Chair of Medical Engineering at Helmholtz-Institute for Biomedical Engineering | RWTH AACHEN UNIVERSITY

Chair of Medical Engineering
Faculty of Mechanical Engineering

Engineering Science and Innovation for better Health Care

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Introduction

The mission of the Chair of Medical Engineering (mediTEC) of the RWTH Aachen University is to provide an active link between interdisciplinary basic sciences and application-oriented engineering research and development of innovative solutions for a better health care.
In September 2025 we celebrated the 20th anniversary of "our" mediTEC. Over the past 20 years, a total of 72 research assistants, 5 BTVs, 22 trainees, and 375 student assistants, i.e., 474 mediTEC employees, have worked on more than 70 research projects with a total third-party funding volume of approximately □25 million. In September 2025 the proportion of women employees at mediTEC was exactly 50%! Apart from international publications and a practical transfer and implementation of scientific findings, the education of our students from different disciplines and specialties is a major objective. We look back on approximately 4,500 corrected written exams and oral examinations, over 800 supervised student theses (including 398 diploma and master's theses alone), a pandemic that we mastered together, 34 doctorates (including 10 with honors (summa cum laude) and 10 female doctoral students), 7 of whom are meanwhile professors themselves. Since 2009 mediTEC coordinates the newly established master's program "General Mechanical Engineering" of the Faculty of Mechanical Engineering (winter term 24/25 with 252 students, 22.6% women) including the specialization in medical engineering. Based on networks of international partners from research, industry and clinics, a wide range of research projects were initiated and successfully conducted. Among others, large projects such as the BMBF-Projects OrthoMIT (2005-2011; > 15M□) or OR.NET (2012-2016-2016; > 18,5 M□) have been coordinated by mediTEC. Currently the RUBIN alliance Medi.NET (3/24-2/27) with 15 partners and an overall funding of 6,3 Mio □ certainly is another highlight.
In addition to basic research grants and public funding, industrial cooperations represent an important complementary application-oriented pillar of our work for the transfer of our research and developments into clinical applications. This annual report summarizes some examples of our project activities in 2025.

Selected Projects

CSF Biomechanics

We investigated the impact of lumbar spinal canal stenosis on cerebrospinal fluid (CSF) dynamics and its connection to idiopathic normal pressure hydrocephalus (iNPH). Using our validated in vitro model of the CSF system, we aimed to understand the influence of varying degrees of stenosis on intracranial pressure (ICP), compliance and cervical CSF flow. The findings indicate that mild to moderate stenoses do not significantly change CSF dynamics, suggesting that the system can compensate for these changes. In contrast, severe stenoses lead to significant alterations in ICP and CSF flow patterns, which may be associated with typical manifestations seen in iNPH.
The study highlights the critical role of dynamic compliance in maintaining healthy CSF circulation and ICP levels as well as the need for further research, including age-related changes in surrounding tissues. Overall, these insights could lead to new clinical approaches for managing patients with iNPH.

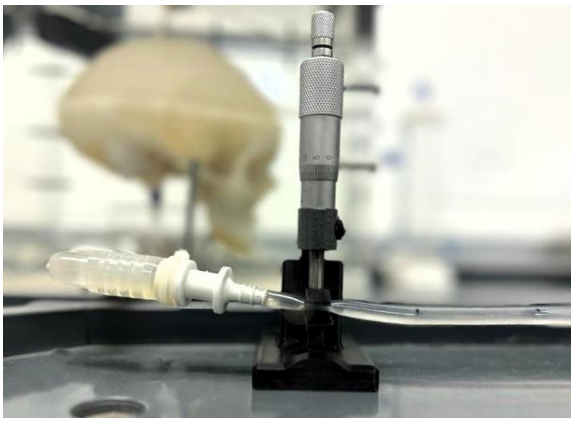

Fig. 1: In-vitro set-up for simulation of spinal canal stenosis.

Patient Specific Hip Biomechanics in THA

Detailed three-dimensional preoperative planning for total hip arthroplasty (THA) becomes more relevant in the context of younger, more active patients with higher requirements on the prosthesis. The load distribution is particularly relevant in order to avoid complications such as loosening of the prosthesis or wear. Therefore, the prediction of the postoperative load situation based on preoperative data is of interest. Based in motion data provided acquired at Charité Medical University Center, Berlin we analysed the hip joint force of 100 probands in different load situation during activities of daily living.

