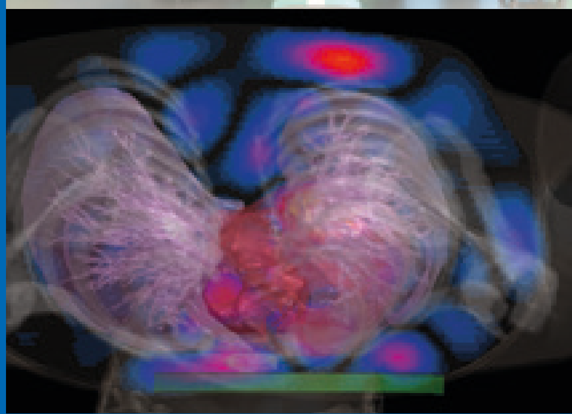
Chair of Medical Engineering
Faculty of Mechanical Engineering

Engineering Science and Innovation for better Health Care



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Introduction

The mission of the Chair of Medical Engineering (med-iTEC) 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. 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. In addition to basic research grants, industrial cooperations, corresponding to about 50% of our annual turn-over, represent an important complementary application-oriented pillar of our work for the transfer of our research and developments into clinical applications.
Based on networks of international partners from research, industry and clinics, a wide range of new projects were initiated or started. Among other projects, the start of the RUBIN alliance Medi.NET (3/24-2/27) with 15 partners and an overall funding of 6,3 Mio € by the German Ministry of Education and Research (BMBF) certainly is one highlight. The alliance is a consequent next step on the path of our OR.NET initiative and research and gathers expert knowledge from clinics, research and industry to establish a center for research, development, testing and training in the context of networked AI systems for digital ORs and clinics of the future and to increase the quality of medical care in the Aachen area.
This annual report summarizes some examples of projects in 2024.

Selected Projects
DFG-Project MOFUMO – THA Biomechanics

Current demographic changes are leading to an increasing number of THA patients in combination with higher demands on the prosthesis. This underlines the need of improved preoperative planning to ensure optimized implant and implantation parameters for the individual patient. With our partners from Charité Medical University Center (Berlin) we analysed the hip joint forces and muscle activation patterns of 100 probands to identify correlations between anthropometric data and simulated loads for different activities of daily living (ADLs).

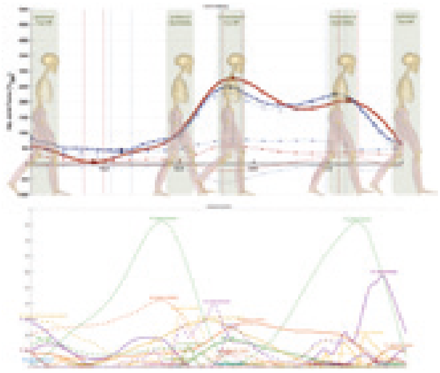

Fig. 1: Analysis of hip joint force and muscle activation pattern for ADLs (here: level walking).

Patient-Specific HTO Biomechanics

Open wedge high tibial osteotomies (HTO) is a well-established surgical procedure in case of varus deformities. These patients often develop osteoarthritis in the medial compartment of the knee joint due to an imbalanced load axis. The procedure aims to shift the load axis to achieve a reduction of medial loading.
Despite its widespread use in clinical practice, this procedure carries a risk of over- or undercorrection of the leg axis, which can lead to altered knee kinematics and compromised outcomes.
Together with our clinical partners from BGU Clinic Murnau and LMU Munich we have developed a patient-specific simulation model. Using this model, the impact of various surgical parameters on patellofemoral knee kinematics and the resultant tibiofemoral force on the tibial plateau can be analyzed.

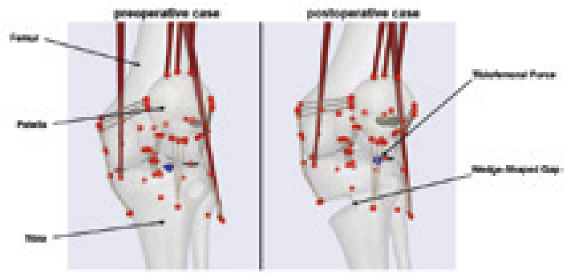

Fig. 2: Pre- vs. postoperative analysis.

