessment, and the competencies expected of future biomedical engineers. As with other engineering programs at UL-FE, our specialization is adapting to these opportunities and challenges while maintaining the interdisciplinary foundations of the field.

### Beyond AI Coding: Competences Biomedical Engineers Need to Drive Impactful AI Adoption in Healthcare and MedTech

*Leandro Pecchia*

Artificial Intelligence is rapidly transforming healthcare, medical technology, and biomedical research. While many educational initiatives focus on teaching algorithms, programming techniques, and data science methods, the successful adoption of AI in healthcare depends on a broader set of competences. In practice, biomedical engineers rarely act only as AI developers. More frequently, they serve as leading intermediaries between technology experts, clinicians, hospital managers, regulatory bodies, and industrial stakeholders. Biomedical Engineering education should move beyond a purely technical view of AI and focus on preparing graduates and PhD to become effective facilitators of impactful AI innovation and adoption. Future biomedical engineers need sufficient technical literacy to understand AI capabilities and limitations, but they also require competences in clinical workflow analysis, health technology assessment, regulatory science, risk management, ethics, data governance, sustainability, change management, and communication with both top management and middle management. A competitive competence-based educational framework structured should be based around five pillars: (1) AI literacy and technical understanding; (2) assessment of clinical, organizational, economic, and societal impact; (3) implementation and adoption within healthcare organizations; (4) leadership and stakeholder engagement; (5) ethics, regulatory science and business models. Such a framework would enable biomedical engineers to identify opportunities for AI, critically assess solutions, support procurement and implementation decisions, and foster responsible innovation. The presentation will discuss whether these competences could constitute part of a common (trans) European core curriculum for Biomedical Engineering in the AI era. Harmonisation efforts should focus less on specific technologies, which evolve rapidly, and more on durable competences that allow graduates to continuously adapt to future innovations while maintaining a central role in healthcare transformation. Biomedical Engineering educators should therefore move beyond content-centred curricula and embrace a new educational paradigm. Our primary mission should no longer be to transfer a finite set of technical notions, but to cultivate professionals capable of continuously learning, unlearning, and relearning throughout their lives. The ultimate goal is not to produce graduates who master today's AI tools, but graduates who can confidently adapt to tomorrow's technologies—many of which do not yet exist. This requires fostering intellectual curiosity, critical thinking, systems thinking, ethical responsibility, and the ability to autonomously acquire new competences. Universities should aspire to develop what might be called "Olympians of Learning": professionals trained to continuously strengthen their own cognitive capabilities, capable of navigating uncertainty and leading innovation across healthcare systems. During the relatively brief period students spend at our institutions, educators have a unique opportunity not only to teach knowledge, but also to transmit vision, values, intellectual discipline, and a lifelong commitment to learning. As Biomedical Engineering education enters the AI era, harmonisation efforts should therefore focus not only on defining common competences, but also on reimagining the very purpose of engineering education itself.

## SS Bridging the Gap: A Multi-Stakeholder Dialogue on Essential Skills for the Future Biomedical Engineer

Session 12D
Tuesday September 15, 12:00-13:30

### The Department of Biomedical Engineering at the University of West Attica in Greece

*Ioannis Kalatzis*

Biomedical Engineering is an emerging field at the intersection of science and technology. The Department of Biomedical Engineering at the University of West Attica is the only higher education institution in Greece offering a comprehensive range of studies in this field. Its programs include a five-year integrated undergraduate degree (equivalent to a master's degree), a master's-level conversion program, and doctoral studies. Graduates of the Department are employed in hospitals and clinics, as well as in biomedical equipment companies across manufacturing, service, and sales sectors. They are also equipped to develop software solutions for medical informatics, conduct research in medical image and signal processing, and design, implement, and support computer-aided decision support systems.

### Challenges and opportunities for future clinical engineers: skills needed to best manage innovation

*Michele Gazzara*

The rapid evolution of healthcare technologies is reshaping the role of clinical engineers, requiring continuous adaptation to increasingly complex and interconnected systems This contribution explores the main challenges and opportunities that future clinical engineers will face, including the integration of digital health solutions, artificial intelligence, and data-driven decision-making processes. Particular attention is given to identifying the key skills needed to effectively manage innovation, such as interdisciplinary collaboration, strategic thinking, regulatory awareness, and proficiency in emerging technologies. The presentation aims to offer a practical perspective on how future clinical engineers can contribute to technological development and strengthen their role as enablers of safe, efficient and sustainable healthcare innovation.

### Learning Across Borders in Biomedical Engineering

*Syuzanna Matevosyan*

Biomedical engineering education varies significantly across countries and institutions. Each system believes it is preparing graduates for real-world demands. While universities continue to provide strong technical foundations, questions remain about whether current educational models fully prepare graduates for the realities of modern biomedical engineering careers. This paper reflects on my experience as an Erasmus Mundus scholar in the EMMBIOME program, studying across Greece, Serbia, and Romania. Through exposure to different educational systems, research environments, healthcare settings, and cultural contexts, I observed significant differences in how biomedical engineering competencies are developed and applied. These experiences highlighted skills that are often difficult to teach through traditional coursework alone, including adaptability, cross-cultural collaboration, problem-solving in unfamiliar environments, leadership, and the ability to connect technical innovation with real clinical needs. Rather than presenting a single best model, this paper will explore how combining different educational environments can better prepare future biomedical engineers. Beyond formal coursework, it will present the importance of student-led initiatives in biomedical engineering, and the crucial lessons that emerge when building them in unfamiliar countries, cultures, and systems. This paper offers concrete recommendations for curriculum development, drawn from experience inside the system — arguing that the goal of education is not only technical preparation, but building in graduates the steadiness, care, and capacity to keep learning that a constantly changing field demands.

## SS Next-Generation Neural Interfaces, Motor Control and Neurorehabilitation

Session 12E
Tuesday September 15, 12:00-13:30

### Invasive and Non-Invasive Neural Interfaces for Limb Prostheses

*Francesca Cordella*

Recent advances in neural engineering and bionics have demonstrated the growing potential of invasive and non-invasive interfaces to restore bidirectional communication with the nervous system. This talk will explore how closed-loop human–machine interfaces can support motor control and sensory feedback restoration in individuals with limb loss. Starting from recent studies on invasive neural interfaces for tactile feedback in upper-limb prostheses, the presentation will then address non-invasive approaches based on transcutaneous electrical nerve stimulation for eliciting somatotopic sensations in both upper- and lower-limb prosthetic applications. The role of multimodal sensing, bio-inspired encoding strategies and AI-based control will be discussed as a means to improve prosthesis usability, reduce cognitive burden and promote more natural human–machine interaction. Finally, the talk will open toward future perspectives, highlighting current challenges and research directions for the development of next-generation bionic prostheses.

### Multimodal Assessment of Postural Control in Parkinson’s Disease Using BioVRSea: Insights from CoP and Muscle Activation Patterns

*Federica Pescaglia, Ida Maruotto, Carmine Gelormini, Francesca Cioffo, Giorgio Di Lorenzo, Halldór Jónsson Jr, Emil Malucelli and Paolo Gargiulo*

Postural control (PC) impairment is a key feature of Parkinson’s disease (PD), arising from altered sensorimotor integration and reduced adaptability to environmental demands. The BioVRSea paradigm enables the assessment of PC under controlled visual and mechanical perturbations through the simultaneous acquisition of center-of-pressure (CoP) and electromyographic (EMG) signals. This study compared PC responses between patients with PD and healthy controls (CTR). CoP analysis revealed consistent between-group differences across phases, with CTR showing greater sway amplitude, spatial dispersion, and directional variability, especially in the POST phase. In contrast, PD participants exhibited reduced sway excursions, suggesting a constrained and less flexible postural strategy. Notably, PRE and POST, which share similar visual conditions without platform movement, showed clear differences, with POST highlighting the persistence of altered postural responses following perturbation. EMG analysis demonstrated muscle-specific patterns. The gastrocnemius lateralis showed widespread differences across amplitude, variability, and spectral features, already evident at baseline and persisting after perturbation. The tibialis anterior exhibited marked baseline alterations with more selective phase-dependent effects, while the soleus showed limited differences, mainly related to variability. These findings indicate that PD-related postural alterations emerge both at rest and after perturbation, reflecting reduced adaptability and altered neuromuscular organization.

### A Closed-Loop Model-Based Control Framework for Human Gait Simulation in Parkinson’s Disease

*Michela Russo, Luisa Erzingher, Rita Granata, Alessandra Franco, Marianna Amboni, Paolo Barone, Carlo Ricciardi, Maria Romano and Francesco Amato*

Human movement is a complex process involving both the central nervous system and the musculoskeletal system. Walking, in particular, represents a sophisticated motor task requiring precise coordination of multiple joints, especially in the lower limbs, along with continuous neuromuscular control. Mathematical modeling plays a key role in describing the dynamics and temporal evolution of gait patterns. In this study, we present the development of a mathematical model and a MATLAB Simulink-based framework for simulating human gait in the sagittal plane during the single-support phase. Specifically, a Proportional Derivative (PD) controller is implemented in conjunction with the compensation of the underlying nonlinear dynamics. Simulations were conducted using data from a healthy control (HC) subject and an age- and gender-matched subject affected by idiopathic Parkinson’s disease (iPD). The results were analyzed and compared with experimental gait data acquired through a motion capture system developed by BTS Bioengineering. Agreement between simulated and experimental trajectories was quantified using the Root Mean Square Error (RMSE). The proposed framework achieved low tracking errors for both HC and iPD conditions, with RMSE values $< 0.006$ m for hip coordinates, $< 0.09°$ for trunk motion, and $< 0.6°$ for the lower-limb joint angles, confirming the ability of the model to accurately reproduce subject-specific gait dynamics.

### Optical neural stimulation for sensory feedback

*Federica Piccirillo, Sarassunta Ucci, Valentina De Vito, Francesca Angelone, Alessia La Rocca, Michela Russo, Silvia Pascarella, Pellegrino Lippiello, Francesco Amato, Maria Concetta Miniaci, Armando Ricciardi and Andrea Cusano*

Electrical stimulation is currently one of the most established neuromodulation strategies and is widely used to activate peripheral nerves in both research and clinical settings. By delivering controlled electrical currents, this approach can reliably induce neuronal depolarization and action potential generation. However, electrical stimulation presents inherent limitations, including limited spatial selectivity, current spread to surrounding tissues, unintended activation of non-target fibers, and challenges associated with the electrode–tissue interface. These limitations have driven the exploration of alternative stimulation modalities capable of providing more localized, contact-free, and potentially cell-type-specific neuromodulation. In this context, infrared optical stimulation (INS) has emerged as a promising approach for peripheral nerve activation. By using light to induce localized photothermal and/or thermosensitive effects, optical stimulation may offer improved spatial precision and tunability compared with conventional electrical stimulation. Within the framework of the Optonerve project, this study aims to develop and validate an optical neuromodulation platform for peripheral nerve stimulation. The project encompasses complementary in vitro, ex vivo, and in vivo investigations designed to progressively evaluate the feasibility, underlying mechanisms, and translational potential of infrared optical stimulation. The preliminary results presented here focus specifically on the in vitro phase, involving dorsal root ganglion (DRG) neurons. Experiments were performed using whole-cell current-clamp recordings to directly monitor membrane potential dynamics during both electrical and optical stimulation. Optical stimulation was delivered through a multimode optical fiber with a 200 µm core at a wavelength of 1480 nm and a stimulation frequency of 5 Hz, while varying the duty cycle to modulate pulse duration and radiant exposure. This experimental protocol enabled a direct comparison between electrically evoked excitability and optically induced neuronal responses. The results demonstrate that infrared optical stimulation can evoke action potentials in a subset of DRG neurons. Electrical stimulation was employed to assess neuronal excitability and to define the depolarization range required for action potential generation. Additional control recordings performed in the absence of both optical and electrical stimulation allowed optically evoked responses to be distinguished from spontaneous firing activity and baseline fluctuations. Preliminary pharmacological experiments were also conducted using HC067047, a TRPV4 channel inhibitor, to investigate the potential contribution of thermosensitive pathways to infrared-mediated neuronal activation. Although some recordings were affected by noise, membrane potential instability, and limited cell viability, the in vitro findings support the feasibility of optical stimulation as a strategy for modulating DRG neuronal activity. Overall, these results provide an initial experimental foundation for the Optonerve platform and contribute to the optimization of optical stimulation parameters for subsequent ex vivo and in vivo validation. Future work will focus on improving reproducibility, refining stimulation thresholds, and elucidating the biophysical and molecular mechanisms underlying infrared-induced activation of peripheral sensory neurons.

### What Works Now, What Comes Next: Electrical Stimulation and Beyond-Electrical Neuromodulation

*Silvestro Micera, Simone Romeni and Eugenio Redolfi Riva*

Electrical stimulation has long served as the cornerstone of therapeutic neuromodulation, underpinning technologies from cochlear implants and deep brain stimulators to spinal cord and peripheral nerve interfaces. Decades of clinical deployment have yielded robust evidence for efficacy across a range of conditions, yet the field continues to grapple with fundamental limitations: poor spatial selectivity, chemical/mechanical mismatch that worsens foreign body reaction at the tissue/electrode interface, and an incomplete mechanistic understanding of how applied fields translate into durable therapeutic outcomes. In the first half of this talk, the current state of the art in electrical neuromodulation will be reviewed, with particular attention to where clinical promise has been realized and where persistent engineering and biological barriers remain. Emerging strategies to expand the functional capabilities of spinal and peripheral nerve interfaces will be presented, including data-driven methods for accelerating stimulation protocol optimization, computational model-guided approaches to surgical implantation, and the use of complex multisynaptic reflex pathways to engage residual neural circuits. The second half of the talk turns to an emerging landscape of modalities that seek to transcend these barriers and exploits alternative source of energies or stimuli-responsive nanostructured materials to interrogate the nervous system in the framework of neuromodulation or peripheral nerve regeneration. Focused ultrasound neuromodulation offers millimeter-scale targeting at depth without implanted hardware, with accumulating evidence for both excitatory and inhibitory effects whose biophysical basis (mechanosensitive ion channels, intramembrane cavitation, thermal micro-gradients) is only now becoming tractable. Chemogenetic and optogenetic approaches, while still largely preclinical, are redefining what cell-type specificity and closed-loop control can mean in practice, and early-phase human trials are beginning to test their translational limits. Light-based approaches, including infrared neuromodulation and photobiomodulation, have shown strong potential as wireless methods to interrogate the nervous system. These modalities were demonstrated to enable reversible stimulation or inhibition of action potential propagation in peripheral nerves and are emerging as promising strategies for chronic neuropathic pain management and peripheral nerve regeneration. Magnetic peripheral nerve stimulation and transcranial temporal interference stimulation round out a toolkit that increasingly allows investigators to interrogate the nervous system with spatial and temporal precision unimaginable a generation ago. Across all modalities, common themes emerge: the need for bidirectional interfaces that record and stimulate simultaneously, the imperative of closed-loop architectures driven by physiologically meaningful biomarkers, and the challenge of long-term biocompatibility in devices designed to function across a human lifetime. This talk argues that the transition from empirical parameter tuning to mechanistically informed, adaptive neuromodulation represents the defining engineering challenge of the coming decade, and that the convergence of beyond-electrical modalities with advanced neural decoding may finally make it achievable.

## SS HPC - driven molecular modelling and enzyme dynamics in precision and translational

Session 12F
Tuesday September 15, 12:00-13:30

### High-Performance Computing as an Enabler of AI-Powered Medical Imaging: Lessons Learned from Prenatal Neurodevelopmental Assessment

*Adna Softić, Dželila Tinjak, Lemana Spahić, Sarah Spahić, Živorad Kovačević and Lejla Gurbeta Pokvić*

The increasing adoption of artificial intelligence (AI) in healthcare is creating unprecedented computational demands, particularly in applications involving large-scale medical imaging datasets. High-resolution imaging modalities, such as four-dimensional (4D) ultrasound, generate massive volumes of data that require substantial computational resources for model development, training, validation, and deployment. High-Performance Computing (HPC) has therefore become a key enabling technology for translating AI innovations into clinically applicable solutions. This presentation introduces a case study focused on AI-assisted prenatal neurodevelopmental assessment based on the Kurjak Antenatal Neurodevelopmental Test (KANET). A custom deep learning pipeline was developed for automated analysis of fetal neurobehavioral patterns extracted from 4D ultrasound recordings. Computational benchmarking was performed between a conventional local workstation environment and an on-premise HPC infrastructure. The results demonstrated significant improvements in computational efficiency, scalability, stability, and model training performance when utilizing HPC resources, highlighting their importance for processing large medical datasets and supporting advanced AI workflows. Beyond the technical case study, the presentation will showcase opportunities available through the EuroCC initiative and the National Competence Centre for HPC in Bosnia and Herzegovina. Special emphasis will be placed on the services available to researchers, healthcare institutions, startups, SMEs, and public organizations, including access to European supercomputing infrastructures, AI and data analytics support, application assistance for EuroHPC resources, training programs, proof-of-concept development, digital innovation services, and capacity-building activities. The presentation will demonstrate how HPC is evolving from a specialized research resource into a strategic component of modern healthcare innovation ecosystems.

## Analytical and Functional Testing Methodologies for Enzymes: Kinetics, Stability Profiling, and Structure–Function Analysis

*Matt Gallant, Dzenan Kovacic, Muamer Dizdar, Sara Deumić, Monia Obučić and Neira Crnčević*

Enzymes represent an important class of functional ingredients for nutritional supplements, particularly in digestion, nutrient utilization, and targeted biochemical support. Their successful application requires a scientific testing platform that links analytical characterization with functional performance under relevant formulation and physiological conditions. Such a platform integrates three complementary approaches: kinetic analysis, stability profiling, and structure–function evaluation. Kinetic analysis provides measurable information on enzyme activity, substrate specificity, and catalytic efficiency. Determination of parameters such as Km, Vmax, kcat, and kcat/Km supports comparison and selection of enzymes with appropriate functional profiles. For supplement development, kinetic testing can be adapted to simulate the gastrointestinal environment, including variations in pH, temperature, and substrate composition. Stability profiling is equally essential, since enzyme activity may be affected by manufacturing, storage, moisture, excipients, coatings, and interactions with other active ingredients. Assessment of thermal stability, pH tolerance, shelf-life behavior, and residual activity after stress exposure provides insight into formulation robustness and product consistency. Structure–function analysis adds a deeper scientific basis by connecting molecular properties with enzyme performance. Techniques such as structural modeling, circular dichroism, mass spectrometry, and comparative or mutational studies help explain how enzyme conformation, active- site features, and amino acid composition influence activity and stability. By integrating these methodologies, enzyme-based supplement development can move beyond simple activity claims toward an evidence-based formulation strategy. This approach supports rational enzyme selection, blend optimization, compatibility testing, and quality specification, contributing to more consistent and functionally relevant supplement products.

## In Silico Approaches to Enzyme Characterization: Structural Modeling, Catalytic Site Prediction, and Functional Simulation

*Matt Gallant, Dzenan Kovacic, Muamer Dizdar, Sara Deumić, Monia Obučić and Neira Crnčević*

Enzymes play essential roles in biological systems and have widespread applications in medicine, biotechnology, environmental science, and industry. Accurate characterization of enzyme structure and function is crucial for elucidating their mechanisms and for the development of novel therapeutics or engineered enzymes. However, traditional experimental approaches are often time-consuming and expensive, particularly given the rapid expansion of genomic and proteomic data. Consequently, computational methods have become indispensable for accelerating enzyme discovery and functional analysis. This review examines the principal computational approaches for enzyme study, emphasizing three core areas: structural modeling, catalytic site prediction, and functional simulation. Techniques such as homology modeling and advanced artificial intelligence tools, including AlphaFold, have significantly improved the accuracy and accessibility of three- dimensional protein structure prediction from amino acid sequences. These structural models serve as foundational resources for subsequent computational investigations into enzyme mechanisms. The review also discusses methodologies for identifying catalytic and ligand-binding sites, including sequence conservation analysis, pocket detection algorithms, and molecular docking techniques. These approaches facilitate the prediction of enzyme substrate specificity and the identification of key amino acid residues involved in catalysis. Additionally, the review addresses molecular dynamics simulations and related techniques, which provide insights into enzyme conformational flexibility and dynamic behavior that static structural models cannot reveal. Integrating structure prediction, active site analysis, and dynamic simulation provides a comprehensive framework for enzyme investigation and experimental planning. These computational strategies offer significant reductions in laboratory time and cost, while advancing efforts in protein engineering, drug discovery, and biocatalyst identification. The review highlights recent progress in artificial intelligence and molecular simulation, and considers the potential future applications of these technologies in enzyme research and biomedical science.

## From Environmental Exposure to Precision Medicine: AI and Multi-Omics Approaches in Neurodegenerative Diseases

*Adna Softić, Madžida Hundur Hiyari, Nejra Merdović, Alessio Luschi, Ali Salman, Lejla Gurbeta Pokvić and Ernesto*

*Iadanza*

Neurodegenerative diseases, including Alzheimer's disease and Parkinson's disease, are increasingly recognized as complex multifactorial disorders arising from dynamic interactions between genetic susceptibility, environmental exposures, epigenetic regulation, and molecular dysregulation. Among environmental risk factors, air pollution and particulate matter have emerged as important contributors to neuroinflammation, oxidative stress, mitochondrial dysfunction, and progressive neuronal damage. Understanding these interactions requires the integration of diverse biological and environmental datasets that exceed the analytical capabilities of traditional approaches. This presentation provides an overview of recent advances in precision neurodegenerative medicine through the integration of environmental health research, epigenetics, multi-omics technologies, and artificial intelligence. Particular attention will be given to the role of pollution-induced epigenetic modifications, including DNA methylation changes, chromatin remodeling, and non-coding RNA dysregulation, as potential mechanistic links between environmental exposures and disease progression. Emerging evidence from transcriptomics, genomics, proteomics, and metabolomics studies will be discussed, highlighting how these complementary data layers contribute to the identification of novel biomarkers and therapeutic targets. Furthermore, the presentation explored how artificial intelligence, machine learning, and explainable AI are transforming neurodegenerative disease research by enabling multi-omics integration, biomarker discovery, patient stratification, and predictive modeling. These computational approaches provide new opportunities for identifying high-risk populations, improving early diagnosis, and developing personalized prevention and treatment strategies. The convergence of environmental epidemiology, systems biology, and AI-driven analytics represents a promising framework for advancing precision medicine and supporting a transition from reactive disease management toward proactive and individualized healthcare.

## Enzyme Cofactors and Catalytic Regulation: Chemical Structure, Activation Mechanisms, and Molecular Modulation

*Matt Gallant, Dzenan Kovacic, Muamer Dizdar, Sara Deumić, Monia Obučić and Neira Crnčević*

Enzyme cofactors represent an important class of functional components for nutritional supplements, particularly in supporting metabolic activity, energy production, and targeted biochemical regulation. Their successful application requires a scientific testing platform that links analytical characterization with functional performance under relevant formulation and physiological conditions. Such a platform integrates three complementary approaches: chemical structure analysis, activation mechanisms, and molecular modulation. Chemical structure analysis provides essential information on cofactor identity, purity, and reactivity. Characterization of metal ions, vitamins, coenzymes, and other organic cofactors supports comparison and selection of components with appropriate functional profiles. For supplement development, structural testing can be adapted to assess cofactor behavior under conditions that simulate the gastrointestinal environment, including variations in pH, temperature, and ionic composition. Activation mechanisms are equally essential, since cofactor function depends on proper binding, availability, and interaction with target enzymes. Assessment of cofactor–enzyme association, activation efficiency, and stability after stress exposure provides insight into formulation robustness and product consistency. These factors may also be affected by manufacturing, storage, moisture, excipients, coatings, and interactions with other active ingredients. Molecular modulation adds a deeper scientific basis by connecting cofactor properties with catalytic regulation. Techniques such as structural modeling, spectroscopic analysis, mass spectrometry, and comparative studies help explain how cofactor structure, binding-site features, and chemical composition influence enzyme activation and overall catalytic performance. By integrating these methodologies, cofactor-based supplement development can move beyond simple activity claims toward an evidence-based formulation strategy. This approach supports rational cofactor selection, blend optimization, compatibility testing, and quality specification, contributing to more consistent and functionally relevant supplement products.

## Bacterial Exoenzymes: Catalytic Mechanisms, Secretion Dynamics, and Functional Roles in Host-Associated Systems

*Matt Gallant, Dzenan Kovacic, Muamer Dizdar, Sara Deumić, Monia Obučić and Neira Crnčević*

Bacterial exoenzymes are catalysts located outside or on the surface of cells. These enzymes enable bacteria to acquire nutrients, interact with hosts, compete with other microorganisms, and facilitate key ecosystem processes. They degrade complex substrates such as proteins, polysaccharides, lipids, and host- derived molecules, which is essential for bacterial survival and adaptation. Advances in structural biology, genomics, and computational biology have significantly enhanced the understanding of exoenzyme mechanisms, regulation, and ecological significance. This review synthesizes current knowledge on the structure and function of bacterial exoenzymes, emphasizing active-site organization, catalytic mechanisms, cofactor requirements, and the regulation of enzyme production and secretion. It further examines the interplay among genetic regulation, cell signaling, and environmental factors in exoenzyme management. The review underscores the accelerating role of computational approaches, including protein structure prediction, comparative genomics, protein language models, machine learning, and multi-omics, in exoenzyme discovery and characterization. Additionally, it evaluates the influence of bacterial exoenzymes on microbiomes, particularly their contributions to community structure, nutrient exchange, probiotic functions, and microbiome engineering. By integrating molecular, computational, and ecological perspectives, this review demonstrates that bacterial exoenzymes are central to microbial interactions with hosts and hold significant potential for applications in biotechnology, medicine, and environmental science.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 14A
Tuesday September 15, 14:30-16:00

## Advancing Cardiovascular Pharmacogenomics in Europe: Structure and Strategic Vision of the CardioPharmaGENET COST Action Network

*Adna Ašić, Yvan Devaux, Miron Sopić, Amela Jusić, Lemana Spahić, Damir Marjanović, Konstantin Tashkov, Theodora Katsila and Amra Džuho*

Cardiovascular diseases (CVDs) remain a leading cause of morbidity and mortality in Europe, with current treatment strategies often failing to account for interindividual variability in drug response. Pharmacogenomics (PGx) offers a promising approach to optimize cardiovascular therapies by integrating genetic information into clinical decision-making. However, its implementation across Europe remains fragmented due to heterogeneity in healthcare systems, regulatory frameworks, data infrastructure, and levels of clinical adoption. The COST Action CA24165 CardioPharmaGENET was established in October 2025 to address these challenges through a coordinated, multidisciplinary, and pan-European network. The Action is structured into five Working Groups focusing on: (1) mapping the current PGx landscape, (2) developing and harmonizing clinical guidelines, (3) integrating artificial intelligence and machine learning tools, (4) analyzing regulatory and policy frameworks, and (5) ensuring effective communication, dissemination, and stakeholder engagement. CardioPharmaGENET aims to bridge the gap between research and clinical implementation by fostering collaboration across scientific, clinical, and policy domains. Within its first six months, the network has engaged over 250 participants from 41 countries, initiated key deliverables, and established a strong digital presence. By enabling knowledge exchange and capacity building, the Action provides a unique platform to advance precision cardiovascular medicine and promote equitable, data-driven healthcare across Europe.

## On the Evaluation of Biomedical Text Simplification Datasets: A Benchmarking Study

*David Della Morte, Mario Merone, Leandro Pecchia and Luca Bacco*

Biomedical text simplification aims to make specialized medical language accessible to non-expert readers while preserving its original meaning. However, progress in this area is still limited by the lack of reliable benchmark resources. Existing datasets differ in construction strategy, alignment quality, and linguistic complexity, making fair comparison across models difficult. In this work, we present a comparative evaluation of the main biomedical text simplification datasets, analyzing them in terms of readability and semantic alignment between expert and simplified texts.We further assess two open large language models, Mistral and BioMistral, on the same resources without task-specific fine-tuning. Our results highlight substantial variability across datasets, showing that not all of them provide equally reliable grounds for benchmarking. We also find that BioMistral generally achieves higher overlap-based scores, while both models preserve semantic content to a similar extent according to BERTScore. These findings emphasize the importance of dataset quality for fair and reproducible evaluation and provide a benchmark-oriented reference for future research in biomedical text simplification.

## Graph-Immune-Optimization (GIO): An Integrated AI-Driven Framework for Simulation-Guided Design of CAR-T/NK Cell Therapy and CRISPR Gene Therapy in Cancer Immunotherapy

*Forough Izadi, Ali Salman and Ernesto Iadanza*

While chimeric antigen receptor (CAR) T-cell and natural killer (NK) cell therapies, alongside clustered regularly interspaced short palindromic repeats (CRISPR) genome-editing technologies, have revolutionized treatment for hematological malignancies, their efficacy in solid tumors is hindered by the complex tumor microenvironment, immune evasion, and safety concerns such as cytokine release syndrome. Current artificial intelligence (AI) tools show promise in improving specific stages of therapy development, but they remain fragmented and lack a unified, end-to-end computational framework for integrated design. To address this, we introduce graph immune optimization (GIO), an integrated AI architecture that utilizes graph attention networks to model complex tumor–immune interactions and spatial features. The framework employs conditional generative adversarial networks to optimize CAR constructs and reinforcement learning for CRISPR gene-editing strategy selection, integrated with a digital twin simulation layer that predicts therapeutic responses through a feedback-guided iterative loop. This closed-loop optimization system allows for the continuous refinement of engineered immune cells by identifying optimal therapeutic candidates based on predicted safety, efficacy, and persistence metrics before physical manufacturing. Ultimately, this study provides a robust computational foundation for next-generation precision immunotherapy, leveraging simulation-guided design to overcome current barriers in treating solid tumors and improving the precision and scalability of cell and gene therapies.

## Temporal Dynamics of Physiological Responses to Phasic Pain in Healthy Controls and Their Impact on Machine Learning-Based Pain Quantification

*Camila Camacho-Navas, Ling Li and Panicos A Kyriacou*

Objective pain assessment using physiological signals is a significant challenge, with photoplethysmography (PPG) and electrodermal activity (EDA) emerging as promising non-invasive methods. A key assumption in PPG-based approaches is that physiological responses temporally align with pain-stimulation windows; however, this has not been validated. Delays caused by autonomic cardiovascular responses mediated by baroreflex-driven vasoconstriction introduce latency between sympathetic activation and peripheral vascular changes, which conventional labelling schemes do not address. In this study, we utilised the PainMonit dataset, consisting of repeated thermal pain stimulations in healthy volunteers, to explore feature-pain associations across three temporal windows: stimulation, early recovery (10–20 seconds), and late recovery (>20 seconds). We applied Kendall's Tau correlation and linear mixed-effects models to evaluate these associations and examined the impact of temporally shifted labelling on machine learning-based pain classification. Key findings revealed that significant PPG features peak during early recovery rather than aligning with stimulation. EDA features demonstrated stronger associations during stimulation. Temporally shifted labels reduced bias in PPG models and improved classification in EDA models. These results indicate that the labelling strategy is a critical factor in physiological pain assessment, highlighting its importance in dataset design and model development.

### HPC-Enabled Molecular Simulations of Lysozyme Interactions with Cellular Receptors

*Faruk Bećirović, Adna Ašić, Madžida Hundur Hiyari, Nejra Merdović, Una Glamočlija, Aziz Šukalo and Lemana Spahić*

Understanding the molecular mechanisms governing protein–receptor interactions is essential for advancing pharmaceutical and biomedical applications. Lysozyme, a small cationic enzyme widely recognized for its antimicrobial activity, also exhibits complex, non-enzymatic interactions with biological membranes and cellular receptors that remain insufficiently characterized at the molecular level. In this study, we employed high-performance computing (HPC)-enabled molecular dynamics (MD) simulations to investigate the interaction landscape between lysozyme and selected biologically relevant targets, including lactoferrin and immune-related receptors such as TLR2, TLR4, and CXCR2. All-atom MD simulations were performed using GROMACS with GPU acceleration, applying the AMBER03 force field and explicit solvent conditions. The simulation protocol included energy minimization, equilibration under constant Number, Volume, Temperature (NVT) and Number, Pressure, Temperature (NPT) ensembles, and 10 ns production runs. Interaction stability and binding characteristics were assessed through structural and dynamic metrics, including interface distance, hydrogen bonding, and contact frequency analysis. The results indicate that lysozyme interactions are predominantly governed by electrostatic and multivalent low-affinity contacts rather than specific receptor–ligand binding. Stable complexes were characterized by persistent hydrogen bond networks and compact interface geometries, while weaker interactions exhibited higher structural variability. The use of HPC resources enabled efficient exploration of multiple protein systems and provided detailed insights into interaction dynamics. These findings contribute to a deeper understanding of lysozyme behavior at the molecular level and highlight the importance of computational approaches in guiding the design of lysozyme-based therapeutic and formulation strategies.

### Genetic and Inflammatory Markers in Sports Injury Risk: A Precision Medicine Review of COL1A1, COL5A1, IL-6, and TNF-alpha

*Merima Smajlhodžić-Deljo, Ana Lalović, Amra Džuho and Adna Ašić*

This review synthesizes recent evidence (2020–2026) on the roles of collagen genes COL5A1 and COL1A1, and the inflammatory cytokines IL-6 and TNF-α, in sports-related musculoskeletal health and injury. COL1A1 and COL5A1 are central to tendon, ligament, and muscle extracellular matrix integrity, with common polymorphisms (e.g., COL1A1 rs1800012, COL5A1 rs12722) associated with increased risk of tendinopathy, ACL rupture, and muscle strain. Meanwhile, IL-6 and TNF-α act as key mediators of exercise-induced inflammation and tissue remodeling. IL-6 has been shown to upregulate COL1A1 expression (around 5-fold in tendon-derived cells), promoting collagen synthesis and tendon repair, whereas TNF-α tends to drive catabolic processes and ECM degradation when chronically elevated. The interplay between collagen-gene variants and cytokine dynamics creates a genotype-inflammatory-phenotype axis that modulates individual susceptibility to overuse and acute soft-tissue injuries. These findings underscore the potential of combining polygenic risk scores with dynamic cytokine profiling to enable precision-medicine approaches in sports, including risk stratification, load management, and injury prevention strategies for athletes.

## Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management

Session 14B
Tuesday September 15, 14:30-16:00

### Copper-Doped Carbon Quantum Dots Derived from Vitis vinifera and Vaccinium spp.: A Nanobioactive Platform with Antibacterial Potential for Biomedical Applications

*Beatriz Liliana España Sánchez, Rosa Bonilla Peregrino, Irma Robles Gutiérrez, Fabiola Hernández Rosas and Noé Arjona*

In response to the global challenge of bacterial resistance, carbon quantum dots (CQDs) have emerged as biocompatible nanomaterials with remarkable antimicrobial potential. In this study, copper-doped CQDs (Cu-CQDs) were synthesized via a green hydrothermal method using natural extracts from Vitis vinifera and Vaccinium spp. as sustainable carbon precursors. The intrinsic polyphenolic networks and functional groups from these biomasses contributed to stabilizing the carbon core and enhancing cellular affinity. Copper incorporation was designed to modulate the electronic structure of the nanomaterial by introducing intermediate energy levels that promote efficient electron transfer. The obtained Cu-CQDs exhibited characteristic optical properties, including UV absorption (250–350 nm) and intense blue photoluminescence (excitation at 340 nm, emission at 440 nm), confirming the formation of stable carbon nanostructures with functionalized surface groups. Antibacterial assays demonstrated significant inhibitory activity against Gram-positive (Staphylococcus aureus) and Gram-negative (Pseudomonas aeruginosa) bacteria, revealing a synergistic effect between biomass-derived ligands and copper doping. The bactericidal mechanism is attributed to the selective generation of reactive oxygen species (ROS). These findings highlight Cu-CQDs as a versatile and sustainable nanobioactive platform for next-generation antimicrobial therapies.

### Optical fiber–enabled drug delivery for precision oncology: from spatiotemporal control to feedback-enabled systems

*Chiara Mulè, Zesen Li, Tania Mariastella Caputo, Armando Ricciardi, Anna Aliberti, Bai-Ou Guan, Yang Ran and Andrea Cusano*

Light-triggered drug delivery provides precise spatial and temporal control over when and where therapies are activated, allowing for on-demand release and reducing systemic toxicity. However, its clinical use is still limited because light does not penetrate deeply into biological tissues, making it difficult to treat tumors located deep within the body. Recently, optical fibers have emerged as promising tools to address this challenge by delivering light directly to target sites in a minimally invasive and localized way. In this review, we focus on optical fibers as platforms for controlled and feedback-enabled drug delivery, shifting attention from using light as the main therapy to its role in regulating drug activation. We begin by outlining the basic mechanisms of light-responsive drug delivery, including photothermal, photodynamic, and photochemical processes, and emphasize how these approaches can control drug release. Next, we examine fiber-based systems in terms of their materials, designs, and release strategies, highlighting methods such as surface functionalization, nanoparticle-assisted delivery, and hybrid multimodal platforms. We pay special attention to the integration of sensing and actuation within fiber-based systems, which enables real-time monitoring of the tumor microenvironment and supports feedback-informed therapeutic strategies. While fully autonomous closed-loop systems are still in development, current examples already show the potential for adaptive control of drug activation. Finally, we discuss key challenges for clinical translation, such as material stability, drug loading capacity, device integration, and regulatory issues. By positioning optical fibers as multifunctional components of drug delivery systems, this review highlights their potential to support interventional, programmable, and adaptive therapeutic strategies for precision oncology.

### Pharmacoeconomic Analysis of NOAC Therapy in the Prevention of Stroke in Patients with Atrial Fibrillation

*Ajna Hujić, Adna Ašić, Ana Lalović, Lejla Gurbeta Pokvić and Almir Badnjević*

Atrial fibrillation is the most treated type of arrhythmia in clinical practice. Such arrhythmias represent a significant risk factor for the development of ischemic stroke, peripheral embolism, and can ultimately lead to death. This research paper evaluates the cost-effectiveness of switching patients to therapy with novel oral anticoagulants (NOACs) compared to warfarin therapy. The study is based on the perspective of the healthcare system of Bosnia and Herzegovina, and it compares the value of NOAC therapy for stroke prevention in patients with atrial fibrillation with traditionally used Warfarin therapy. The pharmacoeconomic analysis covered a time horizon of 15 years with a discount rate of 3% and included a complete evaluation with appropriate methods such as CEA (Cost-Effective Analysis), CUA (Cost-Utility Analysis), CBA (Cost-Benefit Analysis), BIA (Budget Impact Analysis) and sensitivity analysis.

### Biomimetic hyaluronic acid-based scaffolds for tissue engineering applications

*Melanie Ferrace, Carlos Busatto, Diana Estenoz, Gustavo A. Abraham, Guadalupe Rivero and Florencia Montini Ballarin*

Biomimetic scaffolds incorporating bioactive cues hold significant promise for tissue regeneration. Natural polymers, such as hyaluronic acid (HA), provide intrinsic biological functionality capable of modulating cellular responses. Electrospinning is a versatile technique for fabricating nanofibrous porous matrices that closely resemble the architecture of the extracellular matrix. In this work, HA was incorporated into nanofibrous membranes with high surface-area-to-volume ratios through electrospinning process. Processing parameters were optimized to maximize HA content while maintaining fiber uniformity and structural integrity. The resulting scaffolds exhibited a homogeneous nanofibrous morphology. To improve stability under physiological conditions, post-fabrication crosslinking was implemented. The developed scaffolds demonstrate strong potential for tissue engineering applications, combining biomimetic structure with bioactive functionality. Additionally, this approach enables the fabrication of three-dimensional tubular constructs and hybrid materials, expanding its applicability in regenerative strategies.

### Resting HRV Signatures of Psychological Burden: Time-of-Day Modulation across Anxiety, Stress, and Distress

*Ana de la Torre García, Gema Prats-Boluda, Jose Luis Martinez-de-Juan, Úrsula Martínez-Iranzo and Miguel Ángel Serrano*

Resting heart rate variability (HRV) has been widely investigated as a psychophysiological marker of anxiety- and stress-related states, yet findings remain heterogeneous due to the use of non-equivalent psychological measures, redundant HRV metrics, and limited consideration of time-of-day effects. This study aimed to identify which questionnaire-derived dimensions of psychological burden, spanning anxiety, perceived stress, and distress, are most consistently associated with the latent structure of resting HRV, and to determine whether these associations vary across times of day. A total of 106 adults underwent standardized 300 s resting ECG recordings obtained in the morning, afternoon, or under night-time/sleepiness conditions. After quality control, 283 valid resting windows were retained. A broad set of HRV indices was extracted and reduced via principal component analysis (PCA), and associations with psychological questionnaires were examined using exploratory Spearman correlations and generalised additive mixed models (GAMMs), adjusted for age, sex, body mass index, and habitual physical activity. Four latent HRV components explained 91.8% of total variance. After adjustment, the PCA component dominated by short-term vagally mediated variability was the only HRV dimension showing evidence of association across all six questionnaire totals, whereas the remaining components showed only selective or more context-dependent effects. These associations were strongest at night and generally attenuated in the afternoon. Overall, the findings support a multidimensional, physiologically interpretable, and time-aware approach to resting HRV assessment in anxiety- and stress-related research.

## Medical Imaging, Simulation, and Immersive Technologies

Session 14C
Tuesday September 15, 14:30-16:00

### A Patient-Specific Flow-Enabled Ultrasound Phantom for Femoral Vascular Access Training

*Marina Carbone, Nadia Cattari, Gianluca Orrù, Matteo Nicoletta, Nicola Troisi, Mauro Ferrari and Vincenzo Ferrari*

Ultrasound-guided femoral vascular access is widely used to improve procedural safety, but effective training requires realistic simulators reproducing anatomical landmarks, ultrasound appearance, haptic feedback, and flow-related confirmation of successful puncture. This work presents a patient-specific, flow-enabled ultrasound phantom for femoral vascular access training. A CT-derived mold was used to reproduce the inguino-femoral anatomy, while 3D-printed removable cores enabled controlled positioning of the femoral artery, arterial bifurcation, femoral vein, and inguinal ligament. PVC-plastisol was selected as tissuemimicking material, and heat-shrinkable PTFE tubes were used to reproduce the arterial wall, providing both ultrasound contrast and perceptible resistance during needle penetration. A closed-loop flow circuit was integrated to provide visual fluid return after successful puncture and to support Doppler-based vessel differentiation. Preliminary face and content validity were assessed by eight experienced endovascular surgeons using a structured 24-item Likert questionnaire. The phantom received positive evaluations for ultrasound landmark visibility, haptic arterial-wall feedback, usability, and training utility. The arterial bifurcation was rated as a reliable anatomical landmark, and the flow system was identified as a meaningful improvement over conventional phantoms. These findings support the proposed simulator as a cost-effective and reusable platform for structured ultrasound-guided femoral access training.

### Microwave Medical Imaging for Colorectal Cancer Detection: Electromagnetic Simulations and Tissue-Mimicking Material Fabrication

*Maiar Ahmed*

Colorectal cancer (CRC) screening is limited by cost, invasiveness, and scalability, motivating investigation of non-ionising alternatives. This study assesses a cost-conscious RF/microwave medical imaging (MMI) proof-of-concept for CRC using electromagnetic simulations and tissue-mimicking material (TMM) fabrication. The work comprised full-wave electromagnetic simulations of tumour and non-tumour cases, dielectric characterisation using a single-port open-ended coaxial probe (OECP) with Komarov inversion implemented in PyOECP, and fabrication of gelatine-based colon and healthy-tissue analogues. The dielectric characterisation pipeline achieved <4% average permittivity error on reference liquids, enabling iterative tuning of TMMs over the 2-4 GHz band. Simulations showed measurable tumour-induced scattering perturbations, with peak SAR of 0.022 W/kg, below the cited 4 W/kg limit.

### A Novel Iterative Image Reconstruction Method for Low-dose CT based on Artificial Neural Networks

*Roberta Diana, Maria Maddalena Autorino, Michele Ambrosanio, Stefano Franceschini, Francesca Bifulco, Giuseppe Cesarelli and Fabio Baselice*

Computed tomography (CT) is a commonly utilized diagnostic imaging method that relies on ionizing X-ray radiation, which can pose potential risks to patients. The challenge of reconstructing CT images under low doses of X-rays persists, as conventional algorithms often lead to considerable degradation in image quality. Although advanced iterative reconstruction techniques partially mitigate this problem, recent approaches based on deep learning have exhibited impressive performance, albeit at the expense of needing extensive, high-quality training datasets that are often scarce in the field of medical imaging. In this study, we introduce a novel iterative reconstruction technique that incorporates neural-network-based modeling into the reconstruction process without the need for any training data. This proposed method seeks to leverage the significant representational capabilities of neural networks while maintaining the flexibility and robustness characteristic of model-based iterative methods. Initial results obtained from phantom data containing human-like tissue inserts indicate that the method can successfully reconstruct high-quality images and evidence of its efficacy in scenarios involving reduced doses of X-rays.

### A multiscale cardiovascular digital twin for personalized hemodynamics across a virtual population

*Luca Congiu, Matteo Anselmino, Luca Ridolfi and Stefania Scarsoglio*

Virtual populations are a promising approach for investigating the cardiovascular system under both physiological and pathological conditions. The accuracy of virtual populations in representing the hemodynamics of a real population depends strongly on the subject-specific model used for their generation. Currently, the majority of the subject-specific cardiovascular models available in the literature account only for age, neglecting the effects of body size and sex differences. Moreover, the models often present an open-loop architecture and do not provide information on some important cardiovascular regions such as the cerebro-ocular and coronary circulations. In this work, we propose a new subject-specific multiscale cardiovascular model constructed starting from a validated closed-loop multiscale cardiovascular model previously applied to study arrhythmias, postural changes, and the effects of micro/hyper-gravity on the cardiovascular system. The proposed subject-specific model was validated against clinically relevant hemodynamic variables and used to generate a virtual population of 300 healthy subjects in supine posture. The model showed good agreement with clinically observed age- and BSA-related trends. As a representative example of its practical applicability, it captures the role of age and BSA in shaping pressure waveforms along the aorta.

## SS Bridging the Innovation Gap

Session 14D
Tuesday September 15, 14:30-16:00

### Strengthening Regulatory Pathways for Medical Device Clinical Investigations in Africa: A Policy-oriented Review

*Daniel Atwine, Sunday Nighty, Elna Owembabazi and Caroline Birungi*

Medical devices are essential to modern health systems and central to achieving universal health coverage, strengthening health security, and expanding access to diagnosis, clinical monitoring, treatment, rehabilitation, prevention, emergency care, and assistive technologies in low- and middle-income countries (LMICs). In resource-constrained settings, well-designed technologies can address critical gaps across maternal and newborn care, infectious and non-communicable diseases, emergency response, surgery, and digital health. However, regulatory pathways for clinical investigation, evaluation, and market authorization in many LMICs remain fragmented, under-resourced, and inconsistently implemented which hinders translation of medical device innovation into safe and effective use. This is particularly evident in Africa, where device clinical trials are limited, unevenly distributed, and often disconnected from emerging local innovation ecosystems despite growing biomedical engineering capacity. This policy-or

## Biomedical Engineering Education and Training in Ghana: A Systems Approach Integrating Equipment-Based Learning, Adaptive Digital Platforms, and International Partnerships

*George Boadu*

Biomedical engineering (BME) plays a critical role in strengthening healthcare systems, particularly in low- and middle-income countries (LMICs), where medical equipment functionality and sustainability remain persistent challenges. Ghana has made notable progress in developing BME education and training; however, gaps remain in practical competency development, infrastructure, and clinical integration. This paper presents a systems-based approach, aimed at improving biomedical engineering education and training in Ghana; integrating academic programmes, equipment-centered training, and professional upskilling initiatives. It elaborates key interventions, including the GIZ develoPPP programme and the Korea Foundation for International Healthcare (KOFIH), and examines the role of adaptive digital learning platforms. A multi-tier training model and a retrofitted equipment-based workshop framework are proposed. Findings indicate that combining hands-on training with adaptive learning technologies significantly improves competency development and healthcare technology management outcomes. The paper concludes with recommendations for scaling sustainable training systems in LMICs.

## IMPROVING NEONATAL CARE THROUGH REAL-TIME DEVICE MONITORING, CASE STUDY, PUMWANI MATERNITY HOSPITAL

*Salome Mwaura*

In neonatal care, every second counts — real-time monitoring turns data into life-saving action In most LMICs, there is lack of affordable, continuous and reliable neonatal monitoring systems. Many newborn units face high nurse-to-patient ratios and very limited functional medical equipment. Reliance on manual device checks have led to delayed detection of critical changes to infant's health and thus infant mortality is on the rise. Hadli provides continuous equipment tracking of certain aspects such as functionality, power fluctuations, temperature and humidity, with automated alerts and data visualization sent to facility BMEs. Some of the challenges faced during patient care include inefficient or unmonitored medical devices, insufficient budgetary allocations towards neonatal device management and increased nonfunctional equipment in hospitals. This system was developed by NEST360 and it is an IoT based real-time monitoring solution. Its key Objectives were to improve efficiency, safety and device uptime in neonatal care. Currently we are monitoring 26 devices at Pumwani maternity hospital where we can see how the devices are utilized and the frequency of outage. The system comprises of, IoT device sensors, Voltage monitor, Temperature & humidity sensor, central gateway which collects all data from sensors and transmits to cloud. The Cloud-Based Dashboard (HADLI) does remote monitoring and data visualization and alerts. Tracked parameters includes enhanced device uptime, prompt power outage detection, improved maintenance through early warning of faults, optimal thermal conditions → reduces neonatal hypothermia risks which informs data-driven decision-making in equipment budget allocation Key benefits includes preventive maintenance enabled by real-time alerts, better resource allocation by identifying underused or overburdened devices, improved operational transparency, supports timely clinical interventions and could help in budgeting plans for PPM and continuous maintenance activities – cumulative run hours help in this. Some challenges faced with the Hadli system includes sensors failure over time and not transmitting data, due to hardware related issues like breakages, membrane switch failure, etc. Device users bypassing sensor connections during patient connection hence loss of valuable data. At times, the getaways go offline due to hardware problems and data subscription delays. There are also limitation of use, as sensors are not meant for some devices and SIM and gateway connectivity challenges In conclusion, HADLI system revolutionizes neonatal care in resource-limited settings. The real-time monitoring ensures that there is better outcomes for neonates and more efficient hospital operations and the model can be scaled to other departments within the hospital.

## From Prototypes to Patients and Prosperity: Bridging Africa's Innovation–Commercialization–Health Gap through African Biomedical Engineering Consortium

*Daniel Atwine, Sunday Nighty, June Madete, Sudesh Sivarasu, Philippa Ngaju Makobore, Arti Ahluwalia, Muhammad Ali Rushdi, Carmelo De Maria, Bernard Ahimbisibwe, Elna Owembabazi, Caroline Birungi and Charles Kwesiga*

Africa's health innovation challenge is no longer a shortage of ideas; it is the failure of promising ideas to move reliably from student projects, laboratories, hackathons and pilot studies into regulated, manufactured, adopted and sustained solutions. This opinion review argues that Africa's innovation-commercialization gap is also a health-systems gap: when local innovations fail to scale, health systems remain dependent on imported technologies that are often unaffordable, poorly maintained or mismatched to local realities. The paper positions the African Biomedical Engineering Consortium (ABEC) as a practical continental platform for addressing this gap through human capital development, curriculum harmonization, innovation training, South-South collaboration and ecosystem building. ABEC's future value lies in evolving from a training and networking platform into a full translation ecosystem linking education, prototyping, clinical validation, regulation, manufacturing, procurement, financing and policy uptake.

## Diapetics Technology for Diabetic Foot Care: A Translational Framework Integrating Fuzzy Logic and Personalized Insole Design

*Martha L. Zequera, Mauricio Cubides, Luis Gabriel Marin, Andrea Karina Peña and Santiago Quintero*

Diabetic foot complications remain a critical challenge in Latin America due to fragmented clinical workflows and the absence of data-driven preventive tools. This paper introduces Diapetics, a robust translational framework that operationalizes the transition from clinical multi-source data to precision medical device fabrication. Grounded in patent No. NC2021/0015248 (Resolution No. 51357, July 30, 2025) —Technology Readiness Level (TRL) 4—, the technology integrates a cloud-based architecture with a dual-stage fuzzy logic inference engine designed to handle the stochastic nature of clinical variables. The first computational module utilizes weighted Mamdani-type fuzzy sets to process systemic risk factors, while the second module refines this through region-specific neuropathy and vasculopathy mapping for personalized insole design. To ensure scalability, the framework is designed for integration within the Electronic Health Records (EHR) of the Colombian public health system, aiming for national coverage with a modular architecture transferable across Latin America. Future work aims to expand this patient-centered model to encompass all diabetes-related complications, fostering personalized care and digital patient empowerment. Currently in the proof-of-concept phase, Diapetics demonstrates high fidelity in translating complex clinical reasoning into effective, scalable prescriptions for resource-constrained environments.

## SS EAMBES Special Session on recognition of Biomedical Engineers in European hospitals and health institutions

Session 14E
Tuesday September 15, 14:30-16:00

### BME and MP as health care professions in Czechia and current state in Slovakia

*Lenka Lhotská*

The aim of the presentation is to inform about the situation of the professions of biomedical engineer and medical physi-cist in the Czech healthcare system and Slovakia. The system of undergraduate, postgraduate, and lifelong education in the fields of Biomedical Technology, Biomedical Engineering, and Medical Physics (MP) is regulated by the Act No.96/2004 Coll. on non-medical health service occupations and related regulations. The Act and related regulations define position of technical personnel in the health service system. This legal regulation distinguishes the following categories of technical personnel: another professional, health service professional with technical competence (bio-medical technician (BMT) – B.Sc., biomedical engineer (BME) – M.Sc.), and health service professional with special-ized competence (clinical technician – B.Sc., clinical engineer – M.Sc.), and medical physicists. There exists a system of accredited medical institutions that can perform defined types of postgraduate and lifelong education. As part of lifelong education, credit system was introduced that specifies activities for which credit points can be awarded. The Act No. 96/2004 Coll. specifies the following types of educations: undergraduate education, i.e. bachelor and master study (minimum requirements are given by the official regulations No. 39/2005 Coll.); accredited qualification course; specialized education; lifelong education (this education is obligatory for all health service professionals and also for those working in the category another professional in health service). Basic rules and requirements concerning undergraduate (Bc. and M.Sc.) and postgraduate (Ph.D.) study in general are defined by the Higher Education Act No. 111/98 Coll. and its amendment No. 137/2016 Coll. In this context, it is necessary to stress that in addition to standard accreditation of a study programme or field of undergraduate educa-tion performed by the Accreditation Board of the Ministry of Education, Youth and Sports of the Czech Republic (MEYS), the biomedical study programmes or fields must get the accreditation of the Ministry of Health Care of the Czech Republic (MHC) in the sense of the Act No. 96/2004 Coll. and related regulations. The graduates of these ac-credited fields get the certificate of qualification to perform health service occupations according to the Act No. 96/2004. The BME (BMT) qualification can be obtained by graduation in the Biomedical Engineering field of study (BME) or the Biomedical Technology field of study (BMT). Graduates of another bachelor or master study pro-gramme in electrical engineering can obtain the qualification for health service professionals with technical compe-tence if they pass the accredited course in Biomedical Engineering (for M.Sc./Eng.) or Biomedical Technology (for B.Sc.) The accreditation for these courses is delivered by the MHC. The conditions for this accreditation are defined in the official regulation No. 424/2004 Coll. The MP qualification can be obtained by graduation in the Medical Phys-ics study programme (MSc.) only. In Slovakia, there are similar study programmes and legal regulations. However, the professions of BME and MP are defined as “another healthcare professional” (Act. No. 578/2004, governmental regulation No. 296/2010 and No. 321/2005). It is necessary to note that BME is studied as independent study programme, similarly to other European countries. However, qualification of MP (in Slovakia named clinical physicist) is acquired in two steps: 1. Graduation in MSc. programme physics, nuclear physics or biomedical engineering; 2. Specialized study in clinical physics, guaranteed by a medical faculty.

### Biomedical Engineers as Healthcare Engineers: The Need for New Roles for Engineers in the Spanish National Health System

*Enrique J Gómez Aguilera*

Biomedical engineering is becoming increasingly relevant in healthcare, within the profound transformation and growing complexity of hospital environments. This trend is driven by the emergence of disruptive technologies such as massive genomic sequencing, digital health, artificial intelligence, cloud and edge computing, robotics, digital twins, virtual and augmented reality, 3D printing, regenerative medicine and nanomedicine, to name just a few. This paper raises the need for a deep reflection on the main roles of engineering in healthcare systems, provides an initial analysis of the situation of engineering within the Spanish National Health System, outlines the main challenges and difficulties for the incorporation of engineers, proposes an initial description of professional profiles, roles, and competencies, and aims to address the urgent need for a training program for internal resident engineers.

### The Greek biomedical engineering landscape

*Panagiotis Bamidis*

The Hellenic Society for Biomedical Technology (ELEVIT) has been the point of reference when it comes to the development and education/training on biomedical engineering in Greece. Over the last few years, the pandemic occasion included, ELEVIT has been trying to activate the discussion on the recognition of the profession by suitable governmental authorities in Greece, in accordance with the evolution of the issue in Europe and globally. In parallel to that, and given the opportunity of the re-organisation of public hospital units co-ordinated by the Ministry of Health, a registry of biomedical engineering and clinical engineering workforce capacities in the Greek National Health System (GNHS) has been achieved. These are discussed in view of the globally recommended structures of hospital departments and the associated training needs, as well as, the overall structure and needs of GNHS.

### European Parliament Interest Group of Biomedical Engineering: 10 years of effort for BME recogtnition

*Leandro Pecchia*

In 2015, biomedical engineering (BME) had no formal standing in European Union professional and research policy: no occupation matching it existed in the European Skills, Competences, Qualifications and Occupations (ESCO) database, no EU excellence-science scheme reserved it a funding panel, and it had no institutionalised channel to the European Parliament. This extended abstract reconstructs how that changed over the following decade. Two parliamentary questions filed in 2015, prepared with the support of the Policy Affairs Working Group (PAWG) of the European Alliance of Medical and Biological Engineering and Science (EAMBES), opened a dialogue with the European Commission on BME's absence from EU recognition and funding instruments. That dialogue was institutionalised in 2016 as the European Parliament Interest Group on Biomedical Engineering (EPIG BME), a standing platform between the BME community and Members of the European Parliament (MEPs), which met five times in Brussels and online between 2016 and 2025, across three parliamentary terms and a pandemic interruption. Drawing on EAMBES's public records and, critically, on the live ESCO occupational database rather than only on historical accounts of it, we show that the Commission responded concretely: “Biomedical Engineer” entered ESCO by 2018 and remains today an actively maintained, standalone occupation (ESCO code 2149.4.1) — a status the discipline did not hold ten years ago. Over the same period, biomedical engineers moved from bystanders to contributors in EU regulatory reform (MDR/IVDR, the European Health Data Space, the AI Act) and, during COVID-19, occupied senior technical roles in the World Health Organization's emergency response. In 2025, EAMBES's own member societies mandated the next step: formal certification of the profession and harmonised curricula across Member States. We present this trajectory as a case study in what sustained, evidence-based dialogue between a scientific community and EU institutions can achieve — while stating plainly what is not yet achieved.

## SS ICT and Open Data in Healthcare

Session 14F
Tuesday September 15, 14:30-16:00

### ICT and Open Data in health care

*Marc Nyssen*

Overview regarding the fundamental motivations in favor of "Open Data" and current developments, organisations and developments with emphasis on applications in health care.

### Overcoming Data Scarcity with Generative AI

*Alessio Luschi*

Artificial intelligence promises a profound transformation of clinical practice. However, its translation into routine care remains constrained by a structural bottleneck: the scarcity of high-quality, diverse, and accessible real-world data. Privacy regulations, the statistical rarity of orphan conditions, fragmented and unstructured electronic health records, and the underrepresentation of minority populations together confine usable clinical data within institutional silos. This talk examines how Generative AI can address this data availability crisis within the broader vision of digital health. The architectures driving the field are first reviewed, from the Transformer backbone to large language models for clinical text, generative adversarial networks and diffusion models for high-fidelity medical imaging, variational autoencoders for structured records, and multimodal models that bridge notes, scans, and omics. Three complementary strategies are then analysed, namely the synthetic generation of privacy-preserving cohorts, the targeted augmentation that rebalances rare classes, and the cross-modality imputation that recovers missing longitudinal information. The constraints that govern responsible adoption are further discussed, including trustworthiness and hallucination, limited explainability and auditability, the computational and environmental cost of foundation models, and the risk of model collapse when systems are trained recursively on their own synthetic outputs. Generative AI offers a credible path towards democratising healthcare data, provided that its deployment is anchored in rigorous validation, in federated and human-in-the-loop governance, and in a sustained commitment to patient safety and clinical reliability.

### Cybersecurity in Healthcare

*Chien-Ding Lee, Mei-Fen Chen, Yung-Hsin Chen and Kang-Ping Lin*

The rapid digitalization of healthcare, enabled by integrated information systems such as Hospital Information Systems (HIS) and Electronic Health Records (EHR), has improved care quality while substantially expanding the cybersecurity attack surface. This study presents an integrated framework for analyzing the interdependence among healthcare workflows, security threats, and protection mechanisms in this evolving landscape. Healthcare workflows are examined along two dimensions: intra-hospital operations and inter-hospital workflows. The former involves internal clinical processes, system integration, and access management, while the latter includes health information exchange (HIE) and telemedicine, which introduce additional complexity through distributed systems and external network communication. Major threats to healthcare operations and patient safety are discussed, including ransomware, application vulnerabilities, social engineering, and supply chain attacks. Corresponding technological and managerial protection mechanisms are then reviewed, including authentication, access control, cryptographic techniques, security governance, and business continuity planning. To ground the framework in practice, Taiwan's healthcare infrastructure is examined as a case study, including the National Health Insurance (NHI) IC card system, Healthcare Certificate Authority (HCA), and Electronic Medical Record Exchange Center (EEC), as practical implementations of secure identity verification and cross-institutional data exchange. Finally, emerging trends and challenges are discussed, including the decentralized potential of blockchain for secondary data use, the dual role of artificial intelligence as both a security defense mechanism and a source of novel attack vectors, as well as the growing need for post-quantum cryptography (PQC) to safeguard long-term medical data against future quantum computing threats.

**Plenary session**

Session 15
Tuesday September 15, 16:30-18:00

### A Multi-Backbone Pipeline Combining Biomedical Foundation Models and CNNs for Explainable Triage of Cutaneous Ulcers

*Alessio Luschi, Linda Tognetti, Gabriele Cevenini, Pietro Rubegni and Ernesto Iadanza*

Distinguishing vascular from non-vascular cutaneous ulcers is a critical clinical task that drives treatment selection. However, in non-specialist settings where most chronic ulcers are first assessed, misdiagnosis rates remain alarmingly high. This paper describes the design of an explainable binary classification pipeline that addresses this gap by combining three architecturally distinct backbones through late fusion: EfficientNet-B0 (a convolutional neural network), BiomedCLIP (a biomedical vision--language Vision Transformer), and UNI (a computational pathology Vision Transformer). The proposed fusion configuration aims to evaluate the individual and combined contributions of each backbone systematically. The pipeline incorporates Macenko colour normalisation to handle photographic variability, and dual explainability (GradCAM++ for the CNN and attention rollout for the Vision Transformers) to support clinical interpretability. The architectural rationale and the training protocol are presented and discussed for the intended clinical deployment as a triage tool in primary care and telemedicine.

### Predictive value of EEG features for machine learning–based prediction of functional outcome after thrombectomy in LVO stroke

*Katerina Iscra, Andrea Bonini, Giovanni Furlanis, Edoardo Ricci, Aleksandar Miladinovic, Marcello Naccarato, Paolo Manganotti and Milos Ajcevic*

Accurate prediction of 3-month functional outcome after endovascular thrombectomy (EVT) in patients with acute ischemic stroke due to large vessel occlusion (LVO) remains challenging. Quantitative EEG (qEEG) provides a non-invasive assessment of brain activity and may offer complementary information for prognostic modeling. This study aimed to evaluate whether qEEG-derived features improve outcome prediction within an interpretable Naive Bayes framework. We analyzed 71 patients with LVO stroke treated with EVT. Functional outcome at 3 months was dichotomized as good (modified Rankin Scale ≤2) or poor (modified Rankin Scale >2). EEG recordings were processed offline to extract relative spectral power in delta, theta, alpha, and beta bands, together with the delta/alpha ratio (DAR) and the (delta + theta)/(alpha + beta) ratio (DTABR). Candidate predictors were selected through a univariate feature-selection step and entered into Naive Bayes classifiers. Age, admission NIHSS, hypertension, recanalization status, symptomatic intracranial hemorrhage, and EEG-derived features including delta power, alpha power, DAR, and DTABR were associated with outcome. The clinical-radiological model achieved 68% accuracy and an AUC of 0.73, whereas the EEG-enhanced model reached 73% accuracy and an AUC of 0.78. These findings suggest that qEEG features provide complementary neurophysiological information useful for improving outcome stratification after thrombectomy.

### Enhancing Hypoglycemia Prediction in Type 1 Diabetes via mWGAN-GP-based Augmentation of Pre-Exercise CGM Data

*Libera Lucia Del Giudice, Agnese Piersanti, Kassa Sosna Solomon, Christian Göbl, Laura Burattini, Andrea Tura and Micaela Morettini*

Physical exercise in individuals with Type 1 Diabetes (T1D) significantly increases the risk of hypoglycemia, and despite the widespread adoption of continuous glucose monitoring (CGM) systems, its prediction remains a challenging task. Deep learning classifiers, such as Bidirectional Long Short-Term Memory (Bi-LSTM) networks, have shown promising results as a clinical decision support system, but their performance is often limited by data scarcity and severe class imbalance. To address these limitations, this study proposes a framework for data augmentation purposes based on Generative Adversarial Networks (GANs). In particular, we propose mWGAN-GP, a modified version of the Wasserstein GAN with Gradient Penalty (WGAN-GP), incorporating a diversity regularization term into the generator loss function to improve training stability and variability in the generated signals. This strategy promotes the augmentation of diverse and physiologically plausible CGM sequences. Experimental results on the DirecNet dataset show that mWGAN-GP-based augmentation improves classification performances, with an AUC of 90.9% with respect to that obtained with conventional data augmentation techniques (AUC=88.6%). These findings highlight the potential of GAN-based augmentation to enhance model generalization and support the development of more reliable predictive systems for T1D management.

### DINO by Paperbox: A Serious-Gaming Platform for Early Screening of Learning Difficulties in Children

*Muhammad Farooq Shaikh, Giacomo Pratesi, Alice Ravizza and Davide Piaggio*

Neurodevelopmental disorders (NDDs) such as attention-deficit/hyperactivity disorder (ADHD) and specific learning disorders continue to go undiagnosed during early childhood because of the lack of access to specialist evaluation and delays in referral channels. Non-invasive screening instruments that can be deployed in schools, at large volumes, are thus needed. The paper presents a serious-gaming platform called Dino by Paperbox Health, which targets children aged between 4 and 8 years of age. Interaction features, which are captured by the system, include response time, accuracy and behavioural variability and allow the analysis of cognitive performance to be done using data. Dino is school-deployable and has age adaptive interaction in Reception, Key Stage 1 and Key Stage 2. The platform structure, the gameplay, and the mood tracker system are shown. There is pre-deployment that proves possible and high participation in classroom environments. Dino offers a scalable baseline of early screening assistance and the subsequent AI-driven digital health applications.

### A Practical Handheld Photoacoustic Microscopy System for In Vivo Microvascular Imaging

*Chulhong Kim, Mingyu Ha, Jaewoo Kim, Seonghee Cho, Dasom Heo, Minsu Kim, Joongho Ahn and Eunwoo Park*

Photoacoustic microscopy (PAM) has become a vital tool in biomedical research, providing high-resolution 3D anatomical and functional imaging. While handheld PAM systems are preferred for clinical and point-of-care applications, achieving a compact design without sacrificing imaging speed or spatial resolution remains a significant challenge. This study demonstrats a practical handheld PAM probe that integrates a resonant fiber scanner with a high-frequency transparent ultrasound transducer. The compact device, measuring 17 mm in diameter and weighing only 11 g, achieves high lateral and axial resolutions of 7 and 47 μm, respectively, with a 2.6 mm diameter field of view. Volumetric images are acquired in 1.5 s, effectively minimizing motion artifacts during handheld operation. We validated the system through in vivo imaging of surgically exposed rat abdominal organs, including the stomach and intestine. Furthermore, we investigated the high-speed monitoring capabilities of the system by characterizing the temporal profile of epinephrine-induced vasoconstriction in vivo. Our quantitative analysis of vascular responses highlights the probe's potential for real-time pharmacological assessment and intraoperative guidance.