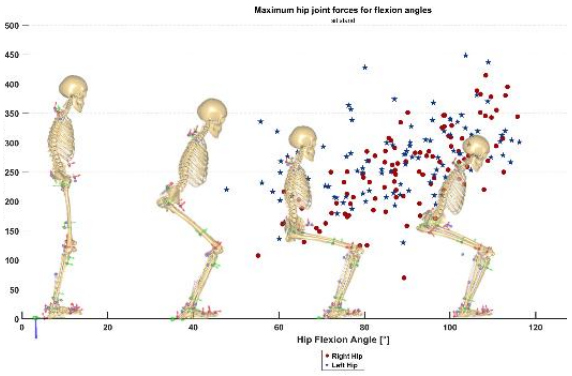

Fig. 2: Hip joint forces while getting up from a chair

Patient Specific Knee Biomechanics in owHTO

Open-wedge high tibial osteotomy (owHTO) is a joint-preserving procedure performed in young and active patients suffering from medial unicompartmental osteoarthritis. Although owHTO is a well-established technique, it is complex to perform even for experienced surgeons, and relatively high rates of overcorrection are reported. Patients with overcorrection often require

conversion to total knee arthroplasty within a few years. Therefore, accurate preoperative planning is essential. Together with our clinical partners at BGU Murnau and LMU Munich, we investigate patient-specific biomechanics in owHTO patients. The aim of this work is to improve biomechanical understanding of owHTO and to support more reliable, patient-specific surgical planning.

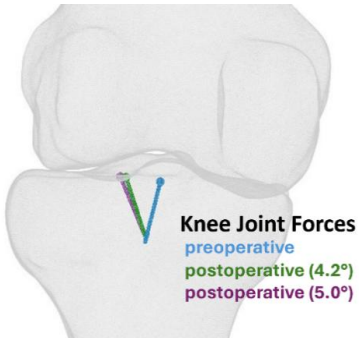

Fig. 3: Force displacement for 4,2°/5° opening angle.

Robotic Ultrasound of the Knee

Robotic ultrasound systems are an emerging technology. These systems aim to either bring ultrasound experts to rural areas using telemanipulated robotic ultrasound, or to assist and relieve medical staff using collaborative or autonomous systems. Assisting tasks for the latter include optimising probe orientation for high-quality images and autonomous scanning procedures, in which the system identifies the region of interest and performs the scan.

Our approach towards robot-assisted US for 3D imaging of the knee can be used to plan patient-specific knee implants. Compared to CT imaging, the advantage is a more compact, cost-efficient, radiationfree approach. The pipeline is fully automated: it detects the skin surface with a depth camera, plans an automatic path and performs an ultrasonic scan, followed by AI- and SSM-based automated segmentation and reconstruction of bone.

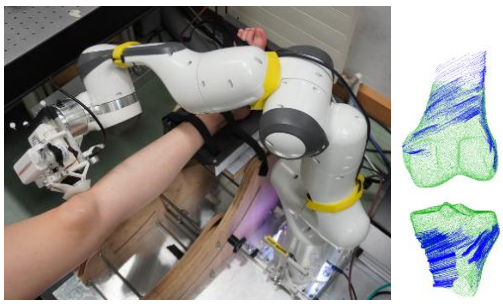

Fig. 4: Robotic Ultrasound System - 3D Knee Reconstruction.

Cooperative Surgical Robotics

The development of surgical robots is a particular challenge due to high risks and intrinsic safety requirements. Modular system architectures have been proposed as a potential solution to meet the specific requirements of different clinical applications. Due to the variable and complex boundary conditions in surgery, cooperative robot systems combine the precision of technical systems with the expertise of the surgeon. To support the development of usable cooperative surgical robots, basic research in cooperation with the Institute for Human Factors, Aachen aims to develop model-based methods for scenario-based selection and evaluation of different interaction patterns of different surgical task scenarios. The parameterization of these interaction patterns allows cooperative assistance systems to be adapted to the specific requirements of a given clinical applications. This will enable the systematic support of the development of cooperative robotic assistance systems in the early stages of the development process in the future.