MR-Compatible Pump for PC-MRI Validation

Measurement of the cerebrospinal fluid (CSF) flow by Phase Contrast magnetic resonance imaging (PC-MRI) is used to diagnose and understand the pathogenesis of normal pressure hydrocephalus (NPH). For validating flow measurements recorded with PC-MRI we developed a MR-compatible pump. We demonstrated the MR compatibility and the ability to reproduce artefact-free flows in PC-MRI. We validated the flow of the pump vs. physiological CSF flow curves. As a result, the pump generates a bidirectional pulsatile flow within a physiological range and can be set in the range of 60-90 RPM with a stroke volume of 0.9 ml. This enables the validation of flow measurements recorded by PC-MRI.

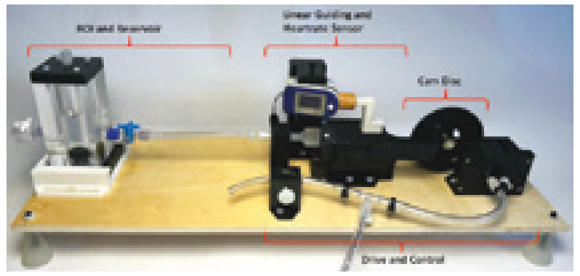

Fig. 3: MR-Compatible Pump set-up for PC-MRI validation.

AI-assisted Integrated OR-CSSD Management

Sterile supplies for the operating room (OR) are provided by the Central Sterile Supply Department (CSSD). However, predictive planning of sterile goods is currently challenging due to the lack of transparency in the cycle and numerous unpredictable dynamics related to staff shortages, complications during surgeries or the need for additional sterile supplies, leading to inaccurate planning, surgery delays and costly overstocking of sterile supplies. To address these challenges, the ASK-KI consortium develops an AI-based process control system. The central element of the system is an AI based decision support to the OR manager for surgical planning and to the CSSD for prioritizing sterile supplies and assigning related tasks. Simultaneously, real-time data throughout the sterile goods cycle is accessed and made available to all parties involved, investigating open interconnectivity concepts adopted from the international ISO IEEE 11073 standard.

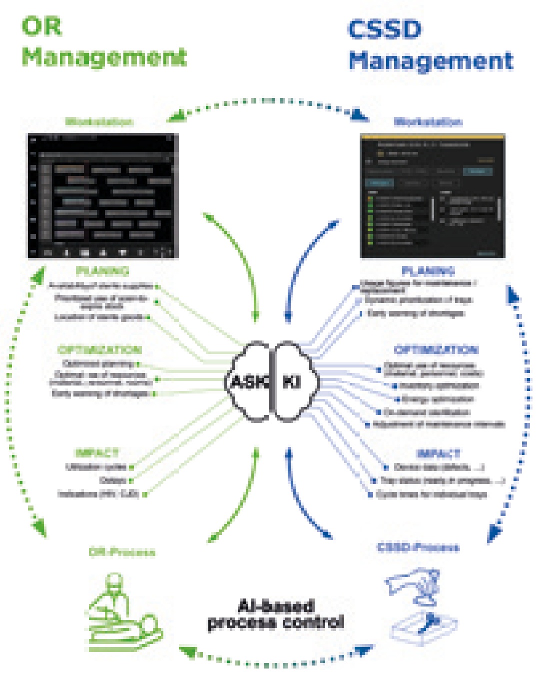

Fig. 4: Concept for an AI-assisted sterile goods cycle.

CSSD Robotics: handling of surgical instruments

Reprocessing contaminated surgical instruments after use is essential to ensure a continuous supply for operating theatres. However, handling contaminated instruments induces a high risk of infection for the Central Sterile Supply Department (CSSD) staff. We developed a robotic system for automated handling during the decontamination process.

