BIOENGINEERING AND MEDICAL-SURGICAL SCIENCES

UNITO - Deep learning-based framework supporting preoperative decisions and AI guided robotic urological surgery

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Context of the research activity	Artificial intelligence (AI) is rapidly emerging in healthcare, yet applications in surgery remain relatively nascent. Precision surgery is becoming more and more common in preserving functional organs. The widespread use of technologies, such as 3D models, virtual reality, augmented reality, and AI, is primarily responsible for making this possible. Although these technologies are becoming increasingly accessible in major centers, the integration of artificial intelligence with organs' 3D models remains limited, lacking a functional platform that effectively supports surgeons in preoperative and intraoperative decision-making. Surgeons can use organs' 3D reconstructions based on the analysis of preoperative CT scans and/or MRIs to simplify the process and get around these problems. However, the precision of these 3D models is restricted, and they can't provide the surgeon with feedback regarding the procedure's appropriate execution or its results. In this regard, AI, supplied by thousands of surgical videos and clinical result data, may be crucial in enhancing these 3D models for carrying out a safe and efficient dissection and maximizing surgical outcomes while lowering the possibility of surgical errors.

	This PhD project aims to develop an integrated co-pilot platform to assist the surgeon in two different steps: preoperative planning and intraoperative guidance. In the preoperative stage, deep learning algorithms, particularly Convolutional Neural Networks (CNNs), would be employed to analyze datasets of medical imaging (MRI, CT, PET) and other patient-specific information (EHR, genomics). This analysis will be focused on supporting the automated and precise segmentation of anatomical