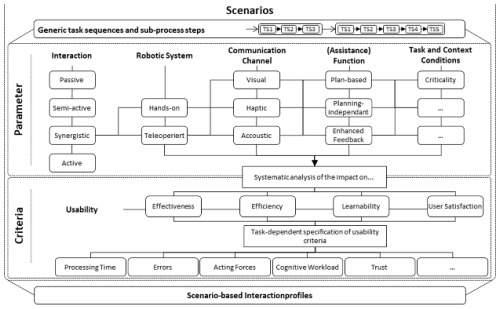

Fig. 5: Interaction profiles of cooperative surgical robotic systems

AI-assisted Monitoring in Dental Implantology

Peri-implant bone thickness influences tissue stability and the risk of peri-implant diseases. Periapical Xrays and digital volume tomography (DVT) are considered standard monitoring means, but are limited in clinical routine by image quality, radiation exposure, costs, and artifacts. Together with our clinical partners of the University Clinics in Graz (Austria) and Aachen we investigate ultrasound (US) for non-invasive, radiation-free imaging of the bone surface. We developed an AI-assisted US bone thickness measurement: The patient specific instrument (PSI) routinely used for implantation is extended by a holder for an US probe.

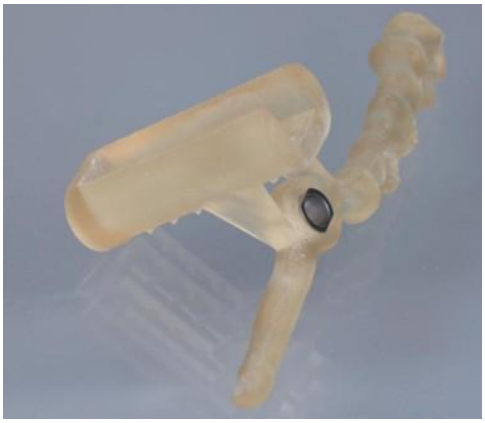

Fig. 6: PSI with integrated US probe holder

Thereby, the spatial reference of the implant and US probe is established and allows repeatable placement of the probe for clinical monitoring. Using AIbased segmentation, the buccal bone surface in the US images is automatically segmented and the bone thickness above the implant is determined. First exvivo studies on porcine mandibles show the suitability of the new approach and a good agreement of all methods for assessing bone thickness.

The AI-supported US method enabled non-invasive, radiationfree, and examiner-independent determination and monitoring of peri-implant bone thickness.

3D Printing of Modular FUS Transducers

Ultrasound transducers are used for many different applications, with great variation in pulse shape and ultrasound power output. For example, low-intensity continuous wave ultrasound can stimulate cells and activate channels in the cell boundary. For histotripsy, high-intensity ultrasound with short pulses is used to destroy soft tissue using high negative pressures, creating cavitation bubbles within cells. Upon collapsing these bubbles rip through the tissue and can e.g. destroy tumor cells. The transducers have to be tailored to specific applications to achieve the necessary sound field and pressures with high electric efficiency. Additive Manufacturing ("3D-Printing") provides high flexibility for fabricating focused ultrasound transducers tailored to different requirements. By combining numerical simulations with 3D printing, we design single-element transducers that can be inserted into a 3D-printed housings, enabling rapid variation of the experimental setup and focus design from single transducers to phased array designs.

Fig. 7: CAD design and 3D printed transducer

Safety of Low Frequency Therapeutic Ultrasound

Ultrasound is also increasingly being used for cosmetic applications, e.g. to reduce fat or wrinkles. In devices with low operating frequencies, resonance effects can occur due to the high penetration depth, which have not yet been sufficiently taken into account in risk assessments. In 3D simulations, different scenarios were analysed on different parts of the body.

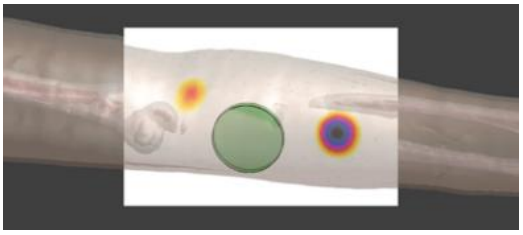

Fig. 8: Simulated resonance effects (30 kHz transducer)

Almost all scenarios exceeded critical thresholds for cavitation effects and pressure increases. Therefore, it cannot be ruled out that cavitation-related damage could occur although measurements in water bath suggest safe operation. Interestingly, the location of maximum pressure is not necessarily on the symmetry axis of the transducer. The results indicate that measurements performed in water baths alone are insufficient for risk assessment. The specific anatomical structures at the application site must be considered.