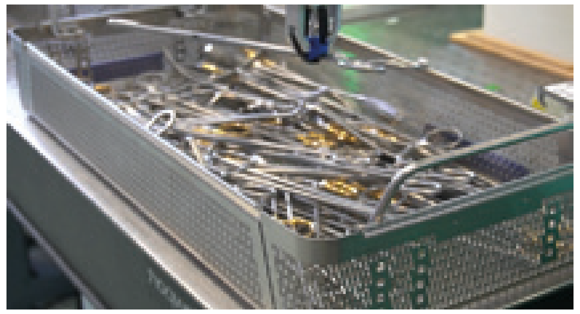

Fig. 5: Robotic picking of contaminated surgical instruments.

The system consists in a robot equipped with a specialized instrument gripper and a 3D-depth camera. The robot system is capable of gripping, separating (and opening) the majority of instruments in an instrument tray with challenging constellations in the border area of the tray. After pouring the instruments from the tray a success rate exceeding 98% could be achieved.

Robotic Ultrasound Scanning

Robotic Ultrasound Systems are an emerging technology. The aim of these systems is either to bring ultrasound experts in rural areas by using telemanipulated robotic ultrasound or to relieve and assist experts by using collaborative or autonomous systems. For the latter there can be assisting tasks such as an optimization of probe orientation for high quality images or autonomous scanning procedures where the system finds the region of interest and performs the scan. In the context of the development of a robotic ultrasound system for total knee arthroplasty (TKA), an automatic contact gel applicator has been developed for the complete automation of an autonomous robotic scanning procedure. A gel pump is feeding gel into a cavity with a silicone ring designed to pull the gel along during the scan to reduce gel consumption. The pump is controlled wirelessly by the system.

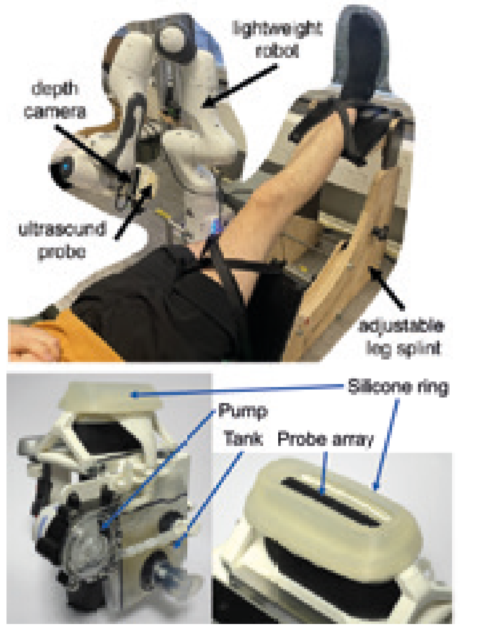

Fig. 6: a) Autonomous robotic ultrasound scanning of the knee; b) automatic contact gel applicator prototype.

Ultrasound-based External Fixation

External fixation is a therapy option for operative treatment of open fractures, especially in low-resource settings. Pins for the fixator need to penetrate cortical bone on both sides of the target bone to ensure mechanical stability, but without extensive protrusion. Evaluation of pin placement is challenging, since medical imaging like radiography may not be available in low-resource settings. In cooperation with our clinical partners from Medecins sans Frontière, Berlin, we designed a device for ultrasound-assisted pin placement using a portable, robust and low-cost ultrasound probe. The device comprises a guiding sleeve and an arm that centers the probe on the opposite side in the pin axis. Penetration of the opposite cortical bone can thus be easily detected in the ultrasound image in real-time, without the need for manual probe placement.

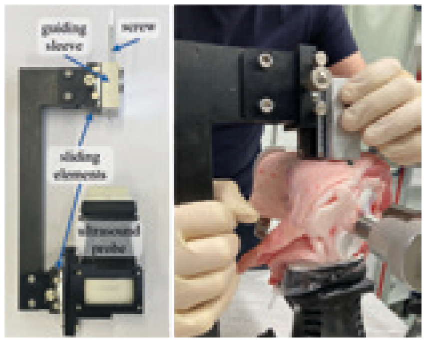

Fig. 7: US-assisted placement of external fixator pins.