### IMU-heart: Nocturnal cardiac monitoring with wearable inertial sensors

*Marcello Sicbaldi, Paola Di Florio, Luca Palmerini, Alessandro Silvani and Lorenzo Chiari*

Wearable inertial sensors are widely used in sleep, mobility, and digital-health studies, but their potential for beat-to-beat cardiac monitoring from non-chest locations remains poorly explored. We investigated whether heart rate (HR) and heart rhythm information can be recovered during sleep from inertial measurement units (IMUs) placed at the lower back and wrists. Nine healthy adults underwent overnight at-home monitoring with lower back and wrist IMUs and a wearable electrocardiograph. Sleep posture was estimated from the lower-back IMU, and heartbeat detection was performed within stable posture bouts using a template-matching cross-correlation approach. Performance was evaluated at the beat-to-beat level using RR intervals and at the 5-minute window level using mean HR and RMSSD index of HR variability. Estimation of RR intervals was best from the lower-back IMU (concordance correlation coefficient, CCC = 0.91 ± 0.30), albeit with a marked reduction in the supine posture, while the dominant and non-dominant wrist showed lower performance (CCC = 0.65 ± 0.23 and 0.63 ± 0.29, respectively). Mean HR was recovered reliably across locations, whereas RMSSD estimates were less robust. These results support the feasibility of opportunistic nocturnal cardiac monitoring from sparse inertial sensor placements, with the lower back emerging as the most promising location.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 17A
Wednesday September 16, 09:30-11:00

### A Generative XAI Driven Mobile App for Improved Skin Cancer Diagnostics

*Sarya Demir and Muhammad Salman Haleem*

Automating steps in early skin cancer detection is critical for early-stage intervention and treatment. While numerous solutions are being developed for skin cancer detection and classification, those are usually not evaluated and validated in real clinical settings, primarily due to challenges associated with image processing, standardization, and limited annotations resulting in class imbalance. To address this, we propose a mobile app driven by Wasserstein GAN with Gradient Penalty (WGAN-GP) with an improved optimization function to augment the synthetic lesions. We enhance feature representation via Local Binary Patterns (LBP) and perform classification via convolutional neural network ensembling with confidence calibration. The proposed framework improves accuracy of 97% and robustness, and a prototype mobile app demonstrates feasibility for real-world deployment

### MediScene: A Semantic Risk Detection System for Safer Drug Prescription Using Structured and Unstructured Medical Data

*Semet Gülen and Furkan Akıncı*

Medication errors resulting from overlooked contraindications, allergies, or interactions remain a critical concern in clinical care. We propose MediScene, a decision support prototype designed to alert prescribers of potential risks at the point of prescription. The system integrates structured drug interaction data from DrugBank with unstructured safety content extracted from pharmaceutical leaflets. Patientspecific information such as known allergies, chronic diseases, and lab results is cross-checked using semantic similarity techniques to detect risks related to four categories: drug–drug, drug–allergy, drug–disease/lab, and drug–food interactions. Embedding models are applied to represent leaflet sentences and patient conditions in a shared vector space. Preliminary testing shows that MediScene can identify risks that would typically be missed by keyword-based or rule-based systems. This paper presents our architecture, methodology, and early outcomes of this hybrid AI-powered framework for safer prescribing.

### PPG-Based Cuffless Blood Pressure Estimation Using an Artificial Neural Network on the MIMIC

*Hicham Loumissi*

This study presents a novel real-time approach for blood pressure estimation from photoplethysmography (PPG) signals processed using Artificial Neural Networks (ANN). The framework employs the MIMIC-IV dataset for ANN training, allowing continuous, non-invasive blood pressure assessment. Signal acquisition is per-formed in real time, during which the PPG waveform is subjected to key prepro-cessing operations, including DC component removal, band-pass filtering, and normalization, in order to improve signal quality. Morphological characteristics, including cardiac period, diastolic time, and systolic upstroke time, are derived from the preprocessed PPG waveform and utilized as ANN input features. The pro-posed model demonstrates high accuracy in estimating both systolic and diastolic blood pressure and shows better performance than conventional methods. The find-ings suggest that the ANN-based approach can deliver accurate real-time blood pressure estimation and is suitable for personal health monitoring in practical healthcare settings today. Future work will focus on further improving the model and exploring its integration into mobile health platforms for wider application.

### Multi-Label Medical Concept Recognition using Asymmetric Loss-Driven EfficientNet: Analyzing the Detection of Rare Concepts Under Long-Tailed Imbalance

*Mehmet Aytuğ Yürük and Abbas Memiş*

Multi-label concept recognition from radiology images is challenging due to the large label space and severe long-tailed class imbalance. This study examines the effects of some specific loss functions and their multiple configurations for multi-label concept recognition on ROCOv2, a long-tailed radiology dataset consisting of 79,789 images annotated with 1,947 UMLS (Unified Medical Language System) concepts. To this end, we conduct a three-phase empirical study. The first phase evaluates two base loss functions, Binary Cross-Entropy (BCE) and Asymmetric Loss (ASL), using the EfficientNet-B0 backbone. The second phase investigates the effect of different ASL hyperparameter settings under increased model capacity with EfficientNet-B4. Finally, the third phase analyzes hybrid loss formulations that combine BCE and ASL under the same network settings. In the experiments, promising concept recognition rates were achieved with ASL. ASL improves the overall concept recognition performance score from 0.5809 (BCE baseline) to 0.5882 on the EfficientNet-B0 backbone and to 0.5916 on the EfficientNet-B4 backbone. Although this increase in the overall score may seem modest, the local increases in specific classes are even stronger. In addition, hybrid and other variants were evaluated and it was observed that they do not provide further gains over the best ASL-only configuration.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 17B
Wednesday September 16, 09:30-11:00

### Development of a Dynamic RPI to prioritize medical equipment replacement

*Valeria Piccone, Serena Vecchi, Ferruccio Panzica and Anna Maria Bianchi*

The lifecycle management of biomedical equipment represents a strategic challenge for healthcare organizations, particularly in technologically complex environments. Replacement Priority Indices (RPIs) are commonly used to support decision-making for equipment replacement; however, traditional approaches based on static models and predefined weightings are limited in capturing non-linear relationships, complex interactions, and temporal variability. This study presents the development of a dynamic RPI based on Machine Learning techniques to enhance decision-making accuracy and reliability in clinical engineering. The analysis was conducted using real-world data from the Fondazione IRCCS Istituto Neurologico Carlo Besta (Milan), including demographic, operational, economic, and clinical-functional variables. Two datasets (2024 and 2025) were constructed to ensure a clear separation between training and validation phases. Following preprocessing and feature engineering, multiple classification algorithms were evaluated, addressing class imbalance. XGBoost achieved the best performance (Macro F1-Score = 0.83), outperforming both baseline models and a traditional RPI. Feature importance analysis highlighted the relevance of dynamic indicators such as downtime and failure rates. Prospective validation on updated data, along with comparison against the institutional Investment Plan, confirmed the model's consistency and operational value, demonstrating its ability to anticipate technological criticalities and support investment planning. The proposed system enables a transition from static planning to dynamic and proactive management of the technological asset portfolio.

### A Gemini Flash Thinking Protocol for Interpretable Feature Assessment in Synthetic Alzheimer's Disease Data

*Oliwia Kudyba and Ankica Babic*

Alzheimer's disease classification often depends on heterogeneous patient-level variables, including demographic indicators, lifestyle factors, comorbidities, cognitive scores, and functional assessments. Predictive models can perform well when direct cognitive and functional markers are included, but this does not necessarily imply early diagnosis or clinically transparent reasoning. This paper presents a revised Gemini Flash Thinking methodology for interpretable feature assessment in a synthetic Alzheimer's disease dataset containing 2,149 patient records. The main contribution of this study is a structured Gemini Flash Thinking protocol for categorizing Alzheimer's disease dataset variables as direct diagnostic markers, indirect risk factors, possible early indicators, or unsupported associations. The method uses a fixed prompt protocol, explicit output categories, tabular reasoning summaries, and author review to improve reproducibility. The dataset is examined under full-feature and reduced-feature conditions to distinguish current symptomatic evidence from weaker non-clinical risk information. The resulting Gemini-based reasoning framework identifies MMSE, ADL, Functional Assessment, Memory Complaints, and Behavioral Problems as direct clinical markers carrying the dominant diagnostic signal, while lifestyle and demographic features are treated as indirect and hypothesis-generating rather than sufficient for point-in-time diagnosis. The study therefore supports Gemini Flash Thinking as an interpretability and clinical-plausibility layer for feature reasoning, not as a validated early-diagnosis system. Validation on real-world longitudinal data is required before claims about earlier diagnosis can be made.

### Probabilistic SVM for Knee Osteoarthritis Classification

*Ida Maruotto, Federica Kiyomi Ciliberti, Carmine Gelormini, Halldór Jónsson Jr and Paolo Gargiulo*

Artificial intelligence (AI) has demonstrated significant potential to improve healthcare outcomes, yet its adoption in clinical practice is threatened by concerns about transparency and trust. Explainable AI (XAI) can address these challenges, ensuring more reliable AI implementation in healthcare. This study introduces an XAI-supported decision system for knee osteoarthritis (OA) classification, using a probabilistic Support Vector Machine (SVM) to estimate the likelihood of OA. The model uses logistic regression (LogReg) and a sigmoid function to transform SVM hyperplane distances into probabilistic interpretations, thereby enhancing explainability. The dataset consists of 131 knee scans (52 OA-diagnosed, 79 healthy). From these images, densitometric and geometric features of cartilage were extracted, yielding eight key features for classification. The model was evaluated using stratified 5-fold cross-validation, achieving strong performance with an F1-weighted score above 80%. Notably, the combined SVM + LogReg system improves classification performance to 83% while providing a probabilistic score, making AI-driven diagnostics more interpretable for clinicians. This approach links AI models to their applicability, particularly in clinical diagnosis, thereby enhancing their usability in healthcare environments.

### Short-Lead Routine Discordance Detection in PIR-Based Smart Homes Using Transformer Occupancy Prediction

*Aleksandar Miladinovic, Alessandro Biscontin, Simone Kresevic, Agostino Accardo and Milos Ajcevic*

Passive infrared (PIR) motion sensors are frequently used in Ambient Assisted Living (AAL) because they are low-cost, unobtrusive, and less privacy-invasive than camera- or microphone-based monitoring. However, PIR sensors provide sparse binary activations rather than direct activity labels or continuous occupancy information. This study proposes a privacy-preserving home-monitoring pipeline that converts PIR events into room-level occupancy states using a Finite State Machine (FSM) and then applies a transformer encoder to predict multi-room occupancy at a 5-minute lead time. The median sampling interval was 0.483 min, corresponding to approximately 10 samples for the 5-minute prediction horizon. The model achieved a training binary accuracy of 89.4% and a validation binary accuracy of 87.3%, with final training and validation losses of 0.273 and 0.322, respectively. Habitual discor- dance was computed as the mean absolute deviation between predicted and observed room-occupancy vectors. The held-out 24-hour test window showed how short-lead discordance can be visualized as an interpretable candidate flag for routine deviation. These results support the feasibility of transformer-based, short-latency discrepancy monitoring in PIR-based AAL settings.

### Toward Personalized Surgeons' Cognitive Workload: A Linear Mixed-Effects Model Analysis of EEG Features

*Damiano Fruet, Sanjana Mendu, Roger D Dias, John D Rolston, Stefano Cimignolo, Giandomenico Nollo and Marco A Zenati*

Surgical Flow Disruptions in the operating room can increase cognitive workload and the risk of technical errors. While electroencephalography (EEG) provides an objective framework for monitoring mental effort, traditional statistical methods often rely on group-level analysis. This approach potentially ignores the significant degree of inter-subject variability among individuals. This study evaluated the effectiveness of various EEG features in monitoring the impact of SFDs using a Linear Mixed-Effects Model (LMEM) framework to distinguish between group trends and individual-specific responses. EEG data were recorded from nine surgical trainees during a simulated microvascular anastomosis, during which participants were subjected to six predefined SFDs, including auditory alerts and visual distractions. EEG features were analyzed using LMEM with random intercepts and slopes, and a subjectivity index was introduced to quantify the degree of individualization across 36 extracted EEG features. An initial analysis of variance on the fixed effects revealed that, generally, theta and beta power bands were significantly impacted by disruptions across the group. However, the subjectivity index identified several features, such as Gamma Asymmetry, that exhibited high individualization despite the absence of a significant group trend. Features characterized by both significant fixed effects and high subjectivity indices, such as Mean Power Beta, were identified as the most reliable metrics for tracking cognitive load. These results demonstrate that traditional group-averaging methods can mask critical individual physiological responses. By utilizing LMEM and the associated subjectivity index, this research establishes a statistical foundation for developing personalized intraoperative monitoring systems tailored to a surgeon's unique cognitive profile.

## SS Nonlinear Methods for Medical Data Analysis

Session 17C
Wednesday September 16, 09:30-11:00

### Entropy-based differentiation of IGHV subtypes of chronic lymphocytic leukemia patients' DNA

*Alexander Martynenko and Xavier Pastor*

Chronic lymphocytic leukemia (CLL) comprises two major biological subtypes defined by the somatic hypermutation status of the immunoglobulin heavy chain variable region (IGHV): mutated (M CLL) and unmutated (U CLL). Although these subtypes differ markedly in clinical behavior, B cell receptor biology, epigenetics, and clonal evolution, statistical distinctions at the level of raw DNA sequence structure remain insufficiently explored. In this study, we analyze V–D–J region DNA sequences from 1,032 CLL patients using a suite of entropy based methods to determine whether information theoretic metrics can differentiate IGHV subtypes. Classical measures—including nucleotide distributions, Kullback–Leibler divergence, and Shannon entropy—revealed no significant differences between M CLL and U CLL, indicating highly similar base level composition. A robust differential entropy estimator (EnRE) likewise showed no subtype specific divergence. In contrast, two newly developed metrics—Randomized Entropy Divergence (EnRD) and the Entropy based Homogeneity Index (EnHI)—identified statistically significant differences. M CLL sequences exhibited greater intra sequence relational complexity, while U CLL sequences demonstrated markedly higher group level homogeneity, consistent with known biased IGHV usage and stereotyped BCR subsets. These findings show that deeper structural dependencies, rather than simple nucleotide frequencies, distinguish IGHV subtypes. Entropy derived metrics therefore provide a refined quantitative framework for characterizing CLL clonal architecture and complement existing prognostic markers. Integrating IGHV status with EnRD and EnRE substantially improves survival prediction, underscoring the clinical relevance of entropy based approaches in CLL stratification.

### Mental Fatigue Preserves the Balance Between Alpha-Band EEG Connectivity and Small-Worldness in Resting-State EEG

*Maive Hanni, Laura Päeske, Kairi Kreegipuu, Anna Dadatskaja, Aire Leppik and Maie Bachmann*

A negative correlation between EEG functional connectivity and small-worldness in the alpha band has been previously reported. The aim of the present study was to examine whether this correlation is preserved in the resting-state following cognitive tasks, as mental fatigue has been shown to affect both functional connectivity and small-worldness. Functional connectivity was quantified using phase locking value (PLV) and weighted phase lag index (wPLI), and Pearson correlation coefficients were calculated between these measures across a range of network densities. The results demonstrated a statistically significant decrease in functional connectivity in the post-task resting-state compared to the pre-task state for both PLV and wPLI, along with a significant increase in small-worldness for wPLI. A strong negative correlation between functional connectivity and small-worldness was consistently observed across both resting-state conditions. Although the correlations were stronger in the post-task state, no statistically significant differences in correlation strength were found between the states. These findings suggest that although functional connectivity and small-worldness change following cognitive tasks associated with increased mental fatigue, their inverse relationship remains stable. This supports the view that the balance between functional connectivity and small-world organization may represent a fundamental characteristic of brain network organization that is important for maintaining brain's efficiency also during mental fatigue. However, as post-task resting-states showed stronger correlations, future research could investigate whether and how this balance is altered during active cognitive engagement.

### Entropy Measures for Heart Rate Variability

*Ravneet-Rahul Sandhu Singh, Alexander Martynenko and Xavier Pastor i Durán*

Entropy-based measures of heart rate variability (HRV) capture nonlinear aspects of cardiac regulation that time- and frequency-domain methods may miss, but most studies assess them separately, making it difficult to determine which measures provide unique information and which are redundant. This study compares seven entropy metrics within a single framework for distinguishing Normal Sinus Rhythm (NSR) from Congestive Heart Failure (CHF): four traditional measures (Shannon Entropy, Approximate Entropy, Sample Entropy, and Spectral Entropy) and three recently proposed ones (Robust Entropy Estimator, Randomized Entropy Divergence, and Entropy Index of Group Homogeneity). RR interval sequences from 54 NSR subjects and 29 CHF subjects, obtained from PhysioNet, were segmented into 500-beat windows. Six of the seven metrics differed significantly between groups, whereas

Approximate Entropy did not. Univariate models identified Randomized Entropy Divergence as the strongest individual predictor, with an AUC of 0.854, while multivariate models achieved an AUC of 0.892. Principal Component Analysis and Factor Analysis showed that the six significant metrics span three independent dimensions, which helps explain why some combinations perform better than others. Generalized Linear Models and Linear Discriminant Analysis produced highly consistent results across 57 combinations ($r = 0.993$). Selecting one measure from each latent factor, namely Spectral Entropy, Randomized Entropy Divergence, and Entropy Index of Group Homogeneity, provided the best balance between classification performance and coefficient stability.

### A Hybrid Fuzzy-Logic Framework for Interpretable Prediction of TMS-EEG Responses from Pre-Stimulus Neural Dynamics

*Sadaf Moaveninejad, Simone Cauzzo, Marco Falda, Antonio Luigi Bisogno, Maurizio Corbetta and Camillo Porcaro*

Pre-stimulus brain state is a major source of variability in transcranial magnetic stimulation (TMS) responses, motivating predictive models that remain physiologically interpretable. We propose a fuzzy-logic framework for predicting binary TMS-evoked EEG response levels from pre-stimulus EEG features, offering a transparent alternative to black-box machine-learning approaches. The post-stimulus target was defined as the area under the absolute EEG waveform in the stimulated channel over 0–1000 ms, and trials were labeled as low or high using the median target value. Pre-stimulus predictors included alpha, beta, gamma, delta, theta, and Higuchi fractal dimension (HFD). Four model configurations were compared: Manual Only, Auto Only, Auto + Fallback, and Hybrid. Under a stratified trial-level 80/20 held-out split, the Manual Only model achieved the best performance (macro-F1 = 0.782, accuracy = 0.782), followed by the Hybrid model (macro-F1 = 0.770, accuracy = 0.772). The reduced four-feature automatic setting matched the six-feature setting while slightly improving coverage. These findings support fuzzy logic as a transparent framework for modeling TMS responsiveness and suggest that expert-defined rules already capture much of the relevant structure.

### Effect of EEG Reference Montage on Higuchi's Fractal Dimension Estimates for Discriminating Depression

*Safoora Masoumirad, Laura Päeske, Jaanus Lass and Maie Bachmann*

Electroencephalography (EEG) signals exhibit complex, nonlinear dynamics that can be characterized using nonlinear measures such as Higuchi's Fractal Dimension (HFD), which quantifies the signal's complexity based on its self-similarity. While HFD has been widely applied in clinical research, the influence of reference montages on its estimation remains insufficiently explored. This study investigates the effect of EEG reference montage on HFD estimates and assesses their ability to differentiate depressive and control groups. The EEG signals were originally recorded with the linked mastoids reference and subsequently re-referenced using three additional montages: vertex reference (Cz), reference electrode standardization technique (REST), and common average reference (CAR). Results indicate that the reference choice substantially influences HFD estimates and the detectability of group differences. At the global level, only the mastoid reference yielded statistically significant group separation. At the channel level, mastoid referencing produced the highest number of significant channels and the largest effect sizes, with significant channels located in central, centroparietal, and parietal regions, as well as in frontal regions. In contrast, REST and average yielded significant channels that were more spatially confined, while the Cz reference exhibited the least pronounced group differences, limited to frontal channels. These findings indicate that re-referencing is a transformation that can influence HFD estimates, potentially affecting the detectability of group differences. Future studies with larger cohorts are needed to further investigate the effects of referencing and to enable more generalizable conclusions.

## Biomedical Signal Processing and Physiological Systems Engineering

Session 17D
Wednesday September 16, 09:30-11:00

### Covert visuospatial attention is associated with frequency- specific power and connectivity modulation

*Matteo Fraternali, Davide Borra and Elisa Magosso*

Covert visuospatial attention enables the selection of a spatial location without overt eye movements and is classically associated with a lateralized modulation of posterior alpha-band activity. However, how other frequency bands contribute to the cortical organization of this process remains less clear. In this study, we compared leftward and rightward covert orienting using source-level EEG, with the aim of investigating frequency-specific modulations of both oscillatory power and functional connectivity during the anticipatory interval. Twenty-five healthy participants performed a cueing task requiring covert attention to the left or right hemifield. EEG source activity was reconstructed with eLORETA and analyzed in 20 regions of interest occipital, parietal, and frontal. Power and directed connectivity, estimated via spectral Granger causality, were assessed in theta, alpha, low-beta, high-beta, and gamma ranges using a time-resolved approach, and connectivity network organization was summarized through hubness and authority indices. Power results showed the typical lateralized modulation in posterior regions in the alpha band, consistent over time, with weaker but qualitatively similar effects in theta and low beta, whereas high-beta and gamma power exhibited less clear modulation patterns. Connectivity and centrality analyses revealed lateralized reorganization of the cortical networks, with interactions increasing ipsilaterally in all bands, but with distinct timing and spatial patterns, as high-beta and gamma connectivity effects emerged later and engaged more ventral regions than lower-frequency bands. These results support the view that covert visuospatial attention relies on multi-band oscillatory mechanisms, with lower and higher frequency bands possibly contributing differently.

## Automated Detection of Auditory Brainstem Response: Evaluation of New and Literature Indices Using Simulated Data

*Anna Candeo, Jessica Rupil and Giovanni Sparacino*

The Auditory Brainstem Response (ABR) is an electrophysiological signal routinely used in clinical settings to determine hearing threshold and assess auditory pathway integrity. Due to background electroencephalographic (EEG) noise, its assessment requires averaging a large number of sweeps acquired after repeated stimulus presentations. To reduce the number of sweeps, several automated detection indices have been proposed and implemented in commercial devices. However, their relative performance remains uncertain, especially in presence of noise and artifacts, and they generally do not account for non-stationarity in EEG noise. The present work provides a simulation-based comparison of six indices for automated ABR detection: five from the literature (Hotelling's $T^2$ test in time and frequency domains, q-sample uniform score test, Fsp, and Fmp) and a novel modification of the Hotelling's $T^2$ statistic designed to account for EEG non-stationarity. Performance was evaluated using true positive rate (TPR) and false positive rate (FPR), under different signal-to-noise ratios (SNR) and increasing levels of noise non-stationarity. Results show that methods based on the Hotelling's $T^2$ statistic achieved the best performance, with TPRs above 95% at medium SNR, while Fsp and Fmp consistently showed lower detection rates (below 40% at medium SNR) and increased detection times (about three times those of other methods at high SNR). The proposed method mitigated the effects of non-stationary noise, maintaining high TPR (above 90%) across conditions, whereas the others exhibited substantial degradation (down to below 75%). In conclusion, Hotelling's $T^2$-based methods outperform alternative approaches, and the proposed modification shows promising robustness to non-stationary noise.

## Signal quality assessment of photoplethysmography (PPG) under varying skin pigmentation and wavelength conditions using an in vitro vascular finger phantom

*Laura Osorio-Sanchez, James May and Panicos Kyriacou*

Photoplethysmography (PPG) is widely used for non-invasive cardiovascular monitoring; however, its performance is known to vary with skin pigmentation, raising concerns regarding reliability across diverse populations. While these effects have been previously investigated, most studies rely on in vivo measurements or global metrics, limiting detailed pulse-level analysis under controlled conditions. This study presents a controlled in vitro investigation of PPG signal quality using a multilayer vascular finger phantom with interchangeable skin tone layers representing different pigmentation levels according to the Fitzpatrick skin colour scale. PPG signals were acquired at three wavelengths (530 nm, 665 nm, and 940 nm – representing the most common wavelengths used in wearable devices) and analysed using a pulse-based framework incorporating six signal quality indices (SQIs), including morphology, signal strength and frequency characteristics. Results demonstrated significant main effects of both skin pigmentation and wavelength across all SQIs ($p < 0.001$), with infrared (940 nm) consistently providing the highest signal quality, and green (530 nm) showing the greatest signal degradation. A strong interaction effect demonstrated that signal degradation is not uniform but is amplified at shorter wavelengths under darker skin conditions. While most pairwise differences were statistically significant, the entropy-based metric showed limited differences between red (665 nm) and infrared (940 nm) wavelengths. These findings improve understanding and provide a detailed pulse-level characterisation of skin pigmentation effects on light tissue interactions in PPG signals for wearable optical technologies.

## Multilayer Vascular Wrist Phantom for In Vitro Optical Evaluation of Wearable Sensors

*Karina Awad-Perez, Laura Osorio-Sanchez, James May and Panicos Kyriacou*

Wearable optical sensors based on photoplethysmography (PPG) are widely used for non-invasive cardiovascular monitoring; however, their validation is limited by the lack of physiologically realistic and reproducible testing platforms. This study presents the development of a multilayer wrist phantom designed to replicate the anatomical, optical, and mechanical properties of human wrist tissue. The phantom consists of an adipose-mimicking silicone matrix embedding three vascular layers representing the capillaries microcirculation, arterioles and radial artery, positioned at controlled depths together with interchangeable skin layers representing different pigmentation levels. Optical properties of the adipose and skin layers were tailored using absorbing and scattering agents and validated against literature data, showing good agreement across the 500–1000 nm wavelength range. Mechanical characterisation confirmed that the phantom exhibits tissue-like hardness within the range of human soft tissue. The phantom was integrated into a closed-loop pulsatile cardiovascular system to enable controlled flow conditions and perfused using a blood-mimicking fluid. Laser Doppler Flowmetry (LDF) verified continuous pulsatile flow within the microvascular layer, while multiwavelength PPG measurements demonstrated realistic signal generation across all skin tones, with expected variations in amplitude and signal□to□noise ratio due to pigmentation-dependent absorption. The proposed platform provides a robust and reproducible tool for the evaluation and optimisation of wearable optical sensors under physiologically relevant conditions.

## Markov-Based Random Walk Analysis of Task-Related MEG Brain Networks

*Michele Ambrosanio, Stefano Franceschini, Francesca Bifulco, Roberta Diana, Giuseppe Cesarelli and Fabio Baselice*

Characterizing task-related brain network reorganization requires analytical frameworks that capture both local interactions and global information flow. Functional connectivity derived from magnetoencephalography (MEG) is often analyzed using static, edge-based measures, which may overlook higher-order and sequential dependencies in neural signal propagation. Here, we investigate a Markov-based framework for task-related brain network analysis by modeling MEG functional connectivity as a transition system and studying the resulting random walk dynamics. Using Human Connectome Project MEG data from healthy young adults, we compared working-memory and story-math tasks. From the corresponding transition matrices, we derived multiscale descriptors, including weighted random-walk motifs, the spectral gap, and a two-step round-trip (return) measure. Statistical analyses across frequency bands revealed robust task-related differences, with consistent effects in the alpha band across all measures and additional beta-band effects localized to right-hemisphere sensorimotor regions. These results demonstrate the potential of Markov-based measures to capture taskdependent brain network organization beyond pairwise connectivity.

### Comparison of heart rate variability after treatment of atrial fibrillation with radiofrequency ablation and pulsed field ablation

*Tomaž Jarm, Nastja Žgalin, Jernej Štublar, Matevž Jan and Damijan Miklavčič*

Atrial fibrillation (AF) is the most common arrhythmia, affecting approximately 50 million people worldwide, with prevalence expected to rise. It is commonly treated with catheter ablation to achieve pulmonary vein isolation (PVI). Traditional thermal methods, radiofrequency ablation (RFA) and cryoablation are effective but may damage surrounding tissue, whereas the newer pulsed field ablation (PFA) appears similarly effective and safer due to its nonthermal mechanism. RFA-based PVI often causes parasympathetic denervation, reflected by increased heart rate and reduced heart rate variability (HRV). HRV is primarily governed by the balance between the sympathetic and parasympathetic branches of the autonomic nervous system (ANS). The long-term effects of PFA on cardiac autonomic function and HRV remain unclear. Here, we present preliminary HRV comparisons from an ongoing clinical study. After ablation, mean and minimum heart rates were higher in the RFA group than in the PFA group for up to 6 months. HRV was significantly lower after RFA at 3 months, with a similar trend at 6 months, although differences were attenuated—likely reflecting partial recovery of autonomic function in the RFA group. These findings suggest better preservation of autonomic regulation with PFA, likely due to less parasympathetic denervation compared with RFA.

## IFMBE Scientific Challenge

Session 17E
Wednesday September 16, 09:30-11:00

### An Inspectable Vision-Language and Convolutional Ensemble for Facial Pigmented Lesion Diagnosis

*Argyrios Zafeiriou, Melina Tziomaka, Athanasios Kallipolitis and Ilias Maglogiannis*

Pigmented lesions of the face and neck pose a fine-grained differential-diagnosis problem in which several classes overlap visually on dermoscopy and are ultimately separated by histology, which limits what any image-only system can do. The MEDICON 2026 Scientific Challenge frames the task as a seven-class problem on 777 training images and a hidden test set of 335. We describe a 20-model ensemble of four families, three built on the DermLIP dermatology vision-language backbone (two fine tuned on the challenge data, one on external dermatology images) and a ConvNeXt Base classifier at 768 px input. A supervised contrastive term used during DermLIP fine tuning makes its image embedding double as a retrieval index, so any prediction can be inspected against the nearest training images from the predicted and the annotated class. We treat this built-in diagnostic view as a central feature of the system, not a post-hoc add-on. The ensemble reaches an out-of-fold combined score of 66.9, with errors clustering in the clinically expected LM/LMM and PAK/SL groups.

### A Two-Stage Transfer Learning Framework for Dermoscopic Classification of Facial Pigmented Lesions

*Alessandro Biscontin, Simone Kresevic, Alberto Bortolotto, Aleksandar Miladinovic and Milos Ajcevic*

Facial pigmented lesions represent a challenging diagnostic setting because benign, premalignant, and malignant entities may show overlapping dermoscopic features, particularly on chronically sun-damaged skin. This study developed and evaluated an image-based deep learning model for the multiclass classification of facial pigmented lesions. A two-step transfer learning strategy was used: a ResNet-152 model was first pretrained on a merged ISIC-derived dataset including 92,044 dermoscopic images across nine diagnostic categories, and subsequently fine-tuned on a facial pigmented lesions dataset comprising 1,112 images from seven diagnostic classes. Class imbalance was addressed using weighted sampling and class-weighted focal loss. On the internal test set, the model achieved a macro-AUC of 0.860, averaged recall of 0.697, macro-F1 score of 0.622, accuracy of 0.675. External testing showed preserved discriminative ability, with a macro-AUC of 0.85. These findings suggest that deep learning models based on contrastive learning training technique may support the differential diagnosis of facial pigmented lesions, although further multicenter validation and calibration refinement are required before clinical implementation.

### Clinically Informed Probability-Level Stacking Ensemble for Seven-Class Pigmented Lesion Classification Using Non-Standardized Clinical Images

*Shi-Yi Wu, Shao-Hung Lu, Mei-Fen Chen and Kang-Ping Lin*

Pigmented lesion classification remains challenging because clinical images are often collected under non-standardized conditions and different lesion categories may show highly similar visual characteristics. This study proposed a two-stage probability-level stacking ensemble framework for seven-class pigmented lesion classification using transfer learning. The dataset consisted of 777 clinical lesion images with histological diagnosis labels, including atypical nevus, lentigo maligna, lentigo maligna melanoma, pigmented actinic keratosis, seborrheic keratosis, seborrheic-lichenoid keratosis, and solar lentigo. To address class imbalance, clinically constrained data augmentation was applied to increase the training data to 1,610 images, with 230 images per class. Three ImageNet-pretrained CNN backbones, including EfficientNet-B0, DenseNet121, and ConvNeXt-Tiny, were trained independently using stratified cross-validation. EfficientNet-B0 was trained using five folds, whereas DenseNet121 and ConvNeXt-Tiny were each trained using three folds. The seven-class probability outputs from the three backbones were concatenated into a 21-dimensional meta-feature vector and used to train a multinomial logistic regression meta-classifier. In internal validation, DenseNet121 achieved the highest mean validation accuracy among the individual backbones, reaching 0.5135. The final stacking ensemble was evaluated on the official challenge test set and achieved a Macro AUC of 0.80, averaged recall of 0.47, Macro F1-score of 0.45, Brier score of 0.67, accuracy of 0.54, and global score of 59.39. These results suggest that probability-level stacking of multiple pretrained CNN backbones provides a feasible baseline strategy for multiclass pigmented lesion classification under limited and non-standardized clinical image conditions.

## Facial Pigmented Lesion Classification with SwiGLU-Enhanced Swin Transformer V2

*Maryam Al Rubaye, Abbas Memiş and Baraa'H Mohamed Naser*

Automated classification of facial pigmented lesions from dermoscopic images is a clinically important yet challenging problem due to the high visual similarity between malignant and benign lesions, severe class imbalance, and scarcity of validated training data. This paper presents our approach to the MEDICON 2026 Scientific Challenge, which targets seven-class differential diagnosis of facial pigmented lesions. Our key contributions are twofold. First, we curated an extended, dermatologist-validated dataset by merging the official MEDICON 2026 training images with publicly available external sources (ISIC Archive and HAM10000), followed by GPT-4 Vision-assisted subclass disambiguation and manual clinical validation by a board-certified dermatologist who reviewed and removed any suspicious or incorrectly labelled samples - yielding approximately 400-500 validated images per class. Second, we propose a classification pipeline based on Swin Transformer V2 (pre-trained on ImageNet-22K) with a custom two-layer SwiGLU classification head, trained with Focal Loss, MixUp/CutMix augmentation, Exponential Moving Average (EMA) of weights, and 8-view Test-Time Augmentation (TTA) at inference. On our internal validation set, the model achieved a competition score of 87.95, with Macro-AUC of 0.972, Averaged Recall of 0.811, and Macro-F1 of 0.810. The official hidden test score was 61.65, revealing a distribution shift between the external-data-enriched training set and the clinical test set - a finding with important implications for future challenge design.