Decision support for the sterile goods cycle

Sterile supply processes for surgical instruments are highly interdependent and prone to disruption, which can lead to delays and cancellations of surgeries. Based on a survey of healthcare professionals, we identified key bottlenecks in current workflows and resources, including limited transparency, communication gaps between the operating room (OR) and the Central Sterile Supply Department (CSSD). To address these issues, we propose a Decision Support System (DSS) that integrates process and device data from both the CSSD and the OR.

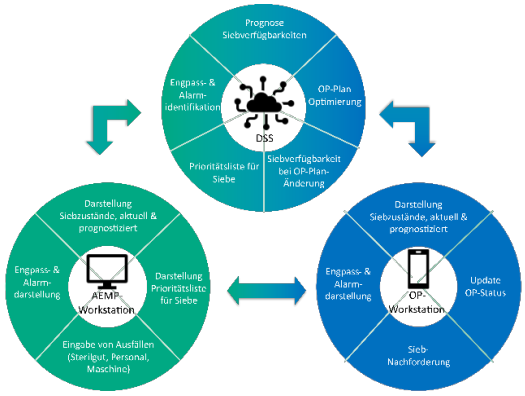

Fig. 9: Concept for a decision support system for the CSSD

As a conceptual framework, the DSS would leverage AI-driven prediction and optimization models to forecast tray availability and workload through role-specific interfaces. In practice, such a system could support surgical scheduling by providing real-time tracking and AI-generated delivery estimates, potentially suggesting schedule adjustments based on the projected availability of sterile goods. To manage supply risks, the DSS could be designed to trigger automated alerts and fast-lane protocols for critical supplies. On the CSSD side, the concept foresees a feedback loop where staff reports disruptions, such as instrument defects or resource constraints. This would enable the generation of proactive workload forecasts and tray prioritization, thereby optimize resource allocation and mitigate the impact of staff shortages.

Towards Smart Sterile Supply Cycles

The sterile supply cycle is often fragmented and operated as an open-loop process in which deviations are detected late. While smart hospital initiatives increasingly emphasize data-driven workflows, they mainly target patient-centered systems and still insufficiently integrate perioperative material logistics and sterile supply processes. In practice, this lack of end-to-end integration limits visibility across

ORs, OR management, and the SSC, making it difficult to identify recurring weaknesses such as missing or defective instruments before they disrupt surgery. As a result, deviations propagate across interconnected subsystems and are handled reactively rather than being incorporated into proactive coordination and decision-making. To address this gap, we propose a conceptual framework that unifies ORs, OR management, and the SSC into a smart hospital network using open and interoperable standards. We followed a model-driven approach that combines preliminary empirical studies with principles from industrial smart manufacturing. An online survey and benchmarking data were used to identify systemic weaknesses and translate them into functional, technical, and architectural requirements, which were iteratively refined through expert discussions. The resulting framework implements a service-oriented architecture organized into five layers (perception, network, gateway, knowledge, and application) and is supported by a hierarchical Apache Kafka-based communication backbone.

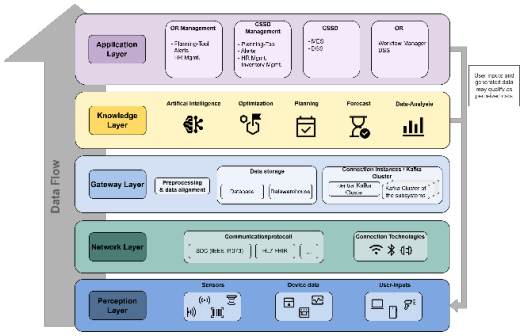

Fig. 10: ASK-KI framework.

Predictability of the Sterile Supply Cycle

The sterile supply cycle should ensure that sterile instrument sets and reprocessed medical devices are available when needed. However, timely availability is often assessed only after the operating room (OR) schedule has been set. As a result, the cycle is expected to compensate for variability, while its process dynamics are rarely incorporated into planning. In practice, the sterile supply cycle is affected by frequent disruptions, including equipment defects, fluctuating personnel availability, unexpected urgent procedures, and cascading delays across interconnected process steps. These changes are typically managed reactively and are not automatically reflected in planning decisions. To address this gap, we conducted initial investigations into time series forecasting of the sterile supply cycle using historic operational data from University Hospital Essen. We evaluated statistical forecasting, machine-learning-based prediction, and simulation-driven approaches.