Ultrasound-based Dental Implant Monitoring

After the implantation of dental prostheses, peri-implantitis, an inflammation of the tissue around the implant, can lead to bone and gingival resorption. Early detection is very important. In the framework of the DFG project ULTIMATE with clinical partners from Aachen and Graz/Austria we develop a system using intraoral ultrasound measurement of the thickness of gingiva and bone, which has the advantage of being radiation-free compared to standard x-ray-based procedures and thus allows for repeated periodic examination. Using deep learning-based methods allows for the automated analysis of ultrasound images through the segmentation of gingival and bony structures and thus enables fast and uncomplicated use.

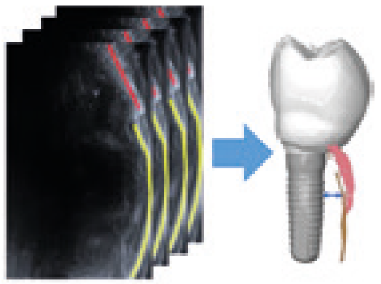

Fig. 8: Intraoral Ultrasound for Implant Monitoring.

Optimizing Histotripsy and Shockwaves

Histotripsy is a therapeutic ultrasound method which uses cavitation – gas bubbles created by the tensile phase of an acoustic wave – to destroy tissue. This method has recently found application as a therapy for liver tumors and as a treatment for certain kinds of cancer. The objective of our actual work is to develop an optimized set-up for a transducer and a drive circuit which can achieve required negative pressure and wave frequencies.
Acoustic Lenses can be applied to therapeutic ultrasound transducers to change the shape of the acoustic field from a point focus to other shapes. An algorithm to calculate these acoustic lenses has been developed and optimized algorithms to better suit the sharp rise times and high pressures of shock waves have been elaborated.

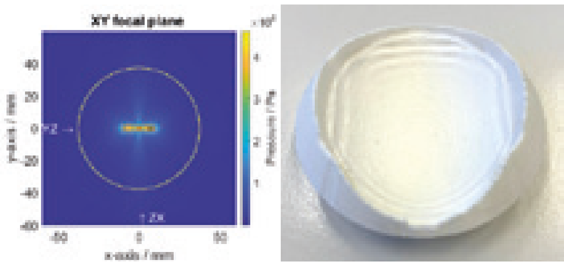

Fig. 9: a) Simulated line focus and b) a 3D printed model of the resulting acoustic lens.

Risk Analysis of Ultra-Low-Frequency US

Ultra-low-frequency ultrasound (below 50 kHz) is gaining attention for its promising use in therapeutic procedures, such as minimally invasive neural stimulation and cosmetic treatments like body sculpting. While these applications offer significant benefits, they also carry risks of unintended effects like hemorrhage and tissue damage caused by acoustic cavitation. Our research employs a combination of computational techniques to understand how ultra-low-frequency ultrasound behaves inside a human body. By simulating these interactions, we aim to develop improved models for risk assessment and enhance the safety of ultra-low-frequency US applications.

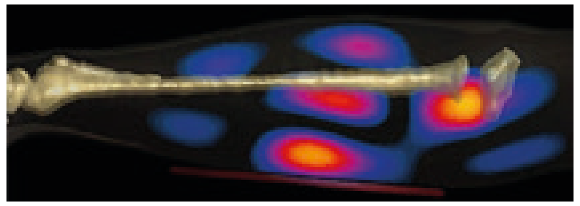

Fig. 10: Simulation of a 40 kHz cylindrical ultrasound probe applied to a human arm, revealing high-pressure buildup on unanticipated locations offset from the probe's central axis.