## Attentive Convolutional Neural Network Ensemble for Automated Facial Pigmented Lesion Classification

*María Herrero-Tudela, Roberto Romero-Oraá, Gonzalo César Gutiérrez-Tobal, María García and Roberto Hornero*

Automated classification of skin lesions located on the face and neck presents a significant clinical challenge due to chronic ultraviolet exposure and overlapping morphological characteristics across different diagnostic categories. In this work, we present an image-based deep learning framework developed for the MEDICON 2026 Scientific Challenge. Relying exclusively on raw dermoscopic pixel data as input, our core architecture leverages an ensemble of state-of-the-art convolutional backbones to promote diverse feature representation. These networks are enhanced with integrated Convolutional Block Attention Modules (CBAM) to maximize the extraction of localized discriminative features from subtle malignant transitions while suppressing irrelevant background noise. Evaluated on the organizer-side private hidden test set (N=335), our method achieved a Global Score of 54.92, with a Macro-AUC of 0.78 and an Accuracy of 0.50. These results demonstrate that a neural network with specialized attention blocks can achieve robust diagnostic discrimination across seven facial lesion classes without relying on supplementary clinical metadata. Ultimately, this ensemble-based method provides a scalable solution to assist primary care physicians and nurse practitioners in screening for skin cancer.

## A Multimodal Pipeline with Metadata Gating and LLM-Assisted Hyperparameter Tuning for Facial Lesion Diagnosis

*Volkan Mazlum and Alberto Antonietti*

We present a multi-modal deep learning pipeline for the MEDICON 2026 Challenge, which requires 7-class classification of pigmented skin lesions from dermoscopic images and clinical metadata. Our models combine three pretrained vision backbones, EfficientNetV2-M, Vision Transformer (ViT-B/16), and Swin Transformer-B, with a metadata-guided gating mechanism that adjusts image features. Also, an XGBoost-based metadata classifier complements the deep models by being fully trained on metadata. All components are trained using 5-fold stratified cross-validation with minority class oversampling, Focal Loss with label smoothing, MixUp and CutMix augmentation, and a custom hair-simulation transform. In inference, 8-view Test-Time Augmentation (TTA) is applied, and predictions from all four models are combined via weighted ensemble averaging with temperature scaling. After all these steps, an LLM Agent is used to optimize possible integrations, such as different parameter settings, changing class weights, and retraining XGBoost with different parameters. The proposed system is evaluated using the official challenge score $S_{total}$, which integrates Macro-AUC, Averaged Recall, Macro F1-Score, Brier Score, and Accuracy. The best performance obtained with the model was: $S_{total}$ = 62.81, Macro-AUC = 0.88, Averaged Recall = 0.46, Macro F1-Score = 0.45, Brier Score = 0.59, and Accuracy = 0.60.

## Two-Stage Ensemble and Metadata Fusion Framework for Skin Lesion Classification

*Furkan Aktay, Mert Mestçi and Ilkay Öksüz*

Classification of images of pigmented skin lesions images from face and neck region is clinically crucial. Benign, malignant, and intermediate lesions may exhibit very similar visual characteristics. This study addresses the seven-class facial pigmented lesion classification problem within the scope of the MEDICON 2026 Scientific Challenge. Two-stage deep learning pipeline was proposed for identifying skin lesions. In the first stage, an ensemble structure consisting of image-only EfficientNetV2-S models trained with three different random seeds was created. External images selected from ISIC-DICM-17k and DERM12345 datasets were harmonized to target classes and included in mixed-source training process. Following mixed-source training, model was fine-tuned using only MEDICON data to better adapt it to MEDICON image distribution. In the second stage, metadata information such as patient age, sex, lesion site, and lesion maximum diameter used. These metadata were combined with image representation using feature-level fusion architecture. Final prediction was obtained by combining the probability outputs of the image-only ensemble model and the models that take metadata into account. Proposed model achieved official evaluation results of 65.99 Global Score, 0.87 Macro AUC, 0.54 Macro F1-score, 0.56 Averaged Recall, 0.60 Brier Score and 0.57 Accuracy.

### Multi-Source Transfer Learning for Facial Pigmented Lesion Classification in Data-Limited Latin American Dermatology Contexts

*Cristina Aldana, Carlos Granados and Salvador Yabar*

Facial pigmented lesions present substantial diagnostic complexity because benign, premalignant, and malignant entities may share overlapping dermoscopic patterns. This study proposes a transfer-learning framework for the seven-class classification of facial pigmented lesions using a pre-trained foundation model. Methods: To address target-domain data scarcity, the original MEDICON dataset was expanded by harvesting external public datasets, including HAM10000, PAD-UFES-20, ISIC 2019, DERM12345, BCN20000, and ISIC_ARCHIVE. These datasets were mapped to the target 7-class taxonomy and directly merged to create a unified training pool of 11,020 images. The proposed vision-only pipeline extracts 6144-dimensional embeddings using the Google Derm Foundation model [1], followed by a lightweight Multi-Layer Perceptron classifier. Results: Preliminary validation showed moderate discriminative performance, with Macro-AUC of 0.6838, a Brier Score of 0.1079, and an Accuracy of 0.3886. However, class-balanced classification remains limited, reflected by an Average Recall of 0.2904 and a Macro-F1 of 0.3012. Conclusions: Foundation model embeddings can support facial pigmented lesion classification by effectively extracting visual features without computationally expensive pretraining.

### Multiclass Diagnosis of Facial Pigmented Lesions Using Dermatology Pretrained Foundation Models

*Marcello Sicbaldi*

This paper describes the submitted solution for the MEDICON 2026 Scientific Challenge on multiclass differential diagnosis of facial and neck pigmented lesions. The task is to assign dermoscopy images, optionally accompanied by clinical and acquisition metadata, to seven lesion classes. The submitted candidates used frozen image encoders rather than end-to-end fine-tuning: DINOv2-base, Google Derm Foundation, and PanDerm representations were combined with metadata features and shallow probabilistic classifiers. Metadata were aligned by sample identifier, imputed, standardized or one-hot encoded. Model selection used stratified five-fold out-of-fold validation on the 777 public training samples. The highest internal validation estimate was obtained by blending a DINOv2 + Derm Foundation + metadata branch with PanDerm Large probabilities, yielding Macro-AUC 0.835, averaged recall 0.490, Macro-F1 0.520, Brier score 0.581, accuracy 0.569, and official-style weighted score 63.205.

### ConvNeXtV2 Ensemble with Domain-Specific Fine-Tuning for Multi-Class Skin Lesion Classification

*Feti Çağrı Eraslan, Mehmet Aytuğ Yürük and Naci Furkan Karaduman*

Accurate automated classification of skin lesions is a clinically significant task, particularly under severe class imbalance and limited training data. This paper presents our approach to the MEDICON 2026 Scientific Challenge on dermoscopy image classification, which requires distinguishing seven skin lesion categories from only 777 training images distributed across classes with a maximum imbalance ratio of approximately 15:1. We propose an ensemble of three ConvNeXtV2 models: a Tiny and a Base variant pre trained on ImageNet-1k via Fully Convolutional Masked Autoencoder (FCMAE), together with a third Tiny model initialised from a publicly available ISIC-2019 skin lesion checkpoint through a two-stage domain specific fine-tuning protocol. All models are trained with five-fold stratified cross-validation, class-weighted cross-entropy loss, and AdamW optimisation. The final ensemble averages out-of-fold probabilities from all fifteen fold-checkpoints and applies per-class multipliers optimised by differential evolution combined with Nelder-Mead local search to maximise the official composite score. On the official held-out test set our system achieves a global score of $S_{\square o \square a \square}$ = 65.46 (AUC = 0.87, Macro Recall = 0.52, Macro F1 = 0.52, Brier = 0.56, Accuracy = 0.60). An empirical analysis of the out-of-fold to test generalisation gap reveals that per-class threshold optimisation appears to overfit strongly at this data scale, whereas the base ensemble transfers with near-zero gap.

## Plenary session

Session 19
Wednesday September 16, 12:00-13:30

### A Radar-Based Framework for the Automated Detection and Monitoring of OSAS

*Federica Sicilia, Marida De Maria, Marco Mercuri, Pierangelo Veltri and Patrizia Vizza*

Obstructive Sleep Apnea Syndrome (OSAS) is a chronic sleep-related breathing disorder defined by recurrent upper airway obstructions. OSAS can lead to a significant reduction in quality of life, and it can be associated with the onset of severe cardiovascular diseases, metabolic disorders, and increased mortality. Current standard diagnostic exams, such as polysomnography, are accurate but often uncomfortable and intrusive to patients and inaccessible for long-term monitoring. To address these limitations, this work presents an innovative non-contact monitoring solution integrating Frequency-Modulated Continuous-Wave (FMCW) Radar technology with a cloud-based data management platform for the automated analysis of vital signs. By leveraging high-precision radar sensing, the solution is able to continuously track the respiratory patterns and heart rate without the need for wearable sensors, ensuring maximum patient comfort. The integrated platform employs advanced signal processing algorithms to detect apnea events and quantify syndrome severity. Preliminary results demonstrate that the system offers a reliable, low-cost, and scalable alternative for early screening and longitudinal home-based monitoring, potentially reducing the clinical burden on healthcare facilities and improving patient outcomes through timely intervention.

### To evaluate the SNR and uniformity of 5.0T MRI

*Chengchen Chu, Jing Tong and Bin Li*

Objective To evaluate the signal-to-noise ratio (SNR) and image uniformity of 5.0T MRI using a standardized water

phantom, and to enhance the reproducibility of quality control procedures. Methods Existing methodologies for SNR and uniformity assessment were systematically reviewed, and a standardized testing protocol based on the SMR 170 phantom was developed. Under identical pulse sequence conditions, various image reconstruction parameters were compared and analyzed to determine optimal settings for image quality control in 5.0T MRI. Results The SNR and image uniformity of the 5.0T MRI system at our institution were evaluated. The results demonstrated that different reconstruction parameters significantly influenced the quantitative outcomes of image quality metrics. Conclusion This study establishes a standardized approach for SNR and uniformity evaluation, along with optimized reconstruction parameters, thereby supporting consistent, reliable, and scientifically sound quality control of 5.0T MRI equipment.

### Design of a High-Voltage-Tolerant Multi-Modal Intracardiac Sensing System Integrating Electrogram and Impedance Measurement for Pulsed Field Ablation

*Shao-Hung Lu, Shi-Yi Wu and Kang-Ping Lin*

Pulsed field ablation (PFA) has recently emerged as a promising non-thermal technique for cardiac arrhythmia treatment. However, the high-voltage pulsed electric fields used in PFA procedures introduce significant challenges for intracardiac electrogram (iEGM) acquisition, including amplifier saturation, severe electromagnetic interference, and signal distortion. Pulsed field ablation (PFA) has emerged as a promising non-thermal technique for the treatment of cardiac arrhythmias. During PFA procedures, real-time intracardiac sensing is essential for evaluating catheter-tissue contact, lesion formation, and electrical activity. However, the high voltage pulsed electric fields introduce significant challenges to conventional sensing systems, including amplifier saturation, electromagnetic interference, and signal distortion. In this paper, a high voltage tolerant multi-modal intracardiac sensing system integrating electrogram (iEGM) and impedance measurement is proposed. The system combines a multi-stage protection circuit, low-noise analog front-end (AFE), and synchronous multi-channel analog-to-digital converters (ADCs) to enable robust signal acquisition under high-voltage conditions. In addition to electrical activity monitoring, an impedance measurement module is incorporated to assess tissue characteristics and catheter-tissue interaction. A field programmable gate array (FPGA) based control unit is employed to coordinate synchronous data acquisition and system operation. The proposed system supports scalable multi-channel configurations and provides complementary electrical and impedance information for comprehensive intracardiac monitoring. This design offers a practical platform for future PFA catheter systems and advanced electrophysiological studies.

### Towards Markerless Mixed Reality (MR) for TAVI: A Proof of Concept in 3D Quantification and Feature Extraction

*Alessia Finti, Michela Franzò, Giovanni Pasini, Giada Testani, Antonella Alessia Mallqui Ramirez, Mizar D'Abramo, Wael Saade, Giuseppe Mazzesi, Franco Marinozzi and Fabiano Bini*

Transcatheter Aortic Valve Implantation (TAVI) requires extreme precision, yet current navigation mainly relies on 2D fluoroscopy, increasing cognitive load and radiation exposure. Building on our previous work in holographic visualization, this study presents a Proof-of-Concept (PoC) for an integrated Mixed Reality (MR) platform. We propose a twofold approach: (i) a pre-operative planning module that employs hierarchical scaling algorithms to ensure 1:1 metric accuracy for patient-specific anatomical analysis, and (ii) a markerless intraoperative tracking pipeline. By leveraging Sobel edge detection, RGB thresholding, and DBSCAN clustering, we demonstrate the feasibility of aligning 3D holograms with the surgical field using intrinsic anatomical landmarks instead of physical markers. Preliminary results show sub-millimetric accuracy in measurements and robust holographic stability, providing a reliable foundation for enhancing surgical awareness and safety in structural heart interventions.

### Effect of 3D-printed holder wall thickness on X-ray attenuation and micro-CT image quality of paraffin-embedded core samples

*Santiago Laguna-Castro, Aino Reunamo, Markus Hannula, Katri Lindfors, Kalle Kurppa, Antti Kaipia and Jari Hyttinen*

X-ray microtomography (micro-CT) is a non-destructive 3D imaging modality, increasingly used to assess the morphometry of soft tissues, including formalin-fixed paraffin-embedded biopsies. As micro-CT imaging is implemented into histological workflows, sample mounting and holder design becomes relevant, especially for small and mechanically delicate core biopsies. This study evaluated how sample holder type and wall thickness influence X-ray attenuation and reconstructed image quality in micro-CT imaging of tissue biopsies. Two custom 3D-printed polylactic acid (PLA) holders with increasing wall thickness were compared with a routinely used syringe-based mounting. Holder-related attenuation was assessed using transmission measurements of empty holders, while image quality was evaluated through qualitative assessment of reconstructed volumes and tissue-background contrast-to-noise ratio (CNR) in representative prostate and intestine biopsies. Increasing the holder wall thickness resulted in a mechanically more stable setup but resulted in higher attenuation and was associated with increased image noise and reduced CNR. The trends were consistent between sample types. These results demonstrate that the sample holder design influences the imaging conditions and image quality in micro-CT imaging of tissue biopsies and should be considered a part of the acquisition setup. Balancing robustness with minimal holder attenuation is essential when designing or selecting mounting solutions for soft-tissue micro-CT workflows

### Data-Driven Smart Clinical Engineering: A Multidimensional Assessment of Patient Safety, Operational Ethics, and ESG Sustainability

*Yi-Chieh Lin, Hsin-Tai Chen, Mei-Fen Chen and Kang-Ping Lin*

This study explores the transformation of clinical engineering from traditional maintenance to data-driven strategic governance, focusing on the integration of patient safety, operational ethics, and Environmental, Social, and Governance (ESG) goals. Utilizing the i-MMS (Intelligent Medical

Management System), we conducted a comprehensive lifecycle assessment of medical assets. In the domain of Technical Assessment, risk evaluations of aging ICU monitors (10–17 years) identified critical End-of-Life (EOL) risks, preventing potential care interruptions. By analyzing maintenance data for 1,036 infusion pumps, the implementation of a "Preventive Battery Replacement" strategy reduced failure rates by 88%. Furthermore, the application of a Predictive Maintenance (PdM) model for CT tubes—monitoring the "Fatigue Index" via i-MMS—allowed for preemptive replacements during non-clinical hours, successfully averting 5-day downtimes and approximately US$30,000 in operational losses per incident. Regarding ESG Sustainability, the transition to digital workflows eliminated tens of thousands of paper records, reducing cumulative carbon emissions by 3,365.37 kgCO2 over 26 months, while centralized dispatching reduced maintenance logistics by 95%. From an Ethical and Social perspective, optimizing point-of-care testing (POCT) systems increased Wi-Fi data upload rates from 31.1% to 89.4%, ensuring 100% data integrity within Electronic Medical Records (EMR). Additionally, digitalization saved 15,101.1 administrative man-hours, significantly mitigating staff burnout. In conclusion, this study demonstrates that modern clinical engineering serves as a vital evaluator of medical technology, leveraging data-driven precision to uphold patient safety, enhance hospital resilience, and achieve measurable sustainability milestones.

## SS Designing Future Ready BME Programs

Session 21A
Wednesday September 16, 14:30-16:00

### Rewriting the Curriculum: What Digital Health Demands from Biomedical Engineering Education

*Lenka Lhotská*

Rapid advances in technology and software tools are reshaping the expectations placed on biomedical engineers, prompting a critical re evaluation of existing curricula. While traditional foundational subjects remain essential, emerging domains must be thoughtfully integrated to prepare a new generation of professionals for evolving roles in research, industry, and health care. Future biomedical engineers will require broader and more adaptive competencies, extending beyond core engineering to include computer science, data analytics, regulatory, legal and ethical frameworks, digital health and soft skills. A key challenge is ensuring that education remains closely aligned with real world job requirements and reflects current trends in clinical practice, industry Innovation, and global health priorities. Equally important is clarifying and strengthening the relationship between biomedical engineering and the rapidly expanding field of digital health, including AI-driven solutions and data-intensive health technologies.

### Transforming BME Education: Challenges, New Approaches, and Emerging Technologies

*Piotr Ladyzynski*

Rapid advances in technology and software tools are reshaping the expectations placed on biomedical engineers, prompting a critical re-evaluation of existing curricula. While traditional foundational subjects remain essential, emerging domains must be thoughtfully integrated to prepare a new generation of professionals for evolving roles in research, industry, and healthcare. Future biomedical engineers will require broader and more adaptive competencies, extending beyond core engineering to include computer science, data analytics, regulatory, legal and ethical frameworks, digital health, and soft skills. A key challenge is ensuring that education remains closely aligned with real-world job requirements and reflects current trends in clinical practice, industry innovation, and global health priorities. Equally important is clarifying and strengthening the relationship between biomedical engineering and the rapidly expanding field of digital health, including AI-driven solutions and data-intensive health technologies. This paper discusses strategic guidelines and practical recommendations for future curriculum development, including the identification of critical topics and the design of flexible, competency-based teaching approaches. Emphasis is placed on experiential learning through hands-on exercises, interdisciplinary seminars, problem-based and project-based learning, and real-world case studies embedded within relevant regulatory, technical, and professional contexts to ensure meaningful and sustainable educational impact.

### Experiential Learning Models in Future Biomedical Engineering Curricula: Bridging Academia, Industry, and Healthcare Systems

*Martha L. Zequera, Ratko Magjarevic, Virginia L. Ballarin, Luis M. Zamudio, Kang-Ping Lin, Shankar Krishnan, Eduardo Guillermo P. Velez, Piotr Ladyzynski and Nubia Arroyo*

Rapid advancements in digital health—including artificial intelligence, interoperable platforms, and data-driven healthcare—are fundamentally reshaping the competencies required of biomedical engineers. This shift necessitates a transition from traditional curricula toward integrative, experiential learning models that align with real-world healthcare ecosystems. This work presents an interdisciplinary educational framework designed to bridge the gaps between academia, industry, and healthcare providers. Inspired by a long-standing Summer School on emerging technologies for healthcare and independent living, the model integrates engineering, health sciences, and social sciences to address challenges related to healthy ageing within the Latin American context. Implemented over ten consecutive years during inter-semester periods at Pontificia Universidad Javeriana—and supported by international societies such as IFMBE and CORAL—the program aims to strengthen soft skills often underrepresented in traditional curricula. It fosters meaningful learning environments where students apply technical knowledge to real-world case studies through critical and reflective thinking. The program targets senior undergraduate students in biomedical engineering, computer science, mechatronics, and medicine. Participants leverage prior knowledge in signal and image processing, data science, machine learning, and project formulation. The pedagogical approach emphasizes experiential learning through case studies focused on chronic disease management, fall prevention, functional decline, and the digital inclusion of older adults. Students employ structured innovation methodologies to design user-centered, scalable digital health solutions, supported by clinical simulation environments, engineering laboratories, and industry collaboration. The framework incorporates interoperability, cybersecurity, cloud infrastructure, and AI-driven decision-making, while integrating essential ethical and regulatory considerations. Designed for versatility, this model can be embedded into standard curricula as elective or capstone courses in engineering, innovation, and entrepreneurship. It provides a practical pathway for aligning biomedical engineering education with the evolving demands of the global healthcare industry.

### The rapid expansion of biomedical engineering education in Europe and its implications for curricula harmonization

*Christos Alexandropoulos, Orestis Papathanasopoulos and Nicolas Pallikarakis*

Biomedical Engineering (BME) has become a vital component of the modern healthcare architecture, driving technological innovation and necessitating a highly specialized, multidisciplinary workforce. Due to the field's inherent complexity, educational programs across the European Higher Education Area (EHEA) display significant curricular heterogeneity, which complicates graduate competency assessment and hinders student mobility. This paper examines the historical progression of BME education and provides an exhaustive update to the pan-European BME program database. By mapping 559 active Bachelor (BSc), Master (MSc), and Doctoral (PhD) programs in 2026, this study offers a comparative analysis against the 2020 benchmark data. The primary objective is to establish a transparent, accessible repository that empowers students to navigate the EHEA and provides a baseline necessary to modernize Curricula Reformation and Harmonization (CRH-BME) criteria.

### Next-Gen Biomedical Engineers: Navigating AI, Sustainability, and Regulation

*Davide Piaggio and Pedro Checa Rifa*

Medical devices are essential enablers of modern healthcare, with the broader sector accounting for approximately 4.4% of global greenhouse gas emissions. While recent research has begun to map the environmental impact of the medical device lifecycle, from manufacturing to end-of-life, the industry now faces a dual challenge: the race toward Net Zero and the rapid integration of Artificial Intelligence and Software-as-a-Medical-Device. As emissions shift from physical supply chains toward high-energy computational infrastructures, existing regulatory frameworks, such as the EU Medical Device Regulation (MDR 2017/745), reveal a critical blindspot regarding the full-lifecycle impact of digital health. Drawing on the methodology established in our recent scoping review, this presentation maps the intersection of circular economy principles, medical device regulatory requirements, and the emerging environmental footprint of digital health. While this is something current biomedical engineers are just coming to terms with, the next generation of biomedical engineers will need to be better prepared for these aspects. This talk provides a concrete blueprint for BME education, advocating for a transition from traditional engineering competencies to a hybrid model that embeds frugal innovation and digital sustainability literacy. By fostering a design framework that balances hardware longevity under strict MDR compliance with resource-efficient software deployment, we can equip future engineers to advocate for accountability across both physical and digital healthcare lifecycles.

## Biomedical Signal Processing and Physiological Systems Engineering

Session 21B
Wednesday September 16, 14:30-16:00

### Towards Objective Screening of Motion Sickness: A Preliminary Study on Head-COP Kinematics in VR

*Alessia Finti, Ida Maruotto, Giovanni Pasini, Federica Pescaglia, Franco Marinozzi, Paolo Gargiulo and Fabiano Bini*

Motion sickness represents a critical occupational hazard in maritime and transport sectors, creating a pressing need for objective, preemptive screening tools to assess an individual's susceptibility. Traditional predictive models often rely solely on subjective questionnaires or isolated physiological signals. This study investigates the predictive power of combining Center of Pressure (COP) and Head kinematics to identify Motion Sickness Proneness (MSProne). Using a subset of the BioVRSea database (N=18), we extracted 54 kinematic features—including time-domain, frequency-domain, and non-linear complexity metrics (Sample Entropy, Higuchi Fractal Dimension), from both COP and Head trajectories. A targeted feature fusion approach followed by a Least Absolute Shrinkage and Selection Operator (LASSO) logistic regression with 10-repetition 3-Fold Cross-Validation yielded a mean classification accuracy of 67.2% and a mean Area Under the Curve (AUC) of 0.72. The most robust predictive biomarkers were non-linear: Head Antero-Posterior Higuchi Fractal Dimension and COP Ellipse Area. These findings demonstrate that non-linear sway complexity and the targeted fusion of Head and COP kinematics are robust, objective biomarkers for predicting innate Motion Sickness Proneness using a VR-based screening protocol.

### Tract-to-Region Incidence Matrices as Native Input for Hypergraph-Based Connectome Analysis: a Longitudinal Study on Quadrato Motor Training

*Begido Doda, Franco Marinozzi, Filippo Carducci, Pedro Real, Tal Dotan Ben-Soussan, Carlo Cosimo Quattrocchi, Carlo Augusto Mallio and Fabiano Bini*

Hypergraph-based methods have emerged as a powerful framework for the analysis of brain structural connectivity, extending classical graph-theoretic approaches by encoding higher-order multi-region interactions. The Boundary Scale (BS) model provides an iterative mathematical framework that progressively amplifies these interactions starting from a binary incidence matrix. While previous studies have applied the BS model to Region-to-Region adjacency matrices, this approach requires an artificial conversion into incidence matrices, resulting in representations of variable dimensions and high computational cost. In this study, we investigate the use of Tract-to-Region (T-R) matrices — which constitute a structurally native incidence matrix input for the BS model — applied to a longitudinal dataset of 32 healthy subjects undergoing twelve weeks of Quadrato Motor Training. T-R matrices were binarized at four overlap thresholds (0.15, 0.20, 0.25, 0.30) and analysed through four iterative BS scales. A paired t-test on average node degree between baseline and the final timepoint revealed significant increases at thresholds 0.20 and 0.25 from the first BS iteration onward ($p \leq 0.030$), with the strongest effect at threshold 0.25, iteration 2 ($t = 2.603$, $p = 0.014$). These results demonstrate that T-R incidence matrices are sensitive to training-induced structural changes and represent a computationally efficient and methodologically sound alternative for hypergraph-based connectome analysis.

## Lung Re-expansion During Therapeutic Thoracentesis: Comparing the Benefits of Cough on Request, CPAP and pause in fluid evacuation

*Anna Stecka, Tomasz Gólczewski, Elżbieta M. Grabczak, Marcin Michnikowski, Katarzyna Faber, Krzysztof Zielinski, Monika Zielińska-Krawczyk, Maria Król and Rafał Krenke*

Background: The incidence of pleural effusion (PE), particularly secondary to malignancy and heart failure, is expected to increase due to population ageing. During therapeutic thoracentesis (TT), an excessive pleural pressure (Ppl) fall caused by the lack of lung re-expansion may lead to complications such as pulmonary edema and pneumothorax. Objectives: The aim of this preliminary analysis of an ongoing prospective study was to investigate effects of cough, CPAP, and a pause in PE withdrawal on re-expansion in patients undergoing TT. Methods: Before TT, patients were randomly assigned to one of three groups: cough on request, CPAP (5 cmH□O) and no intervention. PE was drained in portions of 200 mL, each followed by the 60-second period of Ppl measurement. After drainage of each 600 mL, longer 240-second periods with coughing, CPAP or nothing were introduced. Ppl increase (dPpl) during the measurement periods was treated as an index of re-expansion. Results: Strong Pearson's correlation ($r=-0.9$) between dPpl and the Ppl value at the periods' beginning suggested the following differential equation: $dPpl/dt=-alpha*(Ppl-Ppl0)$, where alpha indicates the re-expansion rate and Ppl0 is some steady-state Ppl value. This equation explained the observed exponential Ppl increase. Neither coughing nor CPAP accelerated re-expansion significantly. However, these findings must be validated in the full study cohort once enrolment is complete. Conclusion: Re-opening needs time and thus slower PE drainage seems to be the simplest method to prevent excessive Ppl fall. This study was supported by the National Science Center, Poland (grant N 2019/35/B/NZ5/02531) and IBBE PAS.

## Dynamic Analysis of Normal and Abnormal Phono Cardiogram Signals for Detecting Heart Condition with Auto Segmentation and Alignment

*Ahmed Ali, Janarthanan Krishnamoorthy and Negasu Erko*

Background: The evaluation of heart sounds produced by the beating heart and the resulting blood flow through it provides a useful method for diagnosing cardiovascular disease (CVD). A phonocardiogram (PCG) signal captures a range of heart sounds, including normal and pathological ones like S3, S4, and murmurs, gathered through stethoscope-assisted cardiac auscultation. Countering subjectivity and the high rate of diagnostic errors, computer-aided detection (CAD) systems play a crucial role in identifying abnormal heart sound conditions with significant importance. In the case of analysis with a computer application statistical model or dynamic model-based could be used. Method: The primary objective of this study is to provide heart condition differentiation using dynamic model simulation based on three coupled ordinary differential equations (ODE). The correct positioning and algorithmic alignment of each heart cycle have been implemented on experimental data, significantly influencing the model's efficacy. In this method, 895 cardiac cycles were segmented, comprising 149 normal beats with only S1 and S2 and 746 abnormal beats with either S3 or S4. The model was fine-tuned by fitting it with the Genetic algorithm using input derived from actual signals, enabling the identification of normal and abnormal sounds associated with S3 and S4. Result: In the heart condition diagnosis using dynamic models, the time-domain correlations between the simulated models and experimentally observed data consistently exceed 0.9 across all examined cases, indicating strong agreement. Conclusion: The study introduces a strong methodology utilizing dynamic modeling to fit experimental data with the Genetic algorithm by extracting key parameters from real signals to perceive the physiological aspects of heart conditions quantitatively.

## Dominant Versus Non-Dominant Lower-Limb Force-Time Behavior During the Countermovement Jump in Elite Judo Athletes: Discrete and Continuous Analyses

*Felipe Guimarães Teixeira, Bruno Jotta, Aleksandro Ferreira Gonçalves, Esteban Aedo-Muñoz, Bianca Miarka, André Luiz Fonseca da Silveira E Silva and Pablo Merino-Muñoz*

Judo-specific training may promote inter-limb asymmetries, however, evidence comparing dominant (DOM) and non-dominant (NDOM) lower-limb force-time behavior during the countermovement jump (CMJ) in elite judokas remains limited. This study compared DOM and NDOM limbs using both discrete force-time variables and continuous waveform analysis. Thirty-seven elite Brazilian judo athletes performed bilateral CMJs on dual force plates. Peak force, phase-specific impulse, and mean force were calculated for the yielding, braking, and concentric phases. Force-time waveforms were also analyzed using Statistical Parametric Mapping (SPM). Cross-correlation and coefficient of variation (CV) were used as complementary waveform analyses, and an exploratory asymmetry classification was performed using the asymmetry index (AI). No significant differences were found between DOM and NDOM limbs for any discrete variable ($p > 0.05$), with trivial-to-small effect sizes. Likewise, SPM revealed no significant clusters across the movement cycle. Cross-correlation showed very high waveform similarity between limbs ($r = 0.970 \pm 0.032$). Most athletes were classified as symmetrical, although a greater proportion of asymmetrical athletes was identified for yielding impulse and yielding mean force. These findings indicate a high degree of lower-limb symmetry at the group level in elite judo athletes, while suggesting that the yielding phase may be more sensitive to individual asymmetry patterns.

## SS Frontiers in Neuroimaging

Session 21C
Wednesday September 16, 14:30-16:00

### Proof of Concept: Multilevel Linguistic Assessment and fMRI-Based Analysis of Brain Regions Involved in Language Learning in University-Level Students

*Lilian Gomez*

Abstract. This pilot proof-of-concept study evaluates a multilevel linguistic assessment paradigm combined with task-based functional magnetic resonance imaging (fMRI) to characterize brain activation patterns associated with second-language processing in university students. Participants were assigned to beginner (n = 5), intermediate (n = 5), and advanced (n = 4) proficiency groups based on standardized linguistic assessments administered by foreign language faculty. The experimental design employed a block-design task-based fMRI paradigm with language-processing stimuli presented in the native language (L1) and the second language (L2). Neuroimaging data were analyzed using the General Linear Model (GLM). As an exploratory pilot study, activation maps were examined at a voxel-wise threshold of $p < 0.001$ (uncorrected), with cluster sizes ranging from 13 to 695 voxels. Results revealed distinct activation patterns across proficiency levels. Beginner participants exhibited widespread bilateral activation involving frontal and occipital regions, reflecting increased cognitive demand. Intermediate participants showed transitional patterns with reduced spatial dispersion and greater engagement of language-related regions. Advanced participants demonstrated focal, left-lateralized activation in classical language areas, including the inferior frontal gyrus and temporal cortex. These findings suggest a shift from distributed to specialized neural recruitment as language proficiency increases.

### Timing Matters: Prenatal Heavy Metal Exposure and Childhood Brain Development

*Rafael Lara-Estrada, Ernesto Roldán-Valadez Roldán-Valadez, Megan K. Horton and Camilo Rios*

Early-life exposure to lead remains a public health problem because the developing brain has limited biological margin for error. Even concentrations that do not produce overt poisoning may interfere with synaptic maturation, vascular regulation, and the integrity of the blood-brain barrier. This conference paper integrates a neurovascular interpretation with structural magnetic resonance imaging findings in Mexican preadolescents with prenatal and early childhood lead measurements. Blood lead was characterized across seven developmental windows, from the second and third trimesters of pregnancy to birth and early childhood. Three-dimensional T1-weighted structural magnetic resonance imaging was used to quantify regional brain volumes, with atlas-based morphometric processing and region-wise analysis adjusted for total brain volume. Median lead concentrations were highest around birth and gradually declined during childhood. Nominal associations were observed in frontal, temporal, parietal, occipital, ventricular, and subcortical regions, including the hippocampus, inferior temporal gyrus, frontal pole, posterior orbital gyrus, precuneus, posterior cingulate gyrus, calcarine cortex, ventral diencephalon, and basal forebrain. The third trimester showed the largest number of associated regions, suggesting that late gestation may be a particularly sensitive window for brain morphometry. Taken together, these findings support the idea that lead-related structural changes should be interpreted not only as isolated regional volume differences, but also as possible signatures of disrupted neurovascular development.

### Reproducibility vs. Representativeness: The Trade-off in MRI AI Algorithm Development

*Fabiola Martinez-Licona*

The growing trend in the design of artificial intelligence models used for Magnetic Resonance Imaging (MRI) has been the emphasis on validation schemes that ensure reproducibility via controlled experiments, without regard for the representativeness of datasets – the degree to which datasets can cover variations in real-world patient populations, imaging modalities and environments. This paper presents a perspective-based analytical synthesis of this issue from a biomedical engineering point of view, examining the ways in which choices made in various phases of AI model creation can lead to or reduce the generalization problem. A classification scheme with four types of domain shift that occurs during MRI imaging is introduced, based on previous classifications but taking labeling and temporal shifts into consideration separately. The trade-off model highlights the inherent incentive discrepancy that results in the systematic underinvestment in representativeness within the field, whereby optimizing reproducibility offers easily observable feedback during development whereas poor representativeness poses delayed costs realized only when the technology is implemented clinically. Empirical studies have documented substantial performance degradation on external datasets – with reductions as large as 0.21 AUC points observed in specific MRI contexts (e.g., prostate imaging) – illustrating the practical consequences of this trade-off. Pipeline-based harmonization and validation techniques, as well as stratified performance reporting, are some proposed solutions to the issue, along with implications in foundation models and regulatory guidelines by the FDA and EU AI Act.

### Magne&c; resonance quan&fiable; metabolites in spinal cord injury recovery

*Axayacatl Morales-Guadarrama, Melissa Puebla-García, Thania Ortega-Cruz, Diana María Osorio Londoño, Laura Alvarez Mejía, Yessica Heras-Romero, Juan Morales Corona and Roberto Olayo González*

TraumaKc spinal cord injury (SCI) leads to severe neurological disability with vast medical and socioeconomic repercussions, affecKng an esKmated 2.5 million people worldwide. Despite various experimental approaches, most current therapeuKc strategies fail to significantly restore lost motor or sensory funcKons. This study invesKgates the neuroprotecKve and regeneraKve potenKal of plasma- synthesized polymers containing amines (pP-NH), which have previously demonstrated the ability to recover voluntary movement in posterior joints in rat models. We conducted a longitudinal evaluaKon using 3.0 Tesla magneKc resonance imaging (MRI) in adult Wistar rats subjected to a complete spinal cord transecKon at the T9 level and subsequent pP-NH implantaKon. Advanced protocols, including Diffusion Tensor

Imaging (DTI) and 1H MagneKc Resonance Spectroscopy (MRS), were uKlized eight weeks post-injury to quanKfy pathophysiological metabolites and microstructural integrity. Findings revealed FracKonal Anisotropy (FA) values ranging from 0.3 to 0.7, indicaKng highly organized fibre orientaKon and potenKal axonal reconnecKon at the lesion site. Furthermore, metabolic analysis idenKfied an NAA/Cr raKo of 0.917 and a Cho/NAA raKo of 0.907, reflecKng a specific profile of neuronal integrity and acKve cellular remodelling or reacKve gliosis. These results confirm the feasibility of in vivo metabolic monitoring and suggest that pP-NH implants posiKvely modulate the injured microenvironment to promote funcKonal recovery.

## MedTechLabel: A Universal Digital Labelling Framework for MDs and IVDs

Session 21D
Wednesday September 16, 14:30-15:00

### MedTechLabel: A Universal Digital Labelling Framework for Medical Devices and In Vitro Diagnostics

*Aris Dermitzakis, Carola Schulz, Lene Lunde, Nicolas Pallikarakis and Anne Moen*

Manufacturers of medical devices (MDs) and in vitro diagnostic devices (IVDs) must comply with increasingly complex and evolving requirements regarding the labeling information to be included with MD/IVD. At the same time, devices are becoming smaller, more sophisticated, and increasingly connected, adding challenges for users to access, understand, and correctly interpret essential labelling information. MedTechLabel is a three-year (2026–2029) Innovative Health Initiative (IHI) project set out to develop a universal, digital labelling framework specification for all categories and classes of MDs and IVDs. To reshape labelling practices, improve user experience, reduce administrative burden, and enhance operational efficiency and regulatory compliance for industry, MedTechLabel addresses two key challenges: (1) scalability and efficiency through greater digitalisation of labelling information; and (2) more accessible information for diverse users, with curated displays that support different roles and needs. To achieve this, the digital labelling framework specification seeks consensus among all involved stakeholders: manufacturers, notified bodies (NB), regulators, health authorities, healthcare professionals, patients, and others. This poster presents how MedTechLabel aims to fulfil this mission and invites input from MEDICON participants on how best to address their needs in the MD/IVD ecosystem.

## SS EAMBES: AI in MDs – Bridging BME Innovation and Clinical Practice in Europe

Session 21E
Wednesday September 16, 14:30-16:00

### WHO-Guided Lifecycle Management for Safe and AI-Ready Medical Devices

*Lejla Gurbeta Pokvić*

The safe and effective use of medical devices depends on reliable information covering their entire lifecycle, from procurement and installation to maintenance, performance monitoring and replacement. This contribution presents the principles of the World Health Organization publication Inventory and Maintenance Management Information System for Medical Devices and explores their relevance to increasingly digital and AI-enabled healthcare environments. Accurate inventories, structured maintenance records and risk-based management provide an essential foundation for patient safety, institutional accountability and evidence-informed decision-making. They also support the quality and traceability of data required for evaluating intelligent medical technologies. The presentation will demonstrate how traditional clinical engineering practices can evolve into integrated information systems that strengthen technology governance, facilitate proactive maintenance and improve organizational readiness for the responsible adoption of AI-enabled medical devices.

### Scaling HealthTech Innovation: From Biomedical Research and Early-Stage Startups to Market-Ready Solutions

*Marko Mimica*

HealthTech startups play an important role in translating scientific knowledge and technological prototypes into solutions that can address practical healthcare needs. Nevertheless, many promising innovations fail to progress beyond the early development stage due to limited clinical validation, insufficient market understanding, regulatory complexity and weak connections with healthcare providers and investors. This contribution examines the support mechanisms required to move biomedical and digital health innovations from research to market readiness. Drawing on experience in startup acceleration, venture building and regional HealthTech ecosystem development, the presentation will discuss the importance of early clinical engagement, business-model validation, multidisciplinary teams, access to funding and collaboration with innovation hubs. Particular attention will be given to the challenges faced by startups developing AI-enabled medical technologies and to the role of regional and European networks in enabling testing, investment, market access and international scaling.

### Explainable by Design: From Trustworthiness to Perceived Explainability in Medical Devices

*Simone Borsci*

Trustworthiness and reliability are difficult to embed in a concrete, verifiable manner in AI-driven systems—and even harder to demonstrate or assess. This is a particular challenge in the medical domain, where AI-based systems are increasingly present on the market. Many of these systems are de facto agentic: they can plan, decide, and act across multi-step sequences with a degree of autonomy that classic interactive systems never possessed. Yet these agents often fail to help clinicians grasp the reasoning behind proposed actions, and rarely allow clinicians and health operators to ask for clarification dynamically during interaction. This raises a fundamental question: if AI-driven devices merely deliver algorithmic outputs, what added value does AI actually provide? The real potential lies in systems that go beyond algorithmic decisions and become tools for exploring alternative decision-making pathways together with clinical operators. This requires systems whose reasoning operators can genuinely understand and interrogate. The EU AI Act is clear that transparency and explainability are essential to trustworthiness and to protecting fundamental rights. Nevertheless, explainability is too often conceptualised as a desirable add-on rather than a design requirement. In this talk, I argue for a shift from post-hoc explainability to explainability by design, and from technical transparency to perceived explainability—explanations that are meaningful, actionable, and calibrated to the clinical context and the operator's needs. This reframes explainability from a purely technical property into a measurable, user-centred one. We define perceived explainability as the degree to which an AI-driven interface makes perceivable, at any moment of an agent's action sequence: (a) the reasoning behind the agent's behaviour, (b) the means to request further clarification, and (c) the means to act on disagreement. In this session, we will discuss our proposed approach to assessing perceived explainability as a measurable proxy for the usability—and ultimately the trustworthiness—of AI-driven medical systems.

### From Promising Algorithms to Trustworthy AI-Enabled Medical Devices: Evidence, Integration and European Pathways

*Giuseppe Fico*

Artificial intelligence is increasingly embedded in medical devices used for diagnosis, clinical decision support, patient monitoring and personalized care. However, strong algorithmic performance does not automatically translate into clinical value or sustainable implementation. This contribution examines the pathway from AI research and prototype development to trustworthy medical technologies integrated into real-world healthcare environments. Particular attention is given to data quality, interoperability, clinical validation, transparency, multidisciplinary evidence generation and alignment with European regulatory requirements. The presentation will also discuss the importance of involving biomedical engineers, clinicians, patients, healthcare institutions and industry throughout the technology lifecycle. By connecting technical innovation with clinical evidence and system-level implementation, the contribution identifies key conditions for accelerating the responsible adoption of AI-enabled medical devices across Europe.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 22A
Wednesday September 16, 16:30-18:00

### Eye-tracking-based personalized text-presentation support for children with reading difficulties

*Ivan Vajs, Vladislava Krsmanović, Vanja Ković, Gordana Čolić, Anđela Šoškić, Katarina Stekić-Stojanović and Milica M. Jankovic*

Reading difficulties in children are increasingly prevalent and one of the digital technologies that is commonly used in reading assessment studies is eye-tracking. In this paper, eye-tracking metrics were used to introduce a rule-based system intended for personalized ranking of text presentation strategies for children. The system was evaluated on 23 Serbian-speaking third-grade children, selected based on the assessment of reading and related language skills. Initially, each child specified the preferred text presentation through an interactive application, including font type and size, spacing, and color combinations. An eye-tracking experiment was then conducted in which participants read two stories across separate sessions, with text segments presented using different modification strategies: basic text formatting, average preferred settings, individual preferences, and modifications based on experience from practice. The modifications were evaluated using eight eye-tracking metrics related to eye fixations, including span, duration, dispersion, and gaze self-intersection. Each feature produced a text modification ranking with higher feature values corresponding to more reading struggles. For each child, the ranks were then averaged across all features and both stories to obtain a personalized ranking. Results show variability in individual preferences, with no universally optimal configuration. However, standard text formatting consistently ranked lowest, highlighting the possible benefit of adaptive presentation. The proposed results support further development of personalized reading assistance for children, providing a non-invasive framework for assessing a broad spectrum of personalization approaches.

### From Neuroanatomical Atlas to Finite Element Mesh: A Modular Pipeline for Rat Brain Implant Digital Twins

*Teodor Vakarelsky, Teodor Minev and Dimiter Prodanov*

Anatomically-realistic digital twins of neural implants are useful in the scope of neurotechnology research and development. We present an open-source, modular pipeline that bridges neuroanatomical atlases and physics-based simulation, enabling finite element (FE) analysis of brain-implant mechanics without requiring commercial software or manual geometry preparation. Starting from the Waxholm Space rat brain atlas, the pipeline automatically produces a watertight (i.e., free of boundary gaps), simulation-ready tetrahedral mesh compatible with the FEniCS FE solver, alongside a fully parametric implant geometry (electrode shaft, cement layer, anchoring cross) ready for Boolean assembly. The modular architecture supports straightforward substitution of subject-specific segmentations or alternative implant designs via a single configuration file. The assembled multi-domain mesh is intended for viscoelastic simulations of tissue deformation under physiological cyclic loads, such as those induced by breathing and locomotion, providing a practical basis for computational studies of neural implant mechanics and device design. All code is publicly available in GitHub.

### Alignment in Gamified Cognitive Assessment

*Ankica Babic*

Game features can improve engagement in cognitive assessment, but they may also change response strategies and threaten score interpretability. This paper combines general design and validation considerations for gamified cognitive assessment with an initial formative evaluation of a three-part prototype based on Mini-Cog, Trail Making Test, and

Stroop principles. The paper argues that such systems should be interpreted in relation to intended use, construct definition, task equivalence, reliability, usability, subgroup fairness, and documentation. Simple progress indicators and neutral feedback are treated as lower-risk engagement supports, whereas recognition prompts, scoring incentives, time pressure, and device-specific input demands are treated as modifications requiring targeted validation. The implemented prototype was evaluated in an initial formative usability study with ten participants. The System Usability Scale was administered separately for the Mini-Cog-derived, Trail Making Test-derived, and Stroop-derived modules, producing mean SUS scores of 95.0, 95.0, and 89.3, respectively. Qualitative feedback indicated that the game-like design was perceived as clear, enjoyable, and motivating, while also identifying task-specific refinements related to instruction clarity, error recovery, feedback, visual accessibility, and colour perception. The findings support the usability and engagement potential of the prototype, but they should be interpreted as formative evidence rather than evidence of diagnostic validity or clinical effectiveness. Future work should refine and version-lock the prototype, compare it with conventional or low-gamification reference measures, and evaluate it with intended clinical or screening-support populations

## Continuous Ordinal Representation of Neural Irritation in IONM via Geometric Modeling

*Pubordee Aussavavirojekul, Robert J. Sclabassi, Alexander Yu, Leila Wehbe and Cameron Riviere*

Intraoperative neurophysiological monitoring (IONM) signals are used to assess neural irritation during surgery, yet their underlying structure remains difficult to characterize due to substantial variability and class overlap. This study investigates the latent structure of EMG-based IONM signals and proposes a geometry-aware framework that enables both discrete classification and continuous ordinal estimation of irritation severity in an interpretable and clinically transparent manner. To capture transitional dynamics, signals are segmented using sliding windows with labels assigned by the terminal timestamp (late-anchor labeling), inducing boundary-aware label blending. High-dimensional features are then projected into a two-dimensional latent space using Linear Discriminant Analysis (LDA), preserving class separability while organizing samples along a continuous ordinal manifold. A smooth manifold is fitted through class centroids, and samples are projected onto it to obtain a continuous severity coordinate, enabling unified discrete and continuous inference. Analysis reveals substantial overlap between the baseline and weak irritation classes, suggesting these labels reflect a shared low-severity physiological regime rather than distinct states. Classification using classconditional Gaussian modeling with maximum likelihood estimation achieves consistent performance, with errors predominantly occurring between adjacent severity levels, supporting the consistency of the learned ordinal structure.

## Differentiating Cognitive Workload Requests by Combined Behavioural Performance and HRV Metrics

*Ludovica Di Pompeo, Michele Tritto, Daniela Cardone, David Perpetuini and Arcangelo Merla*

In safety-critical environments, human performance depends on the interplay be-tween cognitive demands and physiological regulation. Heart rate variability (HRV) is widely used to assess autonomic activity, yet its relationship with perfor-mance remains inconsistent, partly due to linear models that neglect underlying physiological states. This study proposes a distribution-based framework that dis-cretizes autonomic activation into subject-specific regimes and assesses HRV-performance relationships within each regime. Fifty-six participants performed a dual-task paradigm (Tracking and System Mon-itoring) on the AeroStim platform at four ranges of workload levels. ECG signals were continuously recorded; HRV metrics (SDNN, RMSSD, LF/HF) were extracted and normalized within subjects. SDNN defined three activation ranges (low, inter-mediate, and high), and nonparametric analyses assessed performance and HRV-performance associations within each regime. Performance decreased with increasing task difficulty. Critically, HRV-performance relationships varied across ranges: SDNN was primarily associated with performance in low and high activation, RMSSD predicted performance in in-termediate activation, and LF/HF showed complementary associations in low acti-vation. Intermediate activation was linked to higher accuracy and fewer omissions than low activation, supporting a non-linear arousal–performance relationship. These findings demonstrate that HRV-performance associations are regime-dependent, supporting adaptive closed-loop systems to maintain optimal op-erator performance in real time.

## M/EEG Task Classification by Means of Brain Dynamic Analysis

*Francesca Bifulco, Stefano Franceschini, Roberta Diana, Giuseppe Cesarelli, Michele Ambrosanio and Fabio Baselice*

This study focuses on a feature extraction algorithm based on the analysis of dynamic spectral components of magnetoencephalography (MEG) and electroencephalography (EEG) data. During its activity, the brain produces electromagnetic fields that can be sensed outside the head by means of appropriate sensors (e.g., SQUIDs in the case of Magnetoencephalography and electrodes in the case of Electroencephalography). These recordings are commonly acquired and processed to obtain estimates of brain activity with high spatial and temporal resolution. When an individual performs a task, brain activity exhibits task-dependent variations in the measured signals. Consequently, in recent years, the scientific community has increasingly focused on the study of brain signals to detect and classify features associated with specific tasks. Within this framework, we propose a novel paradigm whose core consists of a synthetic feature extraction approach based on the time-varying contribution of brain spectral components. These features are subsequently used as inputs to a machine learning classifier for task discrimination. The proposed strategy is designed to provide a novel and lightweight solution for human--machine interaction pipelines.

## Clinical Engineering, Medical Devices, and Robotics / Medical Imaging, Simulation, and Immersive Technologies / Biomaterials, Regenerative Medicine, Therapeutics, and Chronic Disease Management / Ethics, Regulation, Assessment, and Sustainability of Healthcare Technologies

Session 22B
Wednesday September 16, 16:30-18:00

### Analysis of Glare Level: Design and Realization of Glaremeter Device

*Jan Havlik, Lucie Hosová and Lenka Maierová*

Visual comfort in indoor spaces, particularly those intended for study and work, represents an important aspect in the design of lighting and shading systems and their potential automation. Glare occurs as an undesirable effect of illumination, especially daylight. To mitigate this phenomenon in the design of both new and existing projects, it is essential to have reliable equipment for glare measurement. This paper aims to analyze methods for glare assessment and to develop a costeffective measuring device. Glare is evaluated primarily using the robust probabilistic metric Daylight Glare Probability (DGP), for which extensive support exists within the RADIANCE software package, particularly through the evalglare function. The device is based on a Raspberry Pi microcontroller and a wide-angle Waveshare camera with an OV5647 sensor. The outcome of this work is a functional prototype for measuring daylight glare in indoor environments. Its functionality was experimentally verified under real indoor conditions in both residential and university environments, and potential limitations of the implementation were identified along with proposals for further development of the project.

### Architecting a Future-Ready Clinical Engineering Workforce

*Arif Subhan and Frank Painter*

As healthcare environments transition toward hyper-connected digital ecosystems, the role of the Clinical Engineering (CE) professional is undergoing a radical shift. No longer confined to traditional preventative maintenance, today's CE workforce must navigate the intersection of medical device interoperability, cybersecurity, and data-driven life cycle management. This presentation addresses the critical need for a modernized educational framework within Clinical Engineering departments. We will explore a dual-stream approach to workforce development:Technical Upskilling: Integrating IT fundamentals, network security protocols, and AI-driven diagnostics into standard CE training. Strategic Competencies: Developing "soft" skills such as cross-departmental communication, vendor negotiation, and clinical workflow integration.Participants will gain insights into establishing internal mentorship programs, leveraging manufacturer-agnostic training resources, and creating "career ladders" that incentivize continuous learning. By moving from a reactive "fix-it" mindset to a proactive technology management strategy, CE departments can reduce device downtime, enhance patient safety, and secure their seat at the hospital's strategic leadership table.

### Cost-Effectiveness and Budget Impact Analysis of Introducing Rotavirus Vaccination for Infants in Bosnia and Herzegovina

*Amila Karalić, Adna Ašić, Lejla Gurbeta Pokvić, Merima Smajlhodžić-Deljo and Almir Badnjević*

This study evaluates the economic justification for introducing rotavirus vaccination into the national immunization program in Bosnia and Herzegovina (B&H;). A pharmacoeconomic framework was applied, including Cost-Utility Analysis (CUA), Cost-Benefit Analysis (CBA), and Budget Impact Analysis (BIA), to compare a universal vaccination strategy with the current no-vaccination approach. The findings demonstrate that vaccination represents a dominant strategy, simultaneously improving health outcomes measured in Quality-Adjusted Life Years (QALYs) and reducing overall healthcare expenditures. The calculated Benefit-Cost Ratio (BCR) of 3.14 indicates substantial economic return relative to investment, supporting the integration of rotavirus immunization into the publicly funded healthcare system.

### Pharmacoeconomic analysis of the use of SGLT2 inhibitors in the treatment of type 2 diabetes in Bosnia and Herzegovina

*Adna Jabandžić, Adna Ašić, Lejla Gurbeta Pokvić and Almir Badnjević*

Sodium-glucose cotransporter 2 inhibitors (SGLT2i) are the most recently approved class of drugs (since 2012) for type 2 diabetes mellitus (T2DM), but their economic merits have yet to be fully confirmed. Using Agency for Identification Documents, Registers and Data Exchange of Bosnia and Herzegovina (IDDEEA) data, demographic and population data from the registry, and the available budget in Bosnia and Herzegovina, we analyzed whether to switch from sulfonylurea (SU) derivatives to sodium-glucose cotransporters-2 (SGLT2) inhibitors is economically justified. We constructed a decision-tree model spanning a 15-year period, using a 3% discount rate, to compare SGLT2 inhibitors to sulfonylureas (SU). Analyses included Cost-effectiveness, Cost-utility, Cost-minimization, Cost-benefit and Budget impact analysis and were informed by clinical probabilities, utility weights, and the costs of treatment and hospitalization. The results showed that SGLT2 therapy, while offering a marginal improvement in Quality-adjusted life years (0.0402 QALYs), came at a significantly higher lifetime cost (27,725 BAM vs. 6,000 BAM for SU). The calculated Incremental cost-effectiveness ratio (ICER) of approximately 540,000 BAM per QALY is well above the willingness-to-pay threshold in Bosnia and Herzegovina of 30,000 BAM/QALY. The analysis predicted a significant annual increase in spending, ranging from 72.3 million BAM to 216.8 million BAM, depending on the percentage of patients who would switch therapy. For the general patient population, the switch from SU to SGLT2 is not economically justified. However, due to the benefits of SGLT2 therapy, the switch is certainly justified in high-risk subgroups.

## SS IFMBE Students and Recent Graduates

Session 22C
Wednesday September 16, 16:30-18:00

### Biomedical Engineering in the Age of AI: Reflections on the Transformation of Key Competencies and Educational Challenges

*Karina Zamrazilová*

The rapid advancement of artificial intelligence (AI), particularly the widespread adoption of generative models such as ChatGPT, is reshaping the field of biomedical engineering. This transformation extends beyond technological innovation and is redefining professional roles, required competencies, and educational practices. This paper examines the transition from a predominantly technical profile of biomedical engineers toward a socio-technical role. Drawing on recent literature and industry perspectives, it argues that traditional technical expertise alone is no longer sufficient and must be complemented by communication skills, critical thinking, and interdisciplinary collaboration. Particular attention is given to emerging educational challenges associated with AI integration, including the development of data literacy, ethical awareness, and responsible AI use. The paper highlights the non-neutral nature of data, emphasizing structural biases—such as gender bias in clinical datasets—that may lead to unequal healthcare outcomes and raise critical questions of accountability in AI-driven decision-making. These challenges are further compounded by the risk of deskilling resulting from overreliance on AI systems. The paper aligns with recent studies emphasizing the need for pedagogical strategies that prepare students for responsible AI use, including academic integrity and transparency.

### Curriculum priorities for translational biomedical engineering: A researcher's perspective.

*Anna Stecka, Tomasz Gólczewski, Marcin Michnikowski and Krzysztof Zielinski*

Bridging the gap between engineering education and real-world clinical research remains a persistent challenge in biomedical engineering. Here, we examine the practical competencies that academic curricula should cultivate to prepare graduates for translational research, drawing on direct experience across several methodological domains. A central difficulty for early-career engineers is the complexity of clinical data, which are frequently affected by missing values, artifacts, limited sample sizes and population heterogeneity. Effective training should therefore encompass not only analytical methods for handling such data, but also preventive strategies embedded in rigorous study design. Required competencies span robust statistical inference, data processing, programming, visualization, and the critical use of machine learning and deep learning, whose clinical application is constrained by issues of overfitting, interpretability and ethics. Open-source computational environments such as Python and R further support reproducible analytical workflows. Beyond data analysis, physiological numerical modeling enables virtual experimentation and hypothesis generation when direct in vivo measurement is ethically or technically infeasible. For physical device evaluation, hybrid numerical-physical simulators provide a reproducible and ethically preferable alternative to early-stage animal or human testing. Together, these domains define a curriculum oriented not toward narrow specialization, but toward the formation of biomedical engineers capable of integrating methods, disciplines and clinical perspectives in translational research.

### Analysis of Wearable Sensor Placement Impact on Human Activity Time Series Data

*Krunoslav Jurčić, Ratko Magjarevic, Giuseppe Fico and Laura Lopez-Perez*

This paper presents an interpretability-focused study on the effect of sensor placement on human activity recognition (HAR) using wrist-worn and hip-worn wearable sensors. By performing classification of various activities of daily living (walking, running and sitting) and simulated falling activity on a dataset containing accelerometer, gyroscope and barometric altimeter data, this study focuses on the comparison only wrist-worn part of the dataset versus the hip-worn part in order to establish whether there are any statistically significant differences in model performance. The approach consists of using Random Forest classifier for classification, and Leave-One-Subject-Out cross-validation. Model behaviour was further analysed using SHapley Additive exPlanations (SHAP) for global and local feature attribution and t-distributed Stochastic Neighbor Embedding (t-SNE) for feature space analysis. Wilcoxon signed-rank test found no statistically significant difference between placements, a result attributed to low statistical power given the small number of activity classes rather than an absence of a meaningful effect. Hip-worn data proved to be more suitable for the performance of all three models, with significant macro F1 gaps for accelerometer and gyroscope models respectively. Barometric altitude exhibited the lowest drop-off in model performance and the lowest t-SNE centroid distances generally, proving its robustness regarding sensor placement.

### Beyond Borders: Impact of Erasmus Mundus on Biomedical Engineering

*Syuzanna Matevosyan*

Biomedical engineering education varies significantly across countries and institutions. Each system believes it is preparing graduates for real-world demands. However, the rapid transformation of technologies creates new challenges in biomedical engineering. The constantly changing landscape requires graduates who can quickly adapt to new tools, learn unfamiliar systems, and yet remain careful, as every decision lands on a human being. Adaptability is not a soft skill. It is a technical necessity. This paper draws on my personal journey as an Erasmus Mundus scholar within the EMMBIOME program — a two-year master's conducted across the University of Patras (Greece), the University of Kragujevac (Serbia), and the University of Medicine and Pharmacy "Grigore T. Popa" (Romania). The aim is to identify how international, interdisciplinary education addresses competency gaps and prepares graduates for the rapidly transforming biomedical engineering landscape. I will reflect on how learning and working across borders reshaped my understanding of biomedical engineering — not only as a discipline, but as a responsibility. Rather than presenting a single best model, this paper will explore how combining different educational environments can better prepare future biomedical engineers. Beyond formal coursework, it will present the importance of student-led initiatives in biomedical engineering, and the crucial lessons that emerge when building them in unfamiliar countries, cultures, and systems. This paper offers concrete recommendations for curriculum development, drawn from experience inside the system — arguing that the goal of education is not only technical preparation, but building in graduates the steadiness, care, and capacity to keep learning that a constantly changing field demands.

### The Evolution of Biomedical Engineers into AI Augmented Professionals for the Future Workforce

*Shi-Yi Wu*

The rapid advancement of artificial intelligence (AI) is transforming the role of biomedical engineers, requiring a shift from traditional technical expertise toward interdisciplinary, AI-augmented capabilities. Positioned at the intersection of human physiology and advanced technology, biomedical engineers must address persistent challenges, including workforce skill gaps, increasing regulatory demands such as compliance with ISO 13485 and HIPAA, as well as technical limitations related to data bias, limited datasets, and lack of model interpretability. Beyond algorithm development, modern biomedical engineers are expected to integrate sensing technologies, signal processing, and AI-driven decision support into deployable healthcare systems while addressing constraints such as biocompatibility, power consumption, and device miniaturization. In this context, core competencies extend to analytical thinking, interdisciplinary collaboration, creativity, and ethical responsibility to ensure patient-centered innovation. Ultimately, the future workforce will be defined by professionals who can bridge biological complexity and technological advancement through continuous learning and system-level integration, enabling reliable, explainable, and clinically meaningful AI applications in healthcare.

### Robotic and SSEP-Based System for Objective Plantar Sensitivity Assessment: Design Rationale and Implementation Roadmap toward a Neurophysiological Biomarker for Diabetic Foot Risk Prevention

*César Augusto Moreno Baracaldo and Martha L. Zequera*

Early detection of Diabetic Peripheral Neuropathy (DPN) is hindered by the subjectivity of psychophysical screening tests such as the 10 gram-force Semmes-Weinstein monofilament (SWM-10g), whose accuracy depends on the patient's perceptual judgment and motor response. Building upon a previously validated robotic platform that standardized SWM-10g application across plantar regions in healthy volunteers, we propose a design framework for an objective sensory assessment system that replaces the behavioral response with a neurophysiological marker. The proposed architecture integrates the existing robotic stage with synchronized electroencephalography (EEG) and deferred Artificial Intelligence (AI) analysis to correlate controlled mechanical stimuli with Somatosensory Evoked Potentials (SSEPs). Dedicated hardware (32-bit microcontroller and isolated front-end) supports sub-millisecond synchronization between plantar pressure and cortical activity. A hybrid CNN-RNN pipeline is outlined to identify the cortical P40 component and a data-driven "neural inflection point" that operationally defines an Objective Perception Threshold (OPT). The framework is presented as a hypothesis-generating roadmap; clinical validation against Nerve Conduction Studies in diabetic cohorts is outlined as future work toward a neurophysiological biomarker for diabetic foot risk prevention.

## SS AI and Shared Decision-Making in Breast Cancer

Session 22D
Wednesday September 16, 16:30-18:00

### Clinical Validation of AI-Supported Shared Decision-Making in Breast Cancer"

*Maria Joao Cardoso*

Shared decision-making in breast cancer locoregional treatment remains challenging due to the need to balance oncological safety with aesthetic outcomes, quality of life, and patient preferences. While artificial intelligence (AI) has shown considerable promise in personalized medicine, most available applications in oncology lack prospective clinical validation and real-world implementation. This presentation will describe the development and clinical validation of the CINDERELLA approach, a Horizon Europe-funded initiative designed to support shared decision-making in women undergoing breast cancer locoregional treatment. The CINDERELLA platform combines AI-based prediction of aesthetic outcomes with patient-centred educational content and digital support tools to facilitate informed treatment decisions. The presentation will summarize the rationale, methodology, and implementation of a large prospective multicentre study evaluating the clinical impact of the intervention, including patient engagement, expectation–outcome matching, patient-reported outcomes, and acceptability across diverse healthcare settings. Particular emphasis will be placed on the challenges of integrating explainable AI into routine clinical workflows, ethical and regulatory considerations, and the role of digital innovation in empowering patients. The CINDERELLA experience offers an example of how AI can move beyond proof-of-concept toward clinically validated and scalable patient-centred cancer care.

### Uncovering True Engagement in AI-based interventions: A Mixture Model for Active vs. Unattended Sessions

*Marilia Antunes, Ana Barata, Giovani Silva, Miguel Broes, Felipe Barletta, Eduard-Alexandru Bonci, Helena Cruz, Timo Schinköthe and Maria-João Cardoso On Behalf Of The Cinderella Consortium*

App usage data can provide valuable insights into the information needs of breast cancer patients. By analysing which topics are accessed most frequently, how much time is spent on different sections, and which content is revisited, it is possible to identify the aspects of the disease, treatment, and surgical options that generate the greatest interest or concern. However, registered usage times frequently do not reflect true engagement. For example, a user who leaves a reconstruction-information page open for 30 minutes while doing something else may appear more interested in that topic than a user who spends 10 minutes actively reading and interacting with the content. Thus, observed usage times may arise from two latent processes: active and inactive periods. Finite mixture models offer a robust framework for addressing classification challenges when the underlying process is not fully observable. We propose a two-component finite mixture model to classify session times into real (active sessions) or inflated (unattended sessions) categories, exploring parametric specifications including log-normal and Gamma distributions. Covariates capturing socio-demographic factors, clinical characteristics, and user–application interactions were incorporated using mixtures of generalized linear models. Model estimation was conducted using EM (Maximum Likelihood framework) and NUTS (Bayesian framework) algorithms. Data analysis results indicate that the proposed models effectively distinguish real and inflated usage times, with covariate inclusion improving model fit and classification flexibility. Frequentist and Bayesian approaches yield comparable results for well-specified models. The study highlights the heterogeneity of user behaviour and the importance of accounting for covariates and latent outliers, offering a robust methodology for analysing digital application usage.

### Value-Based Healthcare and Organizational Adoption of AI in Cancer Care

*Ludovica Borsoi*

Despite growing interest in artificial intelligence (AI) in healthcare, most AI-enabled solutions remain at the early validation stage and do not achieve sustained integration into routine clinical practice. A key barrier is the limited understanding of the organizational and contextual factors that influence successful implementation. The ongoing CINDERELLA project responds to this gap by assessing an innovative AI-based APProach intended to enhance shared decision-making and manage patient expectations in breast cancer locoregional treatment through a multidimensional assessment framework encompassing economic, financial, organizational, and implementation dimensions. The organizational impact of the CINDERELLA APProach and its acceptability among healthcare professionals (HCPs) were assessed through focus groups conducted with HCPs involved in the breast cancer care pathway across five clinical centers participating in the CINDERELLA trial. An initial focus group at each site examined the existing organizational model, while follow-up focus groups at 12 and 24 months explored organizational changes associated with implementation and gathered perceptions regarding the acceptability of the intervention. All discussions were audio-recorded, transcribed verbatim, and analyzed using a hybrid inductive–deductive thematic approach. Overall, the CINDERELLA APProach was perceived as acceptable and potentially valuable for enhancing patient engagement, supporting shared decision-making, and strengthening interprofessional collaboration in breast cancer care. Although it was generally integrated into existing clinical workflows without major disruption, its implementation required varying degrees of organizational adaptation across participating centers, shaped by context-specific conditions. These contextual variations are critical not only for interpreting trial outcomes but also for informing future scale-up and adoption across diverse healthcare settings. The talk will also provide an opportunity to discuss current challenges in the assessment and implementation of AI-based health technologies, and to identify priorities for advancing their adoption into clinical practice, drawing on lessons learnt from the CINDERELLA project.

## Workshop: Designing Future Ready BME Programs

Session 22E
Wednesday September 16, 16:30-18:00

### One Digital Health: from Wheel to Intervention

*Oscar Tamburis*

The interventionwill introduce participants to the core digital foundations behind the OneAquaHealth project. Building on the project’s mission to strengthen urban freshwater ecosystem health and human wellbeing, the session will explore how the deployment of the One Digital Health (ODH) framework - the so-called Steering Wheel - is meant to highlight the "digital balance" lying under the OAH project. This becomes possible via the definition of FAIR□aligned digital tools, within the greater scenario of the ODH Intervention, with the objective of enabling transparent, connected, and actionable insights for researchers, policymakers, and communities working toward resilient aquatic ecosystems.

### WORKSHOP: Defining the Competencies of the Next-Generation Biomedical Engineer

*Davide Piaggio, Pedro Checa Rifa, Alessia Maccaro and Lenka Lhotska*

Responsible innovation in healthcare demands professionals equipped to navigate highly complex technological, regulatory, and environmental landscapes. While advancements like AI-driven diagnostics, digital health ecosystems, and Net Zero targets are redefining medical device lifecycles, traditional Biomedical Engineering (BME) curricula often treat ethics as a compartmentalised compliance checkbox, leaving emerging competencies like sustainability literacy and regulatory strategy on the periphery. This interactive 90-minute workshop shifts the educational paradigm from passive listening to collaborative action, inviting educators, researchers, and practitioners to co-create a modernised BME competency framework. Moving systematically through four structured phases, participants will work in mixed-career groups to execute a hands-on curriculum reform exercise. The session begins with a rapid gap analysis to isolate the primary deficiencies in current engineering education regarding AI ethics, EU Medical Device Regulation (MDR 2017/745) compliance, and frugal engineering. Groups will then utilize a specialized 2D framework to map these challenges across two distinct axes, namely Technical Complexity (Basic to Advanced) and Ethical Responsibility (Awareness to Active Implementation), to pinpoint where critical learning gaps exist. In the final phases, teams will select a high-priority competency from their matrix and build a concrete implementation strategy to integrate it into a standard 3-year Bachelor’s program, defending their blueprint in a series of rapid-fire, 1-minute peer pitches. The workshop concludes with a live digital poll to benchmark the systemic barriers to curriculum reform across the participants' global home institutions. Sponsored by the EAMBES and IFMBE Ethics and Education Committees, this session transitions dialogue into a tangible roadmap, equipping the MEDICON 2026 community with the educational tools necessary to train the next generation of socially accountable and future-ready biomedical engineers.

## MS Medical Equipment Ageing: Implications for Maintenance Strategies, Lifespan Modelling and Replacement Planning

Session 22F
Wednesday September 16, 16:30-18:00

### A study on reliability and service life evaluation in service MRI equipment across multiple centers in China

*Bin Li*

This study aims to evaluate the reliability and quality performance of in-service Magnetic Resonance Imaging (MRI) systems in China and to analyze their fault modes through multi-center data analysis. Fault data from 333 MRI devices across 53 hospitals nationwide were collected and analyzed using indicators such as Mean Time Between Failures (MTBF), annual failure rate, and Failure Modes, Effects, and Criticality Analysis (FMECA). The results show that radiofrequency coils, software defects, and water-cooling systems are common high-incidence fault areas across the industry. In addition, equipment reliability decreases significantly as service years increase. MRI systems that have been in use for more than seven years generally enter an aging phase of degradation, with failure rates increasing year by year. At this stage, enhanced maintenance and servicing are required for MRI equipment.

### Artificial intelligence for sustainable management of medical equipment lifecycle

*Alessio Luschi*

Medical equipment aging places growing pressure on healthcare systems that must balance safety, performance, and constrained budgets. Most hospitals still schedule maintenance and replacement by calendar age, an approach that ignores the real deterioration and variability of device functional life. This talk shows how AI can support a sustainable and data-driven view of the medical equipment lifecycle. Deep learning and natural language processing can turn maintenance records, adverse event databases, and operational logs into reliability indicators that reflect actual condition and usage. These models estimate performance degradation, predict failure risk, and produce age-informed metrics that help clinical engineers prioritise interventions and plan capital replacement. By linking such indicators to lifecycle governance, hospitals can move beyond fixed thresholds toward decisions grounded in evidence. Semantic ontologies and evidence-based maintenance are also addressed in structuring heterogeneous data across device fleets, which improves comparability and supports transparent reasoning. Attention is given to the regulatory context and to the need for explainable outputs that managers can trust. AI can extend the judgement of clinical engineering teams. Used well, it reduces waste, lengthens the safe service of reliable equipment, and frees resources in constrained settings.

### Improving Medical Equipment Maintenance and Replacement through Aging Studies

*Binseng Wang*

Analyses of maintenance and management data collected from ~342,000 pieces of equipment in 30+ years show certain equipment types exhibit clear impact of aging (CIA)—i.e., increasing number of repairs with age, while others don't (no impact of aging – NIA), despite consistent scheduled maintenance for all types. In other words, the demand of corrective maintenance resources increases with age for CIA types but remain mostly constant for NIA types, suggesting maintenance planning need to consider aging behavior. Likewise, equipment replacement needs to be planned by type for CIA types, while replacement for NIA types can be made on a contingency basis. A simple, quantitative model has been created and tested for characterizing medical equipment aging behavior, thus eliminating the need for analyzing large amounts of historical data. This aging model enables better maintenance and replacement planning, as well as providing better life expectancy estimates than those offered by the American Hospital Association and ECRI.

### From Maintenance Data to Replacement Decisions: A Data-Driven Framework for Aging-Aware Medical Equipment Prioritization

*Fabiola M. Martinez-Licona*

Medical equipment replacement decisions in resource-constrained healthcare systems are typically governed by calendar-age thresholds rather than by empirical assessment of functional state and operational risk. This paper proposes a data-driven framework that transforms routinely collected maintenance data into a structured Replacement Prioritization Score (RPS) for aging medical devices. The framework integrates four operational indicators — Maintenance Frequency Rate, Maintenance Cost Index, Repair-to-Replace Cost Ratio, and Device Operational Availability — into a composite Degradation Urgency Index (DUI), which is further weighted by clinical acuity and normalized device age to produce a device-level prioritization score. An illustrative case study applied to five representative device types in a low- and middle-income country (LMIC) hospital context demonstrates how the framework distinguishes operationally degraded devices from well-functioning aging equipment, enabling more accurate capital investment decisions. The framework is designed to be implementable using data routinely available in Computerized Maintenance Management Systems (CMMS) and budget records, without requiring additional instrumentation or specialized data infrastructure.

## Plenary session

Session 24
Thursday September 17, 09:30-11:00

### Static and Motion-Adaptive Temporal Propagation for Vessel Segmentation in Thermal Infrared Videos

*Giulia D'Ambrosio, Giuseppe Gatta, David Perpetuini, Daniela Cardone, Michele Tritto, Filippo Aucella and Arcangelo Merla*

Thermal imaging represents a non-invasive and contactless method for vascular assessment; however, vessel segmentation remains challenging due to low contrast, noise and motion artifacts. This work presents a comparative study of two temporal propagation strategies for vessel segmentation using thermal videos acquired with a FLIR A655 infrared camera and stored in proprietary .seq format. Both approaches are developed within a common spatio-temporal framework that integrates ROI-based preprocessing, data-driven temporal smoothing with SNR-based window optimization, arm-background separation via Gaussian Mixture Modeling, adaptive border refinement, and region growing guided by vessel statistics (μ, σ). The strategies differ in temporal propagation: a static approach based on centroid tracking, suitable for quasi-stationary conditions, and a motion-adaptive approach combining local optical flow estimation, thermal-based seed refinement, and motion-dependent search regions. Performance is evaluated against manual ground truth using region-based, boundary, and structural metrics. Under limited motion both strategies yield comparable accuracy (Dice 0.799 vs. 0.818; IoU 0.667 vs. 0.694), while the adaptive strategy markedly improves boundary fidelity in dynamic conditions, reducing mean Hausdorff distance from 16.4 px to 9.2 px (□44%).

### Listening Effort Under Active Noise Cancellation: A Pupillometry Study

*Tommaso Bianchi, Anagha H. Varista, Davide Piaggio, Leandro Pecchia and Margherita A. G. Matarrese*

Active noise cancellation (ANC) may reduce listening effort in noisy environments, but its physiological effect during cognitive tasks remains unclear. This study assessed whether ANC modulates pupil-based markers of cognitive load during working memory performance. Twenty participants completed 0-back and 2-back tasks under ANC OFF and ANC ON conditions while pupil dynamics were recorded using Pupil Labs Invisible glasses. Pupil area, major axis and minor axis were analysed with generalised additive mixed models. Cognitive load increased pupil size in both ANC conditions, confirming higher physiological demand during the 2-back task. However, the load-related increase was larger and more sustained when ANC was OFF. ANC had limited effects during the 0-back task, but reduced pupil size across extended intervals during the 2-back task. These findings suggest that ANC reduces the additional physiological cost imposed by background noise when working memory demand is high. Pupillometry may therefore provide an objective method for evaluating wearable acoustic technologies and their effect on cognitive effort.

### Identification of biological age from clinical pediatric EEG

*Francesco Colussi, Matilde Paramento, Edoardo Passarotto, Jacopo Favaro, Claudio Ancona, Irene Toldo, Stefano Sartori, Nicolai Spicher, Giovanni Sparacino and Maria Rubega*

This study introduces a novel framework for estimating biological age in pediatric populations (ages 2–17) using two minutes of resting-state electroencephalography (EEG) recordings. From a cohort of 190 healthy subjects, 10 spectral and 4 non-linear EEG features were extracted to characterize neurodevelopment dynamics. For age prediction, ElasticNet and Support Vector Regression models were evaluated using a repeated nested cross-validation framework, comparing the standard 10-20 electrode configuration against a reduced 10-electrode subset optimized for clinical feasibility. All models demonstrated high predictive accuracy, with Mean Absolute Errors (MAE) ranging from 1.55 to 1.62 years. The 10-electrode ElasticNet configuration achieved the best performance (MAE = 1.55 ± 0.03 years), suggesting that reliable maturation tracking is possible even with reduced electrode setups. Feature importance analysis identified spectral-profile features (e.g., delta and alpha-frequency power) as primary drivers of the models' decision making, aligning with established neurodevelopment patterns. The best-performing model was then applied to a small cohort of five pathological subjects, where bias-adjusted Brain Age Gap values enabled the identification of subject-specific deviations from the normative developmental trajectory. Although preliminary, the present work underscores the potential of EEG-based biological age estimation as a scalable tool for monitoring neurodevelopment and detecting early signs of neurological divergence.

### Granger-Connectivity Based Identification of Epileptogenic Zones: A Graph-Theoretical Approach to EEG Analysis

*Giulia Piermaria, Silvana Pelle, Anna Scarabello, Lorenzo Ferri, Francesca Bisulli and Mauro Ursino*

Epilepsy is a neurological disorder characterized by excessive neuronal activity. Accurate identification of epileptogenic zones is essen- tial for presurgical evaluation in drug-resistant focal epilepsy. In this study, we propose a framework that combines brain connectivity and graph-theoretical analysis to investigate the pre-ictal period for epilep- togenic zone identification. Thirteen patients with drug-resistant focal epilepsy were retrospectively analyzed using MRI and long-term scalp EEG recordings. Cortical sources were reconstructed on MRI-derived surfaces, and temporal Granger causal- ity was computed during pre-ictal and ictal phases. Functional connec- tivity networks were then analyzed using graph-theoretical measures to estimate centrality and hubness indices for seizure lateralization and lo- calization. Six patients underwent surgical treatment, and five achieved favorable outcomes. In the patient with an unfavorable outcome, the analysis sug- gested a bilateral epileptic network. Among the patients with favorable outcomes, both lateralization and localization were correctly identified in three cases, and lateralization alone in one. The remaining case was affected by motion artifacts. Among the three patients monitored with stereo-EEG, lateralization was correctly identified in all cases, and localization in one. In the remaining four patients who

underwent neither surgery nor stereo-EEG, lateraliza- tion and localization agreed with the qualitative clinical prediction.

### Prototyping Agentic Post-Market Surveillance via ISO 13485 Digital Twins

*Ali Salman and Ernesto Iadanza*

This study presents a functional prototype for autonomous post-market surveillance of medical devices, bridging the execution gap between theoretical AI frameworks and live hardware orchestration. Using the OpenClaw multi-agent system powered by Gemma 4 language model and Exa for real-time regulatory intelligence, we developed a proactive technical loop that interfaces a whitelisted WhatsApp control layer with digital twin telemetry. To ensure deterministic device identification and minimize AI hallucinations, we implemented a declarative metadata layer for autonomous agent discovery. The system's reliability was validated through forced-stress simulations where the orchestrator autonomously refactored device logic to trigger and report critical thermal anomalies in compliance with ISO 13485:2016. Results demonstrate 100\% discovery accuracy and successful closed-loop alerting, proving that generative AI integrated with deterministic safety gates can effectively automate the link between hardware drift and mandatory vigilance reporting. This architecture provides a scalable, human-in-the-loop framework that maintains strict adherence to the safety mandates of the EU AI Act.

### Breast Tumour Imaging via Tomographic Microwave and Ultrasound Sensing: a Preliminary Numerical Study

*Michele Ambrosanio, Stefano Franceschini, Roberta Diana, Francesca Bifulco, Giuseppe Cesarelli, Vito Pascazio and Fabio Baselice*

Breast cancer remains one of the leading causes of cancerrelated mortality among women worldwide, underscoring the importance of early and accurate detection to improve prognosis and survival rates. Conventional imaging modalities, including X-ray mammography, ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI), are widely used in clinical practice but each suffers from intrinsic limitations in terms of sensitivity, specificity, spatial resolution, cost, or patient comfort. In recent years, microwave tomographic imaging (MWTI) has emerged as a promising complementary modality due to its non-ionizing nature, low cost, and intrinsic sensitivity to the dielectric contrast between healthy and malignant tissues. In this work, we propose a deep-learning-based multimodal imaging framework that jointly exploits microwave and ultrasound measurements for breast cancer detection. The proposed approach integrates scattered electric and acoustic field data within a unified neural architecture to directly produce a pixel-wise classification map of breast tissues. By leveraging the complementary physical information provided by electromagnetic and acoustic wave propagation, the method aims to enhance tumor localization without relying on intermediate image reconstruction steps. The framework is validated on a synthetic dataset of numerical breast phantoms, showing encouraging performance in terms of structural similarity and classification accuracy.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 25A
Thursday September 17, 11:30-13:00

### Intelligent Quality Assessment of Magnetocardiography Time-Series Signals Based on Deep Learning

*Tong Jing, Chu Chengchen and Li Bin*

Magnetocardiography (MCG) signals, which are highly susceptible to environmental noise during acquisition, which may result in acquisition failure. Meanwhile, due to the lack of publicly available universal datasets as evaluation criteria, it is highly necessary to develop a method capable of online automatic quality assessment to improve the efficiency and quality of clinical diagnosis based on MCG. This study proposes an intelligent MCG signal quality evaluation method integrating time-frequency analysis and deep learning. Raw MCG signals undergo preprocessing, including noise reduction via signal averaging and R-wave-based normalization to ensure consistent segment length. Continuous wavelet transform (CWT) is then applied to generate two-dimensional time-frequency representations. A novel InceptionTime-CBAM network, enhanced with convolutional block attention modules, is developed to classify signal quality as acceptable or unacceptable. Experimental results, based on a clinically collected dataset of 1625 samples, demonstrate that the proposed method achieves an accuracy of 94.36%, sensitivity of 97.46%, specificity of 89.17%, and an F1-score of 95.57% in five-fold cross-validation, significantly outperforming classical CNN models such as ResNet and VGGNet. The framework provides a robust and automated solution for MCG quality assessment, facilitating more reliable cardiac disease diagnosis and supporting the development of clinical tools based on MCG analysis.

### Multiscale Statistical Process Control of RR Interval Dynamics for Explainable Pre-Onset Characterization of Paroxysmal Atrial Fibrillation

*Michel Alexander Castañeda Alarcon*

Paroxysmal atrial fibrillation (PAF) may be preceded by subtle changes in rhythm dynamics that are difficult to characterize using conventional heart-rate variability (HRV) descriptors alone. This study proposes a multiscale statistical process control (SPC) framework for explainable pre-onset characterization of PAF from RR interval dynamics. The analysis used the PhysioNet PAF Prediction Challenge Database learning set, restricted to the main 30-min p-records. For each consecutive odd-even p-record pair, the odd record was labeled as PAF-distant and the even record as pre-onset. Continuation records ending in c and n-records from subjects without documented atrial fibrillation were excluded from the primary paired task. RR intervals were derived from QRS annotations and analyzed using RR-count windows, 5-min windows, and full-record aggregation. Interpretable HRV and SPC features were extracted using Shewhart, CUSUM, EWMA, moving-range, and runs-rule descriptors. Grouped validation by pair identifier and 500 pair-level bootstrap iterations were used to reduce leakage and quantify uncertainty. SPC configurations improved over the evaluated reduced and expanded time-domain/Poincaré HRV descriptor panels, with B_SPC reaching AUC = 0.776 (95% CI: 0.704–0.862) and pairwise concordance = 0.840 (95% CI: 0.733–0.941). Shewhart out-of-control rate and count showed the strongest paired pre-onset increases. These findings support SPC as an interpretable feature-engineering layer for ECG rhythm characterization, requiring external validation before clinical deployment.

### Deep Learning-based Model of Embryo Formation from Multi-Plane Time-Lapse Oocyte Images

*Alessandro Biscontin, Milos Ajcevic, Stefania Luppi, Aleksandar Miladinovic, Elena Giolo, Agostino Accardo, Gabriella Zito and Giuseppe Ricci*

IVF has become a standard fertility treatment. Deep learning has the potential to support automated embryo assessment from imaging data; however, most methods rely on single-plane or single time-point images. This study aims to develop a deep learning-based tool to support the workflow by predicting whether an individual mature oocyte will give rise to an embryo, using early multi-plane time-lapse imaging acquired in an intracytoplasmic sperm injection (ICSI) setting. Time-lapse stack images (11 focal planes) were acquired every 10 minutes and assembled into fixed-length sequences of 10 time points per oocyte. A focal-plane fusion module compressed each stack into a 3-channel frame, which was embedded by a masked-autoencoder (MAE) pre-trained Vision Transformer. Frame embeddings were modeled with a bidirectional long short-term memory (LSTM) network and classified via a sigmoid output. The developed deep learning model was evaluated on a held-out test set of 67 oocytes. It correctly identified 11 of 12 embryo-forming oocytes (sensitivity: 0.917), critical to ensure potential embryos are not overlooked during IVF procedures. For non-embryo oocytes, 34 of 55 were correctly classified (specificity: 0.618). Although specificity is lower, the model still effectively reduces the number of oocytes to track without discarding potentially useful material.

### Physics-Informed Neural Networks for the Identification of Digital Twins in Type 1 Diabetes: A Proof-of-Concept Study

*Francesco Prendin, Simone Del Favero, Giacomo Cappon, Giovanni Sparacino and Andrea Facchinetti*

Digital twins (DTs) are increasingly recognized as key tools for improving Type 1 Diabetes (T1D) management, enabling patient-specific simulation of glucose dynamics and the development of personalized therapies. Central to the creation of an accurate DT is the twinning procedure, which is the identification of patient-specific parameters from continuous glucose monitoring, carbohydrate and insulin information. Physics-Informed Neural Networks (PINNs) are an emerging paradigm for this task: by integrating a physiological model (described by ordinary differential equations, ODEs) into the training process, a PINN can learn a continuous approximation of the state trajectory and, in principle, can recover hidden physiological dynamics. As a first step toward this goal, this paper aims to: (i) investigate whether a PINN can consistently identify three key patient-specific parameters: basal glucose (Gb), gastric emptying rate (kempt), insulin sensitivity (SI); and (ii) understand the role that different elements of the PINN loss function play in parameter identification. To this end, we leveraged a simplified model of glucose-insulin dynamics and performed a Monte Carlo simulation study varying model parameters and exogenous inputs. Then, we challenged the PINN to recover the true parameters under three different configurations of its loss function. The PINN in its complete configuration achieves a Mean-Absolute-Relative-Difference (MARD) of 0.95%, 3.85%, and 5.09% for Gb, kempt, and SI respectively, with root-mean-squared-error (RMSE) = 1.49mg/dL and $R^2$=99.3%. Removing the physics loss term causes kempt MARD to increase fivefold (to 24.3%) and SI MARD sixfold (to 32.7%), demonstrating that the ODE-based constraint in the training process is key for accurate parameter identification.

### Optimizing EEG preprocessing for Deep Learning-based Interictal Epileptiform Discharge detection

*Alberto Bortolotto, Simone Kresevic, Katerina Iscra, Aleksandar Miladinovic, Giovanni Furlanis, Edoardo Ricci, Marcello Naccarato and Milos Ajcevic*

Automated detection of interictal epileptiform discharges (IEDs) in EEG is clinically relevant but remains methodologically challenging because of signal variability and sensitivity to preprocessing. The aim of this study was to investigate how preprocessing choices, particularly normalization strategies and band-pass filtering settings, affect the performance of deep learning models for automated detection of interictal epileptiform discharges in EEG signals. To this end, five normalization methods under both window-level and record-level schemes, combined with seven band-pass filtering configurations, were evaluated using the HTNet-EEG hybrid architecture on a publicly available 84-subject clinical EEG dataset. The best-performing pipeline, record-level robust median absolute deviation (MAD) normalization paired with a 5–100 Hz Butterworth band-pass filter, improved ROC-AUC from 0.92 to 0.98, PR-AUC from 0.31 to 0.84, and F1-score by +0.39 over the unoptimized baseline ($p < 0.001$, DeLong test). These findings suggest that preprocessing plays an important role in the automated identification of EEG patterns and may provide useful guidance for designing reliable and reproducible preprocessing pipelines for EEG-based IED detection systems.

### Towards Agentic Refactoring for Autonomous Maintenance in Smart Infusion Pumps

*Leya El Halabi, Ali Salman and Ernesto Iadanza*

The reliability of Infusion Pumps remains a critical concern in healthcare, as traditional reactive maintenance models often lead to abrupt shutdowns that can compromise patient safety. This study intro- duces an autonomous maintenance framework that utilizes a three-layer architecture to bridge the gap between physical hardware performance and high-level regulatory intelligence by integrating a digital twin simu- lation with an agentic orchestrator. By continuously monitoring device telemetry and cross-referencing performance data with safety standards such as ISO 13485 and IEC 62304, the orchestrator demonstrated the ability to execute graceful degradation through autonomous logic refactor- ing. Experimental results confirm that the system successfully maintains therapeutic delivery during mechanical drift, silent hardware failures, and power crises while ensuring absolute transparency through automated audit trails and clinician-facing decision logs.

Ultimately, this research proves that transitioning from passive monitoring to active hardware resilience provides a viable pathway for meeting modern regulatory de- mands for high-risk medical AI, ensuring that devices are not only smart enough to report failures but resilient enough to survive them.

## Artificial Intelligence, Data-Driven, and Physics-Driven Precision Medicine

Session 25B
Thursday September 17, 11:30-13:00

### Deep Learning-Based Coronary Artery Segmentation for the Comparison of CCTA Reconstruction Methods

*Beatrice Guidalotti, Ruben Piperno, Luca Bacco, Simone Pasquale Crispino, Francesca Pinto, Martina Marinelli, Maria Marcella Laganà, Mario Finazzo, Cristiana Duranti, Leandro Pecchia and Mario Merone*

Background: Coronary CT angiography (CCTA) reconstruction methods are commonly evaluated through reader-based assessment and conventional image-quality metrics, although these approaches do not fully reflect how reconstructed images support downstream automated analysis. Objective: To propose and validate a reconstruction-aware CCTA evaluation framework that integrates coronary artery segmentation as a complementary criterion for reconstruction-method comparison. Methods: We analyzed a private paired-reconstruction dataset of 26 patients, in which each examination was reconstructed using three representative reconstruction categories: iterative reconstruction (IR, AIDR 3D), model-based iterative reconstruction (MBIR, FIRST), and deep learning reconstruction (DLR, AiCE). The framework combined: (i) whole-heart quantitative image-quality analysis based on masks obtained from an adapted whole-heart segmentation pipeline, (ii) coronary artery segmentation using a reproduced ImageCAS-based deep learning framework, evaluated both in inference-only conditions and after supervised fine-tuning on the manually annotated subset, (iii) coronary-specific quantitative metrics, and (iv) blinded qualitative radiological assessment. Results: Across the different evaluation levels, AiCE showed the most favorable performance overall, and AIDR 3D yielded the least favorable results in most comparisons. Importantly, coronary segmentation performance reflected the same ranking observed in quantitative image-quality metrics and blinded qualitative assessment. Conclusion: Coronary segmentability captures reconstruction-dependent differences in a meaningful and consistent way. These findings support the use of coronary segmentation not only as a downstream task, but also as a practical complementary criterion for reconstruction-method comparison in CCTA.

### Benchmarking Automatic Question Generation from Clinical Practice Guidelines for Education: a Case Study for Low Back Pain Management

*Agnese Bonfigli, Mario Merone, Felice Dell'Orletta, Giuseppe Francesco Papalia, Girolamo Maltese, Fabrizio Russo, Gianluca Vadalà, Rocco Papalia, Leandro Pecchia and Luca Bacco*

linical practice guidelines are essential for evidence-based care, but their length and complexity often limit their educational use in routine practice. In this study, we investigate whether large language models (LLMs) can automatically generate clinically meaningful educational questions from raw low back pain guidelines. We built a fully automatic pipeline combining PDF parsing, structure-aware segmentation, question generation, and multidimensional evaluation. We compared three chunk granularities and four LLM configurations, and introduced a novel Clinical Information Density (CID) as a measure of the concentration of clinically relevant information within each text segment. Results suggest that (i) smaller, semantically coherent chunks produced better questions than larger document-level inputs, (ii) information-dense chunks could improve the question generation, and (iii) both biomedical specialization and instruction tuning could improve LLMs' question generation from guideline text, recovering relevance even for less information-dense chunks.

### Electrophysiological response to atosiban therapy across gestational stages and preterm vs term outcomes: a GAMM-based analysis of EHG temporal dynamics

*Yu Meng, Javier Garcia Casado, Gema Prats Boluda, Carmen Sánchez Arco, Carmen Padilla Prieto, Fernando Modrego Pardo, Rogelio Monfort Ortiz, Beatriz Marcos Puig and Yiyao Ye Lin*

This study investigates the temporal evolution of uterine electrophysiological activity within 48 hours following atosiban administration using electrohysterogram (EHG) signals. Three representative features were analyzed, including peak-to-peak amplitude (PPA), dominant frequency (DF), and multi-state Lempel–Ziv complexity (LZM). Generalized additive mixed models (GAMMs) were employed to characterize nonlinear temporal dynamics and to evaluate their modulation by gestational age (GA) and pregnancy outcome (preterm labor vs. term labor, PL vs. TL). The results demonstrate that frequency-domain and nonlinear features exhibit stronger GA-dependent modulation than amplitude-related measures. Regarding pregnancy outcome, the PL and TL groups exhibited distinct responses to atosiban therapy in PPA and LZM for GA $\geq$ 32 weeks, while for GA $<$ 32 weeks, the difference was observed in DF. These findings indicate that the electrophysiological response to atosiban is GA stage-dependent and varies with pregnancy outcome. EHG-derived temporal dynamics may therefore serve as a non-invasive biomarker for assessing short-term tocolytic response and supporting outcome prediction in threatened preterm labor.

### From Cellular Heterogeneity to Tissue Architecture: Single Cell and Spatial Bioinformatics for Precision Medicine

*Roberto Semeraro*

Precision medicine has long relied on bulk molecular profiling, an approach that can obscure the cellular heterogeneity, regulatory diversity, and tissue architecture that shape disease behavior and therapeutic response. Over the past decade, single-cell and spatial omics have reshaped this landscape by enabling the identification of rare and clinically relevant cell populations, the reconstruction of dynamic state transitions, the integration of multiple molecular layers, and the recovery of tissue context in situ. These advances have moved disease interpretation beyond descriptive profiling toward a mechanistic understanding of cell identity, regulatory programs, clonality, intercellular communication, and spatial organization. Here, we discuss how single-cell and spatial bioinformatics have transformed precision medicine by shifting analysis from bulk-average representations to cell state aware, network aware, and tissue context aware models of pathology. We argue that bioinformatics is not merely a downstream support, but the enabling layer that converts high-dimensional measurements into biologically interpretable and clinically actionable knowledge. From multimodal integration and trajectory inference to receptor aware immune profiling, regulatory network analysis, perturbational modeling, interactome reconstruction, and spatial computation, modern computational methods determine how these technologies can be translated into robust hypotheses, target prioritization, and patient relevant disease models. Finally, we highlight how emerging artificial intelligence frameworks may accelerate this transition by providing generalizable representations of cellular and tissue organization, opening the way to a more predictive and mechanistically grounded precision medicine.

## Biomedical Signal Processing and Physiological Systems Engineering

Session 25C
Thursday September 17, 11:30-13:00

### Investigating extracranial circulation and skin pigmentation effects on cerebral photoplethysmography using a perfused head phantom

*Karina Awad-Perez, Maria Roldan and Panicos Kyriacou*

Abstract: Optical brain monitoring offers a non-invasive approach for continuous assessment of cerebral physiology. Among these techniques, cerebral photoplethysmography (PPG) has gained interest due to its potential to estimate intracranial pressure. However, cerebral PPG signals may be affected by extracranial circulation and skin pigmentation, limiting their reliability. In this study, a multilayer pulsatile head phantom was developed and used to investigate the effects of extracerebral circulation and skin pigmentation on cerebral PPG signals. The phantom incorporated anatomically representative brain, skull, scalp, and interchangeable skin layers, and was integrated into a cardiovascular system enabling controlled perfusion of cerebral and extracranial layers. PPG signals were acquired at 770, 810, and 880 nm using a 3 cm source–detector separation. Results showed that PPG is sensitive to cerebral haemodynamic changes, as reductions in signal amplitude and signal-to-noise ratio (SNR) were observed during brain occlusion. However, extracranial circulation was found to dominate the pulsatile signal, with scalp occlusion reducing signal amplitude and quality. Increased skin pigmentation reduced amplitude and SNR, although pulsatile signals remained detectable across all conditions. These findings demonstrate that while PPG retains sensitivity to cerebral haemodynamics, measurements are influenced by extracerebral layers, highlighting the need for careful interpretation and potential correction strategies

### Silent Hypoxia in COVID-19: A Systematic Literature Review of Current Evidence and Research Gaps

*Amra Džuho, Maria Salah Alfilali, Adna Softić and Adna Ašić*

Hypoxia in COVID-19 results from viral entry into host cells, leading to increased vasoconstriction, thrombosis, and lung inflammation, impairing oxygen metabolism. "Silent hypoxia" describes significantly reduced oxygen saturation without dyspnea. This phenomenon may be linked to ACE2 receptor overexpression, enhancing susceptibility to COVID-19 damage. Possible mechanisms for absent dyspnea include mild carbon dioxide elevations masking symptoms, direct viral effects on the brain and nervous system, and vascular changes. Silent hypoxia arises from a complex interplay of factors, including pneumonia, alveolar collapse, and impaired oxygen exchange, potentially causing indirect organ damage. Early detection is crucial to mitigate long-term effects and mortality. This review systematically examines the current literature on silent hypoxia in the context of COVID-19, based on a search of PubMed using the keywords "silent hypoxia" and "COVID-19" in February 2024. Findings remain inconclusive due to conflicting results on risk factors and comorbidities. Asymptomatic patients with severe hypoxia are at risk of rapid deterioration, underscoring the importance of improved diagnostics and early intervention. Current research is limited by small sample sizes and heterogeneous methodologies, necessitating larger cohorts, standardized study designs, and exploration of genetic predispositions and comorbidity interactions. Silent hypoxia highlights COVID-19's unique pathophysiology, blending respiratory, vascular, and neurological impacts. Addressing this condition requires better tools for early detection and tailored interventions to prevent rapid progression and severe outcomes.

### Wearable Sensor-Based Evaluation of Jump Characteristics in Unilateral Standing Long Jumps

*Selena Bogojević, Milica M. Janković, Olivera Knežević and Vladislava Krsmanović*

This study investigated whether angle signals and their derived features can effectively characterize unilateral standing long jump (SLJ) performance and assist in assessing trial validity. Twenty healthy participants were recorded performing jumps using inertial measurement units (IMUs). Using gyroscope data from the IMUs, the lower-body segment and joint angles were estimated and characterised using amplitude, temporal, and smoothness features. The extracted feature values were analysed with respect to gender and the leg used for execution, as well as their relevance to trial validity. The findings indicated that the leg used for jumping had a minimal impact on most features in valid trials, suggesting symmetric movement patterns among healthy individuals. Conversely, the features related to local extrema most frequently showed significant differences between female and male participants. In the validity assessment, the segment model with fewer parts exhibited the best overall fit, indicating that kinematic data at the segment level offers more meaningful insights into distinguishing valid from invalid trials.

### A simple waveform-based method for automatic detection of patient-ventilator asynchrony in

**non-invasive ventilation**

*Emelia Sewell, Federico Longhini, Carlo Cosentino, Eugenio Garafalo, Gianmaria Cammorota, Declan Bates and Liam Weaver*

Patient–ventilator asynchrony (PVA) is a clinically significant complication of non-invasive ventilation (NIV), occurring when ventilator-delivered breaths fail to align with a patient's spontaneous respiratory effort. Despite its high prevalence and association with increased patient discomfort, prolonged ICU stay, and elevated mortality risk, detection in clinical practice remains largely manual and highly operator-dependent. This study presents the development and preliminary validation of a simple, rule-based algorithm for the automated detection of the three most clinically important trigger asynchronies during NIV: double-triggering (DT), auto-triggering (AT), and ineffective effort (IE). Requiring only the airway pressure waveform and a measure of neural respiratory rate as inputs, the algorithm was validated against clinician-derived ground truth in identifying 52 asynchrony events using retrospective data from 13 NIV patients, achieving an overall sensitivity of 0.89 and specificity of 0.83. DT detection was perfect across all patients (sensitivity and specificity of 1.00), IE detection successfully identified all but one clinician-labelled events (sensitivity 0.97, specificity 0.6), and AT detection was weakest (sensitivity 0.50), attributed to the absence of a direct trigger signal. These results represent an encouraging proof of concept for a lightweight, automated PVA detection tool for NIV settings where continuous monitoring is currently lacking.

**Monte Carlo simulation of oedema detection in neonates using near infrared spectroscopy with skin hydration acting as a confounding factor**

*Mariana Castro Montano, Ling Li, Panayiotis Kyriacou and Meha Qassem*

Skin hydration and oedema are governed by distinct physiological mechanisms; hydration is primarily influenced by local barrier properties and environmental or topical factors, whereas oedema is driven by systemic hemodynamic processes and lymphatic or renal handling. Consequently, changes in one parameter may occur independently of the other, making skin hydration a potential confounding factor in the detection of oedema using near-infrared spectroscopy. To investigate this interaction, Monte Carlo simulations were performed to model nine tissue conditions combining different hydration levels and oedema stages. The simulations evaluated light–tissue interactions, absorbance, and mean light penetration depth under two optical fibre configurations, perpendicular and parallel to the skin surface. Comparison of these geometries showed that fibre orientation affects both the magnitude of the optical response and its sensitivity to hydration changes. Although the parallel configuration remained capable of differentiating oedema stages across hydration levels, measurements at 1450 nm were particularly susceptible to hydration-related interference, with absorbance changes potentially mimicking or masking oedema signatures. Importantly, the absorbance ratio between 1200 nm and 1050 nm ($\Delta A_{(1200/1050)}$) was found to be a robust metric ($R2 = 0.999$, $\beta 1 = 0.188 \pm 0.002$, $p < 0.001$), demonstrating potential to distinguish oedema stages despite variations in skin hydration and fibre orientation.

**Differential Effects of Gait Rehabilitation Exercises on Cortical Haemodynamics in Multiple Sclerosis**

*Davide Borra, Jacopo Pandolfi, Matteo Fraternali, Andrea Baroni, Nicola Lamberti, Fabio Manfredini, Sofia Straudi and Elisa Magosso*

Multiple sclerosis (MS) is a chronic neurodegenerative disease characterized by progressive motor impairment, in which gait dysfunction significantly contributes to disability and reduced quality of life. Although gait rehabilitation improves functional outcomes, the neural mechanisms underlying recovery remain poorly understood, particularly across different training modalities. In this context, identifying how rehabilitation modulates cortical haemodynamics is crucial to better understand recovery processes and optimize treatment strategies. Here, we investigate the cortical haemodynamic changes induced by different gait training exercises within the context of the PROGR-EX clinical study. Twenty-four MS patients underwent distinct gait interventions: robot-assisted gait training (RAGT) with progressively increasing walking speed at low intensity (low-RAGT), RAGT at constant walking speed (conventional-RAGT), or overground gait training (OGT). Functional near-infrared spectroscopy (fNIRS) signals were recorded during an upper-limb motor task before treatment (T0), at the end of treatment (T1), and at follow-up (T2). A cross-sectional comparison with healthy controls was also performed. At baseline, MS patients showed altered cortical lateralization in a frontal-dominant brain network, with increased ipsilateral and reduced contralateral oxygenation compared to healthy controls. Longitudinal analyses revealed intervention-specific effects. Low-RAGT promoted a shift toward a more lateralized pattern, with increased contralateral and reduced ipsilateral activity at T1, and sustained reduction of ipsilateral involvement at T2. OGT induced a reduction of ipsilateral activity at both T1 and T2, while conventional-RAGT showed no clear shift toward a physiological oxygenation pattern. Gait rehabilitation modulates cortical haemodynamics in an exercise-dependent manner, with low-RAGT appearing to be the most effective in promoting a shift toward physiological motor lateralization.

## SS Responsible AI in Healthcare

Session 25D
Thursday September 17, 11:30-13:00

**Pointwise Reliability in ML Regression: A Comparison of Density, Local Fit and Knowlegde-Based Methods**

*Zhan Zhao, João Loureiro, Ricardo Valentim, Jorge Henriques and Paulo Gil*

Traditional evaluation metrics, such as accuracy and AUC, provide only a global assessment of ML models and cannot indicate whether an individual prediction may be considered reliable. This limitation is particularly significant in critical domains, where incorrect predictions can have significant consequences. To address this issue, this work investigates pointwise reliability estimation, which aims to quantify the trustworthiness of each individual prediction. A comparative analysis is conducted using three representative reliability approaches: a density-based method (RCD), a local fit method

(CCNR), and a knowledge-based rule-driven approach. The evaluation is performed through a case study based on a real-world clinical dataset, motivated by hospital resource management, and formulated as a regression task for length-of-stay prediction. Reliability scores are computed for each test instance in order to analyse the relationship between reliability levels and predictive performance. The results consistently demonstrate a stratification effect, where higher reliability intervals are associated with lower prediction errors, whereas lower reliability intervals capture instances with higher instability of the model performance. Across all approaches, reliability scores show a clear alignment with actual model performance at the instance level, and in addition, the rule-based approach incorporates domain knowledge and interpretability, which is particularly relevant in clinical contexts. These findings highlight the importance of pointwise reliability as a complementary tool to improve transparency and support more informed decision-making.

### Pointwise Reliability Assessment for Continuous Non-Invasive Blood Pressure Estimation

*João Loureiro, Zhan Zhao, Paulo Gil, Erik Bresch, Jorge Henriques and Jens Muehlsteff*

Continuous non-invasive blood pressure (cNIBP) monitor- ing still remains an open challenge. While numerous methods have been proposed to estimate blood pressure (BP) from physiological signals, lit- tle attention has been given to quantifying the trustworthiness of these estimates in real time, particularly in the absence of reference measure- ments. This work addresses the pointwise reliability problem in continuous BP estimation by proposing a model-agnostic evaluation framework for un- supervised reliability measures. Using a dataset of 40 surgical patients, reliability scores are computed from physiological feature spaces and eval- uated alongside blood pressure estimates obtained from a zero-order hold (ZOH) model in 10-second epochs. Two density-based approaches are analysed: Mean Neighbour Similarity (MNS) and the kernel-based den- sity measure (DENS). The proposed framework combines correlation analysis, threshold-based rejection curves, and distribution-aware diagnostics to characterize the behaviour of the reliability scores in relation to estimate error. Results show that both measures provide consistent ranking of prediction error and enable effective filtering of unreliable estimates, with error reductions of up to 40% under selective rejection. However, reliability scores exhibit limited calibration with absolute error, restricting their interpretation as confidence estimates. Overall, the findings point to the practical value of reliability measures for gating and quality control, while emphasizing the need for improved calibration and adaptive strategies for clinical deployment.

### Density-Based Reliability Estimation for Medical AI with Gaussian Mixture Models in Centralized and Federated Settings

*Junjian Yan, Paulo Carvalho, Jorge Henriques, João Loureiro, Benjamin Ng, Chan-Tong Lam, Ricardo Valentim, João Santos, Pablo Holanda, Tiago Barreto and Henrique Madeira*

Reliability estimation is essential for the safe deployment of medical AI systems, particularly in high-stakes clinical environments where incorrect predictions may have serious consequences. However, many existing reliability assessment methods, such as distance-based and neighborhood-based approaches, rely on access to global data or sample-level comparisons, which limits their applicability in privacy-sensitive settings. In this paper, we present a density-based reliability estimation method based on Gaussian Mixture Models, which promotes data obfuscation by replacing sample-level comparisons with compact parametric density representations. The core idea is to model class-conditional data distributions in the representation space and estimate prediction reliability through likelihood-based scoring, thus avoiding explicit neighborhood search and direct distance computation. This makes the method well suited to settings where data sharing is restricted. The approach also extends naturally to federated learning, where each client learns local density models from private data without exposing raw samples. By aggregating model parameters rather than transferring instance-level information, a global reliability estimator can be constructed across distributed medical data sources. In this way, the proposed method provides a practical and privacy-preserving solution for reliability estimation in medical AI, while also offering a unified perspective across centralized and federated settings.

### Physiological Nonconformity Score for Uncertainty Quantification in Cuffless Blood Pressure Estimation

*João Loureiro, Zhan Zhao, Paulo Gil, Erik Bresch, Jorge Henriques and Jens Muehlsteff*

Continuous cuffless blood pressure monitoring has the poten- tial to improve patient safety by providing uninterrupted, non-invasive haemodynamic information. However, current data-driven estimators of- ten provide only point predictions and lack mechanisms to assess the reliability of individual estimates during operation. This is particularly important in clinical settings, where signal artefacts, physiological vari- ability, and temporal drift may cause estimation errors to vary substan- tially over time. This work proposes a local conformal prediction frame- work for uncertainty-aware cuffless blood pressure estimation. A simple regression model is used to estimate mean arterial blood pres- sure from window-based ECG, PPG, and respiratory features. To quan- tify uncertainty, we introduce a physiologically motivated nonconformity score that combines local feature-space consistency with prediction con- sistency among neighbouring calibration samples. A local conformal cal- ibration strategy is then used to construct adaptive uncertainty intervals and derive reliability labels for individual predictions. The framework was evaluated on 51 ICU recordings from the PhysioNet/Computing in Cardiology Challenge 2010 MIMIC II dataset. Results show that the proposed uncertainty estimates are positively cor- related with true prediction error and can identify unreliable predic- tion windows with high specificity. Although empirical coverage does not perfectly match nominal conformal guarantees under the non-stationary time-series setting, it remains monotonic with the confidence level, sup- porting the use of the method as a relative uncertainty and reliability indicator. These findings suggest that physiologically informed local con- formal prediction can support safer cuffless blood pressure monitoring by flagging estimates that may require reference measurement or recalibra- tion.

### Pointwise Reliability Assessment in the Prediction of Emotional States

*Lorena Petrella, Nicole Lavaredas, Duarte Ferreira, João Loureiro, César Teixeira and Jorge Henriques*

The classification of human emotions is being explored in diverse brain-computer interaction applications, including psychotherapies, gamming, and automotive systems, among others. However, some practical limitations in the adoption of these techniques are related to the lack of trustworthiness in the predictions provided by the associated machine learning (ML) models. In the present study, different methods for pointwise reliability assessment in the prediction of human emotions, evaluated through electroencephalography (EEG) signals, are explored. Pointwise reliability provides an estimate of how much an individual prediction for a new instance can be trusted. For this purpose, a dataset containing EEG recording from individuals exposed to video clips intended to induce positive, negative, and neutral emotions was used. The signals were preprocessed, features were extracted, and feature engineering techniques were applied to improve data quality and reduce the number of features. Five ML models (shallow learning) were trained, and eight reliability metrics were implemented. The results demonstrated moderated classification performance, with an accuracy of about 51 % (for three classes), while the reliability metrics showed strong correlation with accuracy for some of the implemented approaches, including a newly proposed metric (Pearsons's correlation coefficient of 0.88). Although these methodologies require further exploration to improve performance, the study demonstrates the suitability of incorporating reliability metrics into the prediction of human emotions, representing a novel approach.

# POSTER PRESENTATIONS' ABSTRACTS

### Influence of Lateral Meniscus Morphology on Load Redistribution Following High Tibial Osteotomy: A Patient-Specific Finite Element Analysis

*Tae Soo Bae, Bo Won Jeong and Dai-Soon Kwak*

High tibial osteotomy (HTO) is a widely established surgical intervention for realigning varus knee kinematics; however, the resulting biomechanical redistribution is highly sensitive to the morphological variants of the lateral meniscus. This study quantifies morphology-dependent load redistribution following HTO using patient-specific finite element models categorized into non-discoid (non-DLM), incomplete discoid (iDLM), and complete discoid (cDLM) meniscus types. Under simulated gait (75% BW) and running (80% BW) conditions across a parametric range of weight-bearing line (WBL) increments, the 95th percentile Von Mises stress was evaluated to assess the mechanical demand on the joint. The FE analysis revealed divergent biomechanical behaviors: the non-DLM model maintained relatively stable meniscal stress (27.8–32.3 MPa) despite significant stress concentration at the tibial hinge (112.2 MPa at 62.5% WBL), while the iDLM model exhibited negligible load transmission (<0.6 MPa), indicating a functional bypass of the lateral compartment. In contrast, the cDLM variant demonstrated pronounced alignment-dependent stress amplification, with magnitudes escalating from 19.2 to 69.9 MPa during gait and from 20.0 to 73.9 MPa during running. These findings suggest that post-HTO load redistribution is not a uniform mechanical phenomenon but is governed by meniscal morphology, necessitating morphology-specific alignment strategies to ensure biomechanically optimized outcomes.

### Assessment and Dead-band Threshold Derivation for the Sentinel Wearable Reaction-Wheel Balance Assistance System – A Preliminary Study

*Ioannis Katsaronas, Alexander Astaras, Alkinoos Athanasiou and Panagiotis Bamidis*

Balance impairment is a common cause of falls and functional decline among neurological patients and aging populations. Wearable assistive devices employing angular momentum exchange – specifically, reaction wheels – remain an underexplored intervention modality for trunk stabilization. Our team developed a novel, wearable, power-autonomous prototype device for active balance assistance, based on a reaction wheel (project Sentinel). This preliminary study uses the prototype device as a data-acquisition platform to assess postural sway in two healthy participants across progressively challenging standing tasks. The aim was to assess the device's measurement capability and to derive a subject-specific dead-band threshold. Both participants wore the device and completed six standing tasks involving sensory, mechanical, and cognitive challenges. Postural sway was quantified using roll root-mean-square, a 95% confidence ellipse area, and sample entropy. A provisional dead-band threshold of 0.281° was derived from participant S00's balance quiet-standing data. Across the tested conditions, the device demonstrated the ability to capture differences in sway amplitude among participants. The consistency of findings across the three metrics points toward reliable device measurements, but a larger cohort is required to confirm it. The posterior mass of 4.8 kg introduced by the device primarily shifts the Center of Mass (CoM) in the sagittal plane and is expected to have minimal influence on the frontal plane in the current experimental analysis. The conclusions from these initial experiments motivate evaluation of the device using closed-loop, threshold-based control, pending cohort expansion and formal validation.

### Monitoring extracellular matrix mineralization in osteogenic cell cultures through metabolic profiling and dual-calibrated quantification of alizarin red

*Pietro Furlani, Karina Ovejero Paredes and Joseph Lovecchio*

The assessment of osteogenic maturation remains a major challenge in bone tissue engineering, due to high variability across cell culture experiments and the lack of a recognized standard for osteogenic maturation. Although extracellular matrix (ECM) mineralization is commonly considered an indicator of differentiation, it does not necessarily reflect actual maturation of the construct. This project aims to develop a more standardized and quantitative approach for assessing ECM mineralization by integrating an improved Alizarin Red assay with longitudinal metabolic profiling of cell cultures. Cultures were maintained in osteogenic conditions and monitored during the early stages of commitment. Free calcium and other metabolites in the culture medium were measured over time using a laboratory metabolite analyzer to investigate extracellular biochemical changes associated with osteogenic progression. To improve the assessment of mineral deposition, a modified Alizarin Red quantification protocol is proposed. After staining, the bound dye was extracted using acetic acid, neutralized with ammonium hydroxide and then quantified using a spectrophotometer. A first calibration curve was generated using Alizarin Red standards prepared in the same extraction solution to estimate the molar concentration of recovered dye. To further relate the Alizarin signal to the calcium deposited in the ECM, a second calibration was performed using calcium phosphate standards processed with the same staining and extraction procedure. This dual calibration strategy was expected to provide a reproducible method for estimating calcium deposited in the ECM. Finally, ECM calcium measurements were compared with longitudinal free calcium levels in the culture medium to identify potential correlations between extracellular metabolic dynamics and matrix mineralization. By combining metabolic profiling with dual-calibrated Alizarin Red quantification, this framework provides a more standardized and non-destructive strategy for monitoring osteogenic cultures over time. If validated, it may support the identification of early biomarkers of osteogenic progression and reduce reliance on endpoint destructive assays.

### Rational Design of Graphene Oxide–Silver Nanoarchitectures: Influence of pH and Phytochemicals on Antibacterial Performance and Cytocompatibility

*Cintia Yvette López-Ruíz, Jhan Danilo Salazar Martínez, Astrid Lorena Giraldo Betancur, Fabiola Hernández Rosas and Jesús González Hernández*

Graphene oxide–silver nanoarchitectures (GO–AgNPs) have emerged as promising platforms for biomedical applications due to their synergistic antibacterial properties. However, controlling their biological performance while maintaining cytocompatibility remains a major challenge. In this work, we investigate the combined influence of graphene oxide chemical state—modulated through pH—and the phytochemical composition of green synthesis extracts on the formation and biological response of GO–Ag nanoarchitectures. Graphene oxide was synthesized and subsequently conditioned at different pH values in order to modulate its surface chemistry and functional group availability. Silver nanoparticles were then nucleated and anchored onto the GO sheets using plant-derived extracts rich in phytochemicals, which served as both reducing and stabilizing agents. The resulting nanoarchitectures were characterized to evaluate their structural and chemical features, and their antibacterial performance was assessed against representative Gram-positive and Gram-negative bacteria, including resistant strains. Additionally, cytocompatibility studies were conducted to identify concentration ranges suitable for biomedical applications. The results indicate that both the chemical state of graphene oxide, governed by pH, and the phytochemical composition of the synthesis medium play a key role in controlling nanoparticle anchoring, dispersion, and overall biological response. Certain nanoarchitectures showed enhanced antibacterial performance while maintaining cytocompatibility, underscoring the importance of controlling synthesis parameters to achieve biologically effective and safe materials. These findings contribute to a better understanding of the structure–property–biological response relationships in GO–Ag nanoarchitectures and support their potential use in antibacterial platforms for wound healing and related biomedical applications.

### Predicting Desmoid Tumor Evolution under Active Surveillance: A Proof-of-Concept Radiomics-Based Machine Learning Study

*Maria Elisabetta Pagnano, Flavia Paternostro, Sarah Orlando, Silvia Calagna, Jacopo Vitale, Alessandro Mazzocca, Mario Merone, Bruno Vincenzi and Leandro Pecchia*

Background Desmoid tumors (DTs) are rare mesenchymal neoplasms characterized by local infiltrative growth and unpredictable clinical behavior. Although they lack metastatic potential, they may be clinically aggressive because of local recurrence and invasion of surrounding anatomical structures. Current international guidelines recommend active surveillance as the initial management strategy for most newly diagnosed, asymptomatic patients since many lesions remain stable or even regress spontaneously. However, up to 30% of patients experience early, clinically relevant progressive disease (PD) and ultimately require systemic therapy or other interventions. To date, no validated clinical, biochemical, or imaging biomarkers reliably predict DT behavior at diagnosis. Radiomics-based machine learning (ML) may provide quantitative imaging biomarkers to support early risk stratification and personalized follow-up. Objective This preliminary study aimed to assess the feasibility of radiomics-based ML for predicting early PD versus stable disease (SD) or spontaneous regression (SR) of DT undergoing active surveillance. Methods A preliminary cohort of 8 patients with histologically confirmed DT was retrospectively analyzed. Follow-up response was defined according to RECIST-based clinical-radiological assessment. Patients with SD or SR were grouped into the non-progressive class, while patients with PD were assigned to the progressive class. The dataset included 4 SD/SR and 4 PD patients. Manual tumor segmentations were used to extract 102 radiomic features from each two-dimensional tumor slice, yielding 147 slices. Due to the limited cohort size, the analysis was performed at slice level; however, all train-test splits were performed at patient level to avoid data leakage. In each external split, 6 patients were used for training and 2 for testing, considering all 16 balanced patient-level combinations. Hyperparameters were optimized on the training set using inner 3-fold stratified group cross-validation. Several supervised classifiers were evaluated, including Logistic Regression, Support Vector Machine, Random Forest, AdaBoost, Gradient Boosting, and Gaussian Naive Bayes (GNB). Models were tested with and without ANOVA F-test-based feature selection. Final performance was reported as mean ± standard deviation across the 16 external test combinations. Results Overall, the tested models showed moderate ability to discriminate PD from SD/SR, with substantial variability across patient-level splits. GNB achieved the best overall performance without features selection, with accuracy 0.658 ± 0.280, balanced accuracy 0.677 ± 0.262, F1-score 0.684 ± 0.258, recall 0.766 ± 0.308, and ROC-AUC 0.683 ± 0.287. The aggregated out-of-sample confusion matrix showed 169 true negatives, 135 false positives, 67 false negatives, and 217 true positives, suggesting good sensitivity for PD but moderate specificity. Features selection did not provide a consistent performance improvement. Conclusion This preliminary feasibility analysis suggests that MRI-derived radiomic features may contain useful information for predicting DT evolution during active surveillance. GNB emerged as the most promising exploratory model, particularly for identifying patients with PD. However, the moderate performance, high variability across splits, limited sample size, and relevant number of false positives indicate that these results should be interpreted as exploratory. Larger cohorts, patient-level validation, and robustness analyses are required before clinical translation. If confirmed, radiomics-based machine learning may enable personalized surveillance strategies, facilitating early treatment for patients at risk of rapid disease progression while reducing unnecessary imaging, patient anxiety, and overtreatment among those likely to experience SD or SR.

### Influence of Bacterial Cellulose Origin and Silver Nanoparticle Nucleation Route on the Physicochemical and Biological Properties of Antimicrobial Biocomposites

*Mónica Pérez García, Cintia Yvette López-Ruíz and Fabiola Hernández Rosas*

The treatment of superficial wounds remains a major challenge in healthcare due to the increasing prevalence of multidrug-resistant microorganisms and their ability to form biofilms, which significantly delay the healing process. In this context, the development of antimicrobial biomaterials has emerged as a promising strategy for improving infection control and promoting tissue regeneration. This work explores the functionalization of vinegar mother-derived bacterial cellulose with silver nanoparticles (AgNPs) through two different nucleation routes. The first approach consists of the in situ synthesis of AgNPs directly on the cellulose matrix, promoting nanoparticle formation and growth in the presence of the biopolymer. The second approach involves ex situ synthesis, where AgNPs are produced separately by conventional chemical reduction and subsequently incorporated into the cellulose network. Additionally, bacterial cellulose obtained from vinegar mothers cultivated using two different fruit substrates will be evaluated in order to determine whether the cultivation source influences the structural characteristics of the cellulose and its interaction with silver nanoparticles. The objective of this study is to investigate the combined effect of cellulose origin and nanoparticle nucleation route on the physicochemical and biological performance of the resulting biocomposites. Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), and Scanning Electron Microscopy (SEM) will be employed to assess structural modifications, crystallinity, nanoparticle morphology, distribution, and anchoring within the cellulose matrix. Furthermore, biological assays will be conducted to evaluate antimicrobial activity and biocompatibility. The results are expected to provide valuable insights into the influence of cellulose microstructure and nanoparticle incorporation pathways on the development of advanced antibacterial biomaterials for wound healing and infection-control applications.

## A Label-free Ultraviolet Photoacoustic Microscopy Enables Nuclear Imaging and Toxicity Assessment in Intact Brain Organoid

*Byullee Park*

Brain organoids have emerged as powerful in vitro models for investigating human brain development, neurodegenerative diseases, and therapeutic responses. However, conventional histological evaluation relies on tissue fixation, sectioning, and staining, making longitudinal and rapid assessment challenging while introducing potential processing artifacts. In this study, we developed a label-free ultraviolet photoacoustic microscopy (UV-PAM) platform for high-resolution structural imaging of intact brain organoids. By exploiting the intrinsic ultraviolet absorption of nucleic acids, UV-PAM enables direct visualization of cell nuclei without exogenous contrast agents or histological staining, providing histology-like images while preserving the native tissue architecture. The proposed approach achieves subcellular-resolution imaging of whole brain organoids and enables quantitative assessment of nuclear morphology and spatial organization through automated image analysis. Morphometric features extracted from UV-PAM images were used to characterize structural alterations associated with biological perturbations, demonstrating the capability of the platform to detect subtle changes in tissue architecture. The label-free and non-destructive nature of the technique further enables repeated imaging of the same specimen, providing opportunities for longitudinal studies that are difficult to achieve using conventional histopathology. To validate the biological relevance of the acquired images, UV-PAM-derived structural information was compared with standard fluorescence histology, demonstrating strong agreement in the visualization of nuclear distributions and tissue morphology. Furthermore, the platform was applied to chemically perturbed brain organoids to demonstrate its utility for quantitative phenotypic analysis of neurotoxic responses. These results highlight the potential of UV-PAM as a rapid and robust imaging modality for organoid research. Overall, this work establishes UV-PAM as a powerful label-free histological imaging technology for brain organoids, enabling high-resolution, quantitative, and minimally invasive characterization of three-dimensional neural tissues. The proposed platform has broad potential for applications in developmental neuroscience, disease modeling, drug screening, and regenerative medicine, where rapid and repeatable assessment of organoid morphology is increasingly required.

## Design and Development of a Microperfusion System for Cellular Bioreactor Applications

*Martina Serio, Marco Catarsi, Caterina Credi and Mattia Dimitri*

Automated fluid management is a critical yet underserved requirement in the development of functional three-dimensional tissue constructs, where static diffusion is insufficient to sustain metabolically active cells beyond the 100–200 μm diffusive limit. This paper describes a modular microperfusion platform that addresses existing gaps in portability, automation, and reproducibility of perfusion-based bioreactor systems. The device integrates a dual-pathway hydraulic architecture driven by Actuonix L16 linear actuators and controlled by optoisolated three-way solenoid valves, mounted on a custom aluminum frame housing hybrid brass-stainless steel fluidic chambers with PTFE plungers and AISI 316L internal sleeves for biocompatibility and sterilizability. System intelligence is centralized on a custom PCB hosting an Arduino UNO microcontroller, a DS3231 TCXO-based real-time clock, a TB6612FNG dual H-bridge motor driver, and a switching buck converter for thermal-stable autonomous powering. Automation logic is implemented as a non-blocking finite state machine incorporating hydraulic safety delays to prevent pressure spikes and retrograde flows. A Python-based graphical user interface provides full protocol customization and real-time telemetry logging. Gravimetric validation ($n = 50$ cycles) yielded a post-calibration coefficient of variation of 0.20% and 0.24% for the feeding and discharging channels, respectively. Kinematic regression models confirmed linear actuator response across unloaded, dry-friction, and hydraulic-load conditions ($R^2 > 0.996$). Prolonged operation at 37°C over 48 hours demonstrated complete functional integrity and sterility. The all-inclusive prototype cost is under 1200 €, representing a cost-effective, reproducible solution for autonomous long-term perfusion in 3D cell culture applications.

## Toward Context-Aware Neuroengineering: EEG-Based Neurological Diagnostics for Sub-Saharan African Healthcare Systems

*Bih Njimbong, Joseph Rugut Kibet and Ambesi Pieranne Manka*

Neurological disorders including epilepsy impose a disproportionate burden on sub-Saharan African (SSA) populations, yet access to electroencephalography (EEG)-based diagnostics remains critically limited across the region. This gap is not solely a consequence of resource scarcity; it reflects an unresolved mismatch between how neurological diagnostic tools are designed and the clinical environments in which they are needed most. The EEG systems and AI-assisted diagnostic tools currently available across SSA are predominantly developed within high-income clinical contexts, embedding assumptions around power infrastructure, specialist availability, connectivity, and dataset composition that do not reflect SSA healthcare realities. This paper proposes that context-aware neuroengineering, treating the specific conditions of SSA clinical environments as primary engineering design inputs rather than post-hoc implementation barriers, is a necessary reorientation for the field. Through a structured decomposition of SSA-specific engineering constraints including power infrastructure variability, offline-first connectivity requirements, cost and maintenance parameters, clinician capacity considerations, and the representational absence of SSA patient populations in published EEG datasets, we define what context-aware EEG diagnostic design demands in practice. These constraints are examined through a comparative analysis of four low-resource EEG diagnostic systems developed or deployed in SSA settings: the SEEDS-derived convulsive epilepsy diagnostic aid, a tablet-based EEG system deployed in the Republic of Guinea, a graph attention network system tested on recordings from Nigeria and Guinea-Bissau, and a published TinyML-based embedded AI seizure detection system developed for resource-constrained deployment but not yet validated within SSA clinical environments. Analysis of these cases surfaces consistent design principles that distinguish contextually grounded systems from adaptations of high-resource tools and reveals persistent gaps that the field is only beginning to address. The paper concludes by proposing directions toward a more comprehensively contextualised neuroengineering practice oriented to the realities of SSA healthcare systems.

### Digital Signal Processing for Biomedical Calibration Applications: FPGA-Based Processing of ECG Signals Using VHDL for Biomedical Calibration Applications

*Ambesi Pieranne Manka, Joseph Rugut Kibet and Bih Njimbong*

Biomedical signal generation and calibration are essential components of healthcare quality assurance. Among the vital signs continuously monitored in clinical settings, cardiac electrical activity recorded by the electrocardiogram is of primary clinical importance, particularly in cardiology, anesthesia, intensive care, and emergency medicine. ECG device calibration requires a reference signal generator capable of reproducing both Normal and arrhythmic waveforms at controlled amplitude and timing parameters. However, comprehensive FPGA-based implementation covering multiple arrhythmic signal types on the Altera FPGA board platform is still a lap. In this study, ECG signals corresponding to Ventricular Tachycardia (210 bpm), Ventricular Paced (75 bpm), and Atrial Flutter (150 bpm) will be mathematically modelled, designed, and implemented on the Altera Cyclone V SoC Field Programmable Gate Array (FPGA) using VHDL in the Altera(Quartus) design environment. Each ECG waveform will first be modelled as a piecewise mathematical function and the resulting amplitude values will be pre-computed and stored within the FPGA Programmable Logic fabric. MATLAB-based ECG signals will serve as the reference, and the FPGA-generated outputs are validated by computing the Mean Squared Error (MSE) between MATLAB and Quartus simulation amplitude values at corresponding time points. This study demonstrates that FPGA-based ECG signal generation is achievable using VHDL on the Altera Cyclone V SoC platform, providing a hardware-implemented ECG calibration system applicable in low-resource healthcare settings.

### Cardiac chamber organoids derived from human induced pluripotent stem cells

*Clara Presciutti, Marianna Langione, Mattia Dimitri, Caterina Credi, Federico Carpi and Jose Manuel Pioner*

In vitro models currently used to study cardiomyopathies fail to reproduce the structural and functional complexity of the human heart. To address this challenge, we are developing a three-dimensional heart chamber organoid based on a fibrin/Matrigel hydrogel molded around a Foley catheter to mimic a ventricular cavity. The construct, supported by 3D-printed structures and compatible with multiwell culture plates, encapsulates cardiomyocytes derived from human-induced pluripotent stem cells. The chamber is designed to accommodate a pressure sensor for investigating pressure-volume relationships, which cannot be obtained with conventional in vitro models. This approach lays the groundwork for the development of patient-specific cardiac organoids for the study of cardiomyopathies and the evaluation of personalized therapies.

**Poster Session**

Session 13
Tuesday September 15, 13:30-14:30

### Artificial Intelligence in Healthcare Systems: Applications, Challenges, and Future Directions

*Sushil Chaudhary*

Artificial intelligence (AI) has rapidly emerged as a transformative technology in the healthcare sector, enabling improvements in patient care, diagnosis, and system efficiency. This paper presents a systematic review of AI applications in healthcare, including clinical decision support systems, medical imaging, predictive analytics, robotic surgery, and healthcare administration. It also highlights key challenges such as data privacy, ethical concerns, and algorithmic bias. Finally, future directions including explainable AI, IoT integration, and precision medicine are discussed.

### Standardized Lung Cancer Detection framework for the Medical Open Network for AI

*Martina De Salazar, Patrizia Vizza, Giuseppe Tradigo and Pierangelo Veltri*

The integration of AI-based techniques, such as Deep Learning (DL), into lung cancer diagnostics represents a pivotal challenge in computational oncology, requiring large-scale, high fidelity datasets to ensure model robustness. However, the development of reliable DL pipelines is frequently impeded by data heterogeneity, such as DICOM, NIfTI, and MHD and stringent data privacy regulations. To address these bottlenecks, we present an extensible framework built upon the Medical Open Network for AI (MONAI). Our architecture contains a complete and reliable workflow, which entails four specialized modules: (i) multi source data gathering, (ii) data transformation, (iii) standardized data preprocessing, and (iv) result visualization. By providing a scalable "plug-in" architecture for MONAI, this framework facilitates the integration of several public and private repositories, ensuring technical interoperability for multimodal applications, including PET imaging.

### ESTABLISHMENT OF ROBOTIC AND AI CALIBRATION CENTRE IN LOW RESOURCE SET UP

*Elizabeth Kamusa*

The establishment of robotic and AI calibration centre in Vihiga County is essential for improving the accuracy, reliability, and safety of measurement systems in healthcare, industry, and trade. Calibration ensures that equipment operates within acceptable standards by comparing measurements against recognized references. This study examines the need, feasibility, and potential impact of setting up a calibration facility within the county. A descriptive research approach was used, relying on secondary data from government reports, healthcare institutions, and engineering practices in Kenya. Findings indicate that the absence of a local calibration Centre leads to increased operational costs, delays in service delivery, and reduced efficiency due to dependence on distant facilities. The study further highlights the benefits of localized calibration services, including improved healthcare outcomes, enhanced industrial productivity, and strengthened regulatory compliance. The establishment of a calibration Centre is therefore recommended as a strategic investment to support technological growth and socio-economic development within the county. 1. Introduction Calibration is a fundamental process in science, engineering, and healthcare that ensures measurement instruments provide accurate and reliable results. In developing regions such as Vihiga County, access to calibration services remains limited, despite the increasing use of sophisticated equipment in hospitals, laboratories, and small-scale industries. Healthcare facilities, including Vihiga County Referral Hospital, rely heavily on properly calibrated devices such as thermometers, blood pressure monitors, and diagnostic machines. Inaccurate measurements can lead to misdiagnosis, ineffective treatment, and potential risks to patients. Currently, many institutions in the county depend on calibration services from major cities like Nairobi, which results in delays, high costs, and logistical challenges. This paper explores the importance of establishing a local calibration centre to address these challenges and improve service delivery. The establishment of this Calibration, and Testing Center will not only bring Kenya to the forefront of the MedTech industry but also stimulate economic development through job creation and the incubation of startups in the MedTech sector

### AnnoStar: An Open-Source Web-Based Tool for Expert Annotation of Autofluorescence Patterns in Stargardt Disease

*Roberto Romero-Oraá*

Stargardt disease (STGD1), caused by autosomal-recessive mutations in the ABCA4 gene, is the most common inherited macular dystrophy. Fundus autofluorescence (AF) imaging reveals a characteristic centrifugal sequence of six disease-specific patterns that reflect disease stage and carry clinical significance for grading progression and evaluating the response to emerging treatments. Despite growing interest in deep learning-based analysis of STGD1 images, methodological progress is hampered by the scarcity of large, rigorously annotated image datasets. No dedicated tool currently exists for annotating the full six-pattern taxonomy in AF images of Stargardt disease. This paper presents AnnoStar, an open-source, browser-accessible web application enabling expert annotation of these six patterns in short-wavelength (SW-AF) and near-infrared (NIR-AF) fundus images. Built on a Vue.js (Nuxt) frontend, the tool provides an intuitive mouse-driven interface with automatic overlap resolution, undo/redo support, per-class visibility control, and structured JSON export. AnnoStar constitutes a foundational resource for the construction of annotated datasets that will enable the development of computer-aided diagnosis systems for Stargardt disease.

### Hidden Costs of Inefficient Health Technology Management in LMIC Hospitals: A Quantitative Analysis from a Kenyan Tertiary Facility

*Millicent Alooh*

In LMIC hospitals, inefficiencies in health technology management (HTM) contribute to significant hidden costs including downtime, repeated repairs, premature equipment replacement, and lost service capacity. These costs are rarely quantified, limiting evidence-based decision-making and resource allocation in tertiary healthcare facilities. This study aimed to quantify hidden HTM costs and identify key drivers of inefficiency in a Kenyan tertiary hospital to inform improvement strategies. A mixed-methods design was used involving retrospective analysis of 12 months of maintenance and procurement data. Cost-of-downtime estimation models were applied, incorporating equipment downtime, emergency repairs, spare parts usage, and idle capacity due to incompatibility or poor procurement decisions. Key informant interviews with biomedical engineers and clinical staff supplemented quantitative findings. Hidden costs were estimated using productivity loss and replacement cost modeling approaches. Hidden HTM costs accounted for approximately 20–35% of annual equipment-related expenditure. Equipment downtime contributed the largest share of losses, followed by inefficient procurement decisions and delayed maintenance response. Intensive care and imaging departments experienced the highest impact, with productivity losses estimated at up to 28%. Hidden HTM costs are substantial and measurable in LMIC hospitals. Strengthening procurement systems, preventive maintenance, and lifecycle management can significantly reduce inefficiencies and improve healthcare delivery sustainability.

## FHIR API Based IoMT Data Security

*Yi-Hsuan Cheng, Ruei-Yan Hong, Chih-Yun Lee, Jiun-Hung Lin and Shih-Tsang Tang*

Background: The rapid growth of wearable devices and mobile health technologies has accelerated the adoption of the Internet of Medical Things (IoMT) for real-time physiological data acquisition. However, current data transmission and device authentication mechanisms often provide insufficient protection against unauthorized access, raising concerns regarding data integrity, source trustworthiness, and patient privacy. Objective: This study aimed to develop a secure IoMT data transmission framework based on Fast Healthcare Interoperability Resources (FHIR) APIs and to evaluate the security enhancement achieved by combining mutual Transport Layer Security (mTLS) with OAuth 2.0 compared with conventional unidirectional TLS. Methods: A secure IoMT data transmission framework based on HL7 FHIR was implemented using an IoMT client, FHIR transformation module, API Gateway, and FHIR server. ECG signals and annotations from the MIT-BIH Arrhythmia Database were converted into FHIR Observation resources, with Provenance and AuditEvent resources added to provide traceability and audit logging. Resources were packaged into FHIR Bundles and transmitted through the API Gateway under two security scenarios: conventional TLS and mTLS combined with OAuth 2.0. TLS provided server-side authentication, whereas mTLS enabled bidirectional authentication using X.509 certificates, with OAuth 2.0 managing user authorization. The API Gateway validated credentials and recorded transmission events. The framework was evaluated for interoperability, resource transmission success, traceability, auditability, authentication effectiveness, resistance to unauthorized access, and compatibility with existing FHIR-based healthcare systems. Results: The proposed framework successfully achieved standardized FHIR-based encapsulation and transmission of physiological data. Observation, Provenance, and AuditEvent resources provided consistent medical semantics, complete traceability, and audit records. Compared with conventional TLS, mTLS effectively prevented unauthorized requests at the transport layer and strengthened device authentication without requiring modifications to existing FHIR standards. All transmission and access activities were successfully logged and monitored. Conclusions: This study demonstrates a practical and interoperable IoMT security architecture that integrates FHIR APIs, mTLS, and OAuth 2.0 to enhance data security, device trustworthiness, and traceability. The proposed framework provides a valuable reference for secure IoMT deployment, FHIR API implementation, and healthcare data exchange systems.

## Application of an equipment transferability index as a decision-support tool for assessing biomedical technology obsolescence during relocation to the new San Cataldo Hospital

*Martina Carulli*

The relocation of medium- and low-technology medical equipment to the new San Cataldo Hospital in Taranto requires a comprehensive assessment of the existing biomedical equipment fleet to support decision-making on equipment suitability for transfer and replacement due to obsolescence. Methods: The study proposes the implementation and use of a Transferability Index (ITA) as a decision-support tool for assessing the technological status and level of obsolescence of biomedical equipment. The ITA index was developed starting from models reported in the literature (IPS), which were adapted by introducing two new parameters: clinical adequacy (X4), assessed through questionnaires administered to hospital departments using a Likert scale (1–5), and IT obsolescence (X5), determined based on the software acquisition year. In particular, the index considers seven variables: equipment age relative to its expected service life (X1), availability of spare parts (X2), type of equipment (X3), clinical adequacy (X4), IT obsolescence (X5), device usage condition (X6), and maintenance costs relative to purchase costs (X7). Results: Statistical descriptive and multivariate analyses were conducted to evaluate the behavior of the ITA and the contribution of variables X1–X7. Mean and standard deviation analyses highlighted different levels of parameter dispersion, confirming the multidimensional nature of the index. The distribution of the ITA identified three classes of equipment: transferable (low ITA), obsolete (high ITA), and intermediate cases requiring further technical evaluation. Principal Component Analysis (PCA) revealed the relationships among the parameters and their contribution to the overall variability of the index. The index was applied to 1,939 biomedical technologies, demonstrating the model’s ability to objectively support decision-making processes for the transfer and renewal of the technological asset base.

## USING REAL-TIME DEVICE MONITORING, TO IMPROVE SERVICE DELIVERY, CASE STUDY, PUMWANI MATERNITY HOSPITAL

*Salome Mwaura*

In neonatal care, every second counts — real-time monitoring turns data into life-saving action In most LMICs, there is lack of affordable, continuous and reliable neonatal monitoring systems. Many newborn units face high nurse-to-patient ratios and very limited functional medical equipment. Reliance on manual device checks have led to delayed detection of critical changes to infant’s health and thus infant mortality is on the rise. Hadli provides continuous equipment tracking of certain aspects such as functionality, power fluctuations, temperature and humidity, with automated alerts and data visualization sent to facility BMEs. Some of the challenges faced during patient care include inefficient or unmonitored medical devices, insufficient budgetary allocations towards neonatal device management and increased nonfunctional equipment in hospitals. This system was developed by NEST360 and it is an IoT based real-time monitoring solution. Its key Objectives were to improve efficiency, safety and device uptime in neonatal care. Currently we are monitoring 26 devices at Pumwani maternity hospital where we can see how the devices are utilized and the frequency of outage. The system comprises of, IoT device sensors, Voltage monitor, Temperature & humidity sensor, central gateway which collects all data from sensors and transmits to cloud. The Cloud-Based Dashboard (HADLI) does remote monitoring and data visualization and alerts. Tracked parameters includes enhanced device uptime, prompt power outage detection, improved maintenance through early warning of faults, optimal thermal conditions → reduces neonatal hypothermia risks which informs data-driven decision-making in equipment budget allocation Key benefits includes preventive maintenance enabled by real-time alerts, better resource allocation by identifying underused or overburdened devices, improved operational transparency, supports timely clinical interventions and could help in budgeting plans for PPM and continuous maintenance activities – cumulative run hours help in this. Some challenges faced with the Hadli system includes sensors failure over time and not transmitting data, due to hardware related issues like breakages, membrane switch failure, etc. Device users bypassing sensor connections during patient connection hence loss of valuable data. At times, the getaways go offline due to hardware problems and data subscription delays. There are also limitation of use, as sensors are not meant for some devices and SIM and gateway connectivity challenges In conclusion, HADLI system revolutionizes neonatal care in resource-limited settings. The real-time monitoring ensures that there is better outcomes for neonates and more efficient hospital operations and the model can be scaled to other departments within the hospital.

## Expert Evaluation of a Biomedical Smart Mirror for Unobtrusive Home-Based Health Monitoring of Older Adults

*Alexandros Moraitopoulos, Konstantinos Mitsopoulos, Niki Pandria, Alkinoos Athanasiou and Panagiotis Bamidis*

Computer vision has emerged as a promising technology for unobtrusive health monitoring in home environments. This study evaluates an AI-enabled biomedical smart mirror designed for remote health monitoring to support independent living among older adults. An interactive workshop was conducted during the 2nd National Geriatrics Conference, where 11 healthcare professionals interacted with the system and evaluated it through usability and user experience surveys. The system exhibited high user acceptance, highlighting its potential as a tool for home-based elderly health monitoring.

## HEALTHCARE TECHNOLGY MANAGEMENT (HTM) IN KENYA, CASE STUDY: PUMWANI MATERNITY HOSPITAL

*Salome Mwaura*

Medical devices are developed to solve health problems and improve quality of life. Health care providers require medical devices for effective and efficient preventive, diagnosis, treatment and rehabilitation services. Due to the importance of Medical Devices, the World Health Organization (WHO) expanded its scope and replaced the term with Healthcare Technologies (HT). In Kenya traditionally, use of herbal or alternative medicine approaches was widespread and even today, we still have communities which still practice “herbal medicine”. Kenya also have some religious beliefs which prohibit people from going to hospital when sick and this practice is on the rise. Others believe that treatment using electricity can kill someone quickly and so patient resistance increases. In Pumwani hospital, we conduct community outreaches every now and then so that we can educate the population on safe deliveries so as to reduce maternal deaths. Unfortunately, the more the device technology advances, the more expensive the treatment becomes and so pregnant mothers may be unable to afford it. Again, these newer health technologies are not available in most parts of the country. This could be due to lack of infrastructure and other important amenities such as electricity. These technologies have the capabilities to: 1) improve quality of Health delivery service 2) Improve efficiency 3) Improve effectiveness 4) Reduce costs 5) Improve accessibly of health services. HT management (HTM) has a life cycle including Invention (conception), Production, Installation, Commissioning and User Training, Operation/ maintenance and repair, Decommissioning, Disposal, and then Replacement or new technology. Clinical or Biomedical Engineers (CE-BME) are responsible for management of all health technologies in the hospital and particularly medical equipment for life cycle management noted above as well as solving health care delivery problems for equipment use and improving quality of care. In Pumwani maternity hospital, most of these management/maintenance services are done in-house but we also out-source some services. We also have partners who assist with donations and required accessories for our equipment, including: 1) NEST 360, who deals with Neonatal Care, https://nest360.org/ 2) Muthaiga rotary club, https://rcnairobimuthaiganorth.org/ and 3) AMREF https://amref.org/ who supplies us with oxygen, and many others resources. In most cases, we have so much inoperable equipment due to some lack of one or more of the following: 1) Technical skills to repair this equipment 2) Inadequate technical knowledge on HT issues 3) Technical Documentation / Manuals 4) Need spare or repair parts 5) Needed repair funds 6) Administrative support In summary, Kenya needs the following to change this narrative repeated in many LMIC countries: 1) Clear national HT regulations and standards 2) Clear professional ethics and code of CE-BME practitioner procedures 3) Health policy and guidelines 4) Adequate technical training 5) Hospital Management trust and partnership The Way forward: (1) HT Policy and guidelines (at the national level); (2) Team work…..and best management practices within CE-BME; and (3) Encouraging innovation and creativity within CE-BME. In conclusion, proper use and management of health technologies can bring a revolutionary change in the health sector. For health workers, embracing HT is inevitable. For patients, they are becoming increasingly aware of their health rights and available clinical best practices due to accessible information on the internet and other information sources, and are also aware when these practices are not followed. For health leaders, there is an increasing need for CE-BME to expand and communicate their knowledge of best practices for best quality HTM.

## Real-time Triple-Modal Photoacoustic, Ultrasound, and Fluorescence Imaging with Transparent Ultrasound Transducer

*Jeongwoo Park and Chulhong Kim*

Combining optical imaging (OI) for functional/molecular data with ultrasound (US) for anatomical structure offers significant synergistic potential. However, the effective integration of these modalities has been hindered by the opacity of conventional transducers, which prevents coaxial light delivery and leads to bulky, inefficient probes. While transparent ultrasound transducers (TUTs) offered a path to integration, progress has been limited to single-element transducers. These are impractical for clinical settings, lacking real-time capabilities and requiring mechanical scanning. We bridge this critical gap with a handheld, tri-modal imaging system built around a 64-channel, 7-MHz transparent ultrasound transducer (TUT) array. This design enables simultaneous and coaxial real-time ultrasound (US), photoacoustic (PA), and fluorescence (FL) imaging from a single, compact probe that integrates all necessary optics and a camera. System capabilities were validated in preclinical models using indocyanine green (ICG) to map blood and lymphatic vasculature. We also demonstrated dual-modal (US/PA) imaging on healthy volunteers, mapping superficial vascular structures and hemoglobin oxygen saturation (sO2). As a key clinical demonstration, the system was employed for guidance during lymphaticovenous anastomosis (LVA) microsurgery in lymphedema patients. The tri-modal data provided precise, real-time localization of both lymphatic and blood vessels, facilitating the procedure. This work establishes the clinical viability of TUT-array technology as a powerful platform for surgical guidance and real-time diagnostics.

## Innovation and healthcare system performance in European Union countries: the mediating role of digital eHealth maturity

*Joanna Machnik-Słomka, Elżbieta Pawłowska and Arkadiusz Szamal*

Innovation and the digital transformation of healthcare systems are increasingly recognized as key factors contributing to improved health outcomes. Existing research points to the potential importance of innovative solutions and digital technologies for improving the performance of the healthcare system; however, the mechanisms linking the level of innovation to health outcomes remain insufficiently understood. The aim of this article is to identify the relationship between the level of innovation and the healthcare system performance in European Union countries and to verify the mediating role of digital eHealth maturity in this relationship. The level of innovation was determined using the Summary Innovation Index, while the digital eHealth maturity was measured using the Composite eHealth Score. The performance of the healthcare system was assessed using the authors' Healthcare Outcomes Performance Index (HOPI), constructed on the basis of normalized values for life expectancy, avoidable mortality, and unmet medical care needs. A statistical analysis was conducted. Descriptive statistics, the Shapiro–Wilk test, Spearman’s rank correlation, linear regression, and mediation analysis were applied. The results showed a significant positive relationship between innovation and the performance of the healthcare system. However, no significant mediating effect of digital eHealth maturity was confirmed. This means that innovation may be directly associated with better healthcare system outcomes, while digital eHealth maturity alone does not significantly explain this relationship. The findings point to the need for further research on a multidimensional approach to assessing the factors that shape the performance of the healthcare system.

## Deep Learning-Based Binary Classification of Knee Cartilage Damage Using Anteroposterior Knee Radiographs

*Chung-Yu Lo, Shuo-Suei Hung and Hung-Wen Chiu*

Knee osteoarthritis (KOA) is a leading cause of disability worldwide. Radiographic assessment using the Kellgren–Lawrence (KL) grading system is widely used but primarily reflects osseous changes rather than cartilage integrity. Arthroscopy remains the gold standard for cartilage evaluation but is invasive. This study develops a deep learning model for predicting cartilage damage using AP knee radiographs. A retrospective cohort of 833 patients was analyzed. ROIs were labeled using the ICRS grading system and dichotomized into mild (I–II) and severe (III–IV). A ResNet-50 shared-backbone model achieved balanced accuracy of 0.822 and ROC-AUC of 0.893. This approach demonstrates potential as a non-invasive clinical decision support tool.

## Poster Session

Session 20A
Wednesday September 16, 13:30-14:30

### An Automated, AI-Driven Safety Alert Cross-Referencing and Workflow Triage Engine for Distributed Healthcare Asset Networks

*Lok Him Tse, Yuk Yin Li, Cheuk Hin Rico Man and Hiu Ching Poon*

Background: Traditional clinical engineering departments must maintain rigorous policies for managing medical device recalls and hazard alerts. These notifications originate from diverse sources, including manufacturers, regulatory authorities, and independent services such as ECRI Alerts [1] and RASMAS [2]. However, according to the U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH), the number of recalls issued increased by 97% between 2003 and 2012 [3]. This upward trajectory has persisted into recent years, representing a continuous escalation in global alert volumes up to the present day. Within large-scale healthcare systems, daily manual screening of this expanding volume poses an operational difficulty and increases the risk of omissions [4]. Conventional manual cross-referencing of textual reports against extensive inventories causes delays, potentially postponing corrective actions and compromising patient safety [5]. This study presents a closed-loop, AI-assisted framework to optimise workflow efficiency, traceability, and standardisation. Method: An AI-assisted Safety Alert Workflow Engine was developed utilising a centralised asset database. An automated data pipeline was created to extract safety information directly from regulatory websites, such as the FDA and the Therapeutic Goods Administration (TGA), while Optical Character Recognition (OCR) technology was integrated to parse unstructured recall documents from manufacturers [6]. A Large Language Model (LLM) was deployed to summarise these raw data streams, creating structured database entries containing specific fields: manufacturer, brand, model, serial number, lot, recall class, and source. The engine then cross-referenced these structured attributes against the inventory to identify affected assets. A clinical risk matrix prioritised alerts, automatically generated action plans, and dispatched notifications to engineers via a centralised platform, integrated with device location identifying and tracking [7]. Result: The system enabled automated cross-checking against the master medical device asset database and enables rapid identification of affected device locations, significantly reducing search time across hospital sites for timely corrective action. The transition to digital workflow has reduced the safety alert-to-field action window from several days to a few hours for high-risk cases. In addition, a dual-layer verification mechanism, integrating automated screening with human validation, has enhanced overall system reliability. Together with real-time auto-logging of field actions, the framework further strengthened auditability and data traceability. Conclusion & Significance: With the increasing diversity of medical device models and the growing volume of safety alerts, this study demonstrated the value of automating and digitalising safety alert handling workflows, enabling a proactive, risk-based approach that enhances operational efficiency and supports timely implementation of corrective actions.

### Optimisation of Medical Device Lifecycle Management Through a Digitalised, Data-driven Clinical Engineering Framework

*Lok Him Tse, Hiu Ching Poon, Cheuk Hin Rico Man and Yuk Yin Li*

Background: Managing large-scale healthcare asset across multiple hospital clusters presents challenges including data fragmentation, transcription errors arising from paper-based records and inconsistent adherence to original equipment manufacturer (OEM) testing requirements [1]. Fragmented and localised record-keeping within individual hospitals limits system-wide oversee and foresee of device degradation, maintenance costs and vendor performance. In response to these challenges, this study proposes a data-driven clinical engineering framework that integrates international management standards, specifically ISO 13485 and ISO 55001, to optimise asset management across the entire lifecycle of medical devices [2]. Methods: The framework was developed based on international management standards, with ISO 13485 for medical device quality and ISO 55001 for asset management as primary references, complemented by the 4M1E methodology (Man, Machine, Material, Method, and Environment). A digitalised Biomedical Engineering Services (BES) e□Form platform was deployed to support numbers of medical devices across more than 40 public hospitals. Conventional maintenance checklists were transformed into model-specific electronic forms embedded with validation logic derived from original equipment manufacturer specifications, thereby standardising data entry and maintenance workflows [3]. The system architecture also incorporates two analytical modules: 1) Master Tester Equipment Calibration System, which manages calibration schedules and records to ensure the use of valid and calibrated test instruments; and 2) Scoring Engine integrating historical maintenance data for each equipment category, including fault frequency, parts costs, labor hours and downtime records, to provide predictive maintenance and performance insights for lifecycle value assessment. Further optimisation was achieved through a hybrid maintenance workflow, combining centralised and decentralised approaches for high-risk medical devices, including a Centralised Infusion Pump Maintenance Workshop for high-volume, controlled-condition servicing and a Decentralised Renal Technology Special Duty Unit for responsive on-site support, thereby maximising the efficient use of labor and technical expertise [4]. Results: Following implementation of the developed framework and BES e-Form platform, over 65,000 maintenance cases were managed by the platform annually, with preventive maintenance compliance consistently exceeding 95%. Moreover, the adoption of centralised and decentralised workflows enhanced turnaround time and resource utilization, resulting in up to a 30% increase in technician productivity while maintaining consistent maintenance quality across hospitals. Furthermore, operating costs were reduced by approximately 15% per asset category, attributable to the integration of predictive maintenance strategies, optimized spare parts allocation, standardised procedures and improved workforce deployment. Conclusion & Significance: The integration of ISO-based governance frameworks approach with a centralised digital data infrastructure facilitates the transition of large public healthcare systems from reactive maintenance practices to a proactive, lifecycle-oriented management model, thereby enhancing asset management across the entire medical device lifecycle.

### Mechanochromic tactile interface for handwriting and drawing analysis

*Giacomo Sasso, Alessandro Pagani, Gianni Pedrizzetti, James Busfield and Federico Carpi*

Early diagnosis and monitoring of neurodegenerative diseases can benefit from quantitative digital biomarkers of neuromuscular function. In this context, handwriting analysis provides a rich, non-invasive source of motor and cognitive information, capturing fine features of sensorimotor control. Here, we present the development of a vision-based tactile sensing interface for quantitative assessments of handwriting and drawing. The novel device integrates a soft mechanochromic tactile sensor that changes structural colour under mechanical deformation. By detecting pixel colour (hue) variations with an internal camera, the system can track contact position and applied pressure with high spatial resolution, fast response, and low hardware complexity. We present ongoing characterizations of the first prototype version of this new device.

### Precision Mental Health Analytics: Scalable Brain-Based Models for Population Insights

*Anushree Bhople*

Mental health diagnostics often rely on symptom based assessments, limiting the discovery of predictive biomarkers. This paper introduces a scalable framework that integrates normative modeling and self-supervised representation learning to decode individual heterogeneity in brain structure and function across 100,000+ multi-modal scans. Using Gaussian process regression for normative trajectories and variational autoencoders with contrastive learning for latent feature extraction, we generate subject-level deviation scores that capture clinically meaningful variation. Key results show that (i) deviation patterns identify four neurobiological subtypes within schizophrenia with distinct symptom profiles, (ii) multi-modal representations achieve 0.84 AUC in distinguishing patients from controls, and (iii) longitudinal models predict treatment response with 71% accuracy at 12 weeks. These findings demonstrate that scalable brain-based models can provide personalized, interpretable insights for improved and fairer mental health care.

### Wearable pneumatic tactile displays for softness rendering in virtual abdominal palpation

*Gabriele Frediani, Filippo Cipriani and Federico Carpi*

Simulating soft object interactions is essential for creating immersive and realistic virtual reality environments, particularly in applications such as medical training, where the perception of tissue softness is critical. However, current haptic technologies still face limitations in reproducing the mechanical compliance of fingertip interactions. Soft actuators offer a promising solution, thanks to their intrinsic compliance, lightweight design, and ability to conform to the skin, enabling more natural cutaneous stimulation. Taking advantage of these properties, we recently developed compact, wearable tactile displays based on pneumatic actuation. To evaluate the performance of this technology in a realistic scenario, we developed a virtual abdominal palpation system integrating hand tracking with wearable pneumatic fingertip displays. We present preliminary psychophysical tests on healthy participants that show high accuracy in discriminating between regions of a simulated abdomen with different levels of softness.

### An Online Transfer Learning Framework with Residual Compensation for End-to-End Hip Angle Prediction in Post-Stroke Gait Using sEMG

*Jinjian Jiang, Davide Piaggio and Neil Evans*

Accurate continuous prediction of lower-limb gait trajectories is essential for the effective control of rehabilitation robots that provide personalized assistance to post-stroke patients. However, current state-of-the-art machine learning methods rely on offline batch learning trained with pre-collected data, which is constrained by the limited availability of post-stroke data and the substantial distribution differences in sEMG signals and kinematics across patients. These differences violate the assumption that source and target domains share the same distribution, undermining the direct deployment of offline-trained models. While offline transfer learning can mitigate this gap, it still requires patient data to be collected in advance, which is costly and burdensome—particularly for severely impaired individuals. To address these challenges, this paper proposes an online transfer learning (OTL) framework for end-to-end continuous prediction of hip joint angles in post-stroke patients across multiple walking modes using sEMG signals. The framework couples a temporal convolutional network (TCN) with a recursive least squares (RLS)–based autoregressive residual compensator. The source-domain network is pre-trained offline on data from healthy individuals walking at self-selected speed, and the target-domain network is updated in real time from streaming patient data via a system-wide update strategy with two data buffers, eliminating any need for pre-collected patient data. The end-to-end design removes manual feature engineering, simplifying the signal-processing pipeline and enabling real-time deployment. The method was validated on a public dataset (15 healthy adults, 26 post-stroke survivors, 16-channel sEMG) across five walking modes and benchmarked against LSTM, MLP, offline TCN, and CNN-BiLSTM baselines. The proposed framework achieved RMSE $\leq 2.49°$, NRMSE $\leq 0.0679$, NMAE $\leq 0.051$, and $R^2 \geq 0.91$ across all walking modes, significantly outperforming every baseline ($P < 0.001$). Its total system response time of approximately 40–50 ms—well below the 200 ms prediction interval—confirms real-time feasibility, and channel-level ablation showed the learned feature attributions are consistent with established biomechanical findings. In conclusion, the proposed OTL framework delivers accurate, robust, and generalizable real-time hip-angle prediction without pre-collected patient data, reducing experimental burden and demonstrating strong potential for cost-effective, personalized lower-limb rehabilitation robots.

### A Machine Learning Framework for the Early Detection of Hepatocellular Carcinoma Using Computational Gene-Pair Signature Analysis

*Priyanka Sarkar and Ernesto Iadanza*

Hepatocellular carcinoma (HCC) is still one of the most important causes of cancer-related death in the world, which is largely attributable to the delay at diagnosis and the limited sensitivity of the current biomarkers for early diagnosis. High-throughput genomic sequencing, artificial intelligence (AI) and precision medicine have created potential to change the way people are diagnosed with HCC from reaction to prediction and prevention. This chapter introduces a detailed machine learning based analysis of the gene pair signatures for the early detection of HCC, highlighting the growing importance of the relative gene expression of the machine-learned gene pair signatures as informative and powerful biomarkers. In contrast to single-gene signatures, gene-pair signatures capitalize on the concept of relative expression ordering, thus improving platform, population, and disease context reproducibility, and are able to detect the dynamic molecular interactions in hepatocarcinogenesis. Next generation computational approaches are discussed – deep learning, graph neural networks, transformer models, self-supervised learning and foundation models – in development of the predictive gene-pair signatures, discovery, optimisation and validation. It also explores some of the challenges of integrating multi-omics data, federated learning, digital twin cohorts, liquid biopsy, and explainable AI into creating an adaptive diagnostic ecosystem that learns over time and can support clinical decision making. The focus is on the challenges around translation such as regulatory approval, clinical validation, algorithmic fairness, data privacy and the ethical considerations of AI-powered genomic diagnostics. Future outlook includes organoid validation and validation of features, feature selection in the context of quantum technologies, translating criteria for precision oncology to specific populations and establishing cost-effective point-of-care screening systems to enhance global access to precision oncology. It presents an outlook on the problems of deep learning in the era of post-genomic HCC diagnostics by combining the developments in computational biology, machine learning, and systems genomics. These plans feature gene-pair signatures as surrogates for living patients, continuously growing with biological discoveries and clinical experiences, and ultimately responsible for earlier detection, individualized surveillance, and enhanced therapeutic results, all ideally with a backdrop of a long-term vision of precision prevention to diminish the global burden of HCC.

## Development and Preliminary Validation of a Personalized Intraoral Device for Bite-Force Measurement

*Ilona Łysy, Miłosz Chrzan, Sławomir Suchoń, Michał Burkacki, Aleksandra Błaszczyk, Sandra Kaczmarek, Katarzyna Jochymczyk-Woźniak and Wojciech Wolański*

Bite force is an important functional parameter used to assess the biomechanical performance of the stomatognathic system. Its measurement is relevant in dentistry, prosthodontics, orthodontics, physiotherapy and biomedical engineering, particularly for evaluating occlusal function, masticatory efficiency, parafunctional activity and temporomandibular disorders. This work presents the development and preliminary verification of a prototype intraoral device for the non-invasive measurement of bite-related compression forces. The proposed solution is based on a mouthpiece-like measuring insert equipped with pressure-sensitive elements and designed to enable independent assessment of loading on the left and right sides of the dental arch. The design process included the development of the bite element geometry, material selection and preparation of the prototype for controlled compression testing. Particular attention was paid to minimizing the influence of the device on natural mandibular positioning while maintaining mechanical stability and measurement sensitivity. An important feature of the concept is its potential for personalization using CAD/CAM workflows and additive manufacturing, allowing adaptation to individual dental arch morphology. Preliminary tests confirmed the feasibility of distinguishing unilateral loading and registering side-specific pressure changes under laboratory conditions. The prototype may serve as a basis for further calibration, optimization and development of a low-cost, patient-specific tool for objective occlusal load assessment.

## Sustainable Medical Oxygen Ecosystems and Green Hospital Technologies: Transforming Last-Mile Healthcare Delivery in East Africa

*Joseph Rugut Kibet, Ambesi Pieranne Manka and Bih Njimbong*

Abstract. Reliable access to medical oxygen remains one of the most urgent unmet healthcare needs in many low- and middle-income countries. In Africa, hospitals and rural health facilities continue to experience shortages caused by weak infrastructure, unstable electricity, inadequate maintenance systems, and fragmented supply chains. This paper examines sustainable medical oxygen ecosystems and green hospital technologies as scalable solutions for last-mile healthcare delivery. A review-based and implementation-oriented approach was adopted using published evidence, field experiences from oxygen infrastructure projects, biomedical engineering interventions, and existing literature on sustainable healthcare technologies Findings indicate that decentralized oxygen systems, Oxygen-as-a-Service models, renewable-powered concentrators, pressure swing adsorption plants, digital monitoring platforms, and strengthened biomedical engineering systems can significantly improve reliability and affordability. Lifecycle-oriented approaches outperform donation-based models that often fail after initial deployment. Africa has an opportunity to leapfrog legacy systems by integrating resilient oxygen infrastructure with climate-smart hospital design. Sustainable oxygen ecosystems should therefore be prioritized in health financing, universal health coverage plans, and emergency preparedness strategies.

## Quality Assurance of Radiology Equipment as a Prerequisite for AI-Driven Diagnostics in Low and Middle Income Countries: Evidence from Sub-Saharan Africa

*Joseph Rugut Kibet, Bih Njimbong and Ambesi Pieranne Manka*

The integration of artificial intelligence (AI) and machine learning (ML) into medical imaging has generated significant optimism for closing the diagnostic gap in low and middle income countries (LMICs). Yet a critical and largely unaddressed prerequisite persists in the literature: the functional integrity and calibration quality of the radiology equipment on which AI algorithms depend. A miscalibrated X-ray unit or poorly maintained CT scanner introduces image artefacts and dosimetric errors that no algorithm can correct downstream. This paper argues that without rigorous quality assurance (QA) and quality control (QC) frameworks for radiology equipment, AI assisted diagnostics cannot achieve reliable clinical outcomes in resource constrained settings.

Drawing on a scoping review of AI adoption in LMIC medical imaging and field evidence from the Christian Health Association of Kenya Medical Engineering Services (CHAK MES), a certified centre of excellence in radiation safety and radiology equipment maintenance in Sub-Saharan Africa, we examine the intersection of equipment integrity, AI diagnostic performance, and regulatory compliance. Five structural barriers are identified and a staged implementation framework is proposed that positions QA/QC as the foundational layer upon which context-appropriate AI diagnostic tools must be built. The findings carry direct implications for biomedical and clinical engineers, health policymakers, and the global community working toward equitable diagnostic access.

## Nonlinear Trimodal Regression Analysis-Based Imaging Biomarkers for Early Prediction of Chronic Disease Onset

*Michela Russo, Lazzaro Cappiello, Federica Kiyomy Ciliberti, Carlo Ricciardi, Alfonso Maria Ponsiglione, Halldór Jónsson Jr, Paolo Gargiulo and Francesco Amato*

With the progressive aging of the population, the prevalence of chronic diseases, such as type 2 diabetes mellitus (DM2) and cardio- vascolar disease, including chronic heart failure (CHF), increases signifi- cantly, posing a growing challenge for healthcare systems. Recent advances in imaging analysis, particularly the application of non- linear trimodal regression analysis (NTRA) to radiodensitometric distri- butions in CT cross-sections, have enabled a detailed characterization of muscle, fat, and connective tissue quality; using the AGES-Reykjavik dataset, we analyzed 3,156 older adults over a five-year period and ex- tracted 11 parameters derived from NTRA, where N, μ, σ, α represent amplitude, location, width, and skewness, respectively. The data were analyzed using Linear Mixed Effects Models (LMMs) which allow mod- eling both intra- and inter-individual changes over time. The model was used to compare subjects who remained healthy with those who devel- oped the disease during follow-up, evaluating differences both at baseline and in their longitudinal trajectories over time. LMM analysis showed significant differences (p-value ≤ 0.05) for both diseases. Compared to the healthy group, DM2 cases showed higher (Nfat, Nmuscle, μmuscle and Nconnective) at T0, with Nconnective exhibiting also a faster increase over time. For CHF, baseline predictors included μfat, σmuscle, μmuscle, αmuscle, Nconnective and μconnective , while longitudinal divergence was driven by αfat, Nmuscle and σconnective. These results demonstrate that NTRA parameters can effectively dis- criminate pathological progression from physiological aging, offering a non-invasive tool for early detection of DM2 and CHF via routine CT scans.

## Sealed Rare-Gas System for Cold Atmospheric Plasma and Electromagnetic Energy Delivery

*Emil Valchinov and Nicolas Pallikarakis*

Cold atmospheric plasma (CAP) has attracted increasing interest for biomedical applications including sterilization, wound healing, tissue modulation, and experimental oncology. However, many existing CAP platforms rely on continuous external gas supply, increasing system complexity, operational cost, and limiting portability. This paper presents the design and preliminary characterization of a compact programmable plasma system based on a sealed reduced-pressure rare-gas applicator energized by resonant high-voltage excitation generated through a dedicated flyback transformer stage. The applicator simultaneously functions as gas reservoir, dielectric barrier, discharge chamber, and treatment interface, thereby eliminating the need for continuous gas flow during operation. The prototype operates from a 12 V DC supply and uses a pulsed high-voltage stage capable of kilovolt-class excitation. Electrical measurements demonstrated no-load electrode voltages up to 17 kVpp and loaded operation in the kilovolt range under multiple coupling conditions. The chamber interface was intentionally designed to exhibit a negative mean surface potential, which may be relevant for future bioelectrical interaction studies. Continuous thermal testing over 30 min showed chamber temperature increase from 22°C to only 30°C, while the switching-stage heatsink stabilized near 60°C. In addition to the fixed-frequency hardware control mode, the architecture includes a BLE-capable controller module for future programmable pulse delivery and user-defined treatment protocols. These findings support the feasibility of sealed rare-gas plasma systems as a promising platform for portable and controllable biomedical plasma technologies.