The Medi.NET Project

Based on the OR.NET initiative (www.ornet.org) the ISO IEEE 11073 SDC standard family for the open communication of medical devices has been developed. However, proprietary system solutions and the lack of interoperability are still common in operating rooms (ORs), intensive care units and central sterile services departments (CSSD). Medical devices are used exclusively in terms of functions rather than optimised processes. The objective of the Medi.NET project is to develop central SDC workstations for different clinical areas with dedicated software modules (e.g. workflow manager, ensemble manager, clinical documentation) and to conduct feasibility studies for the optimization of clinical workflows and decision support for clinical users.

With the Module "Ensemble Manager" medical devices are organized safely into functional groups of devices that are allowed to communicate with each other, based on shared medical context of the device. An Ensemble Manager is currently being developed to support dynamic ensemble handling across the perioperative workflow. Devices recognize members of the same ensemble and reject control signals from devices outside the group.

The "Clinical Documentation" module enables automated, context-aware surgical reporting by fusing multimodal inputs, including endoscopic vision, SDC device data, SOP-based workflow knowledge, and intraoperative team communication. Surgical events are first captured and logged before being transformed into structured, audit-ready documentation. By integrating medical device communication with visual and spoken modalities, the module precisely infers and records surgical actions, facilitating the automatic generation of surgical records and ensuring accurate subsequent documentation. To this end, rule-based subcomponents are combined with a domain- adapted visual–language model to robustly address the task. Medical devices can now be interconnected using the manufacturer-independent SDC Standard. Technical device properties can be transmitted, but Human-Machine-Interaction details, which are crucial to the usability of the developed systems, are not yet part of this in a standardized way. Within the Medi.NET project, we developed a standardized, machine-readable XML device requirement list and a standardized process, with more than 80 categories to describe UI requirements. In addition, we developed a simulation tool to detect usability conflicts before deploying interoperable solutions.

Figure 11: SDC OR workstation demonstrator @ Tuttlingen Innovationsforum Medical Mountains 2025

Standardizing User Interface Requirements for Interoperable Medical Device Systems

Medical devices can be interconnected using the manufacturer-independent IEEE 11073 SDC Standard. Technical device properties can be transmitted, but Human-Machine-Interaction (HMI) details governing usability of the integrated systems, are not considered yet. We developed a standardized, machine- readable

XML device requirement list and a standardized development process with more than 80 categories to describe UI requirements. In addition, we developed a simulation tool to detect usability conflicts before deploying interoperable solutions.

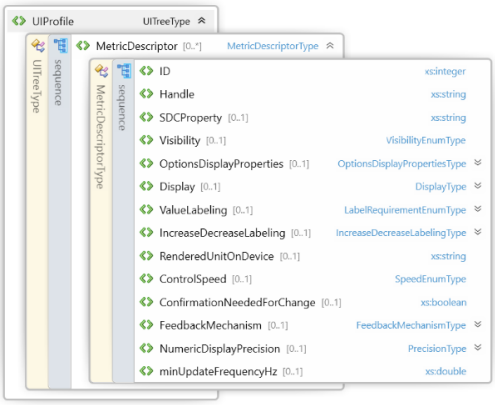

Fig. 12: Excerpt from an UI Requirement List (UI Profile).

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*Note: In this report, we only provide a short overview of selected activities. For further information on the related projects, our cooperating partners, funding agencies, sponsors and awards, please visit our website www.meditec.rwth-aachen.de or contact us directly.

Selected Publications

[1] P. Becker, Y. Li, S. Drobinsky, J. Egger, K. Xie, A. Rashad, K. Radermacher, R. Röhrig, M. de la Fuente, F. Hölzle & B. Puladi: Development and validation of collaborative robot-assisted cutting method for iliac crest flap raising: Randomized crossover trial. Scientific Reports, 2025, 15(16909), pp. 1-18
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[10] O. Yilmaz, M. Lange, K. Radermacher, F. Beger, S. Kämmer, T. Maser, P. Selig, B. Seitz, S. Kißmann & A. Janß: Interoperable medical device GUI for SDC Workstations. In: T. Ahram, W. Karwowski & J. Kalra (ed.): Human Factors in Design, Engineering, and Computing, 199, 2025, pp. 1504-1517
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The mediTEC team