Prospective Surgical Workload Assessment

Excessive surgical workload contributes to 40% of preventable adverse events (60% related to human factors). Cooperative robotic systems can reduce workload, but targeted design requires a clear understanding of workload sources. Existing analysis methods, e.g. CPM-GOMS, Multiple Resource Model, and mAIXuse, rely on subjective assessments or resource-intensive studies. Therefore, a prospective workload analysis method is proposed.
S-TAWL allows clinical and modelling experts to decompose surgical tasks into perception, cognition, and action activities. The workloads of these activities are assessed using scales based on reference tasks with known workloads. Initial studies reveal challenges in selecting appropriate reference tasks for reliable rating scales, but highlight the potential of S-TAWL to identify critical workload factors to inform targeted interventions.

Fig. 11: Prospective surgical workload assessment concept.

Secure Ensemble Formation of Medical Devices

An ensemble is a theoretical combination of medical devices, which allows to perform additional interoperable medical device functions. Examples are displaying vital signs on an endoscopic video stream or performing remote device-control using a workstation.
Incorrect assignments can lead to risks, such as the adjustment of device parameters in other rooms. The goal is to have a safe and useable process to create medical-device ensembles. Three methods have been evaluated in a user-centered study: NFC tags, pop-ups on medical devices and a method using 5G.

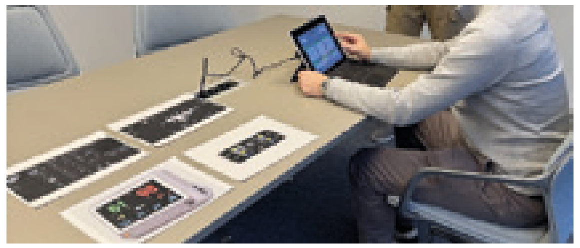

Fig. 12: Usability study at Bonn Surgical Technology Center.

RUBIN Alliance Medi.NET

The RUBIN alliance Medi.NET has the goal to develop a medical device platform for openly networked central workstations within the hospital in accordance with the international ISO IEEE 11073 SDC standard.

Fig.13: DMEA 2024 Demonstrator.

The platform provides the basis for networked user cockpits in the OR, intensive care unit, recovery room and other areas of the hospital with central control possibilities for different medical device and standardised manufacturer-independent user interfaces. The modular structure enables the integration of AI-based decision support as well as workflow and ensemble management for the initial operation of medical devices. Methods for modular risk management and usability engineering of openly networked systems are being developed. A new type of (machine-readable) profile is being developed, that describes the medical device characteristics with regard to the Human-Machine Interface and therefore enables the safe usage of open networked device combinations. Furthermore, these results are incorporated into the SDC standardisation and transferred i.a. into a guidance document for manufacturers within the conformity assessment (together with the interest group of Notified Bodies in Germany).

Scalable Cloud Architecture for 5G/6G RAN

Increasingly, intelligent systems are being deployed across healthcare and industrial domains, yet they often rely on self-contained, local architectures. To address this challenge, the research project CLOUD56 implements a private 5G campus and virtualized Radio Access Network infrastructure employing a hybrid edge-cloud concept. This approach delivers efficient, flexible, and scalable computational capabilities, accessible to both industrial and clinical use cases.
We developed multiple virtualized thoracic surgical assistance applications that integrate high-resolution thoracoscopic imaging, audio data, and medical device information (e.g., SDC IEEE 13073 standard). These data streams are captured in the operating room and processed with ultra-low latency on a common edge-cloud server setup. Consequently, applications such as lung-segment registration, anatomical detection, and surgical speech processing can be seamlessly introduced into existing OR setups, enhancing both efficiency and clinical outcomes.

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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.

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[1] L. Berger, T. Kandels, L. Schmidt-Bleek, K. Tokunaga, P. Damm & K. Radermacher: Modelling of iliopsoas tendon for psoas syndrome evaluation in THA. In: J.W. Giles & A. Guezou-Philippe (ed.): Computer Assisted Orthopaedic Surgery, 7, 2024, pp. 16-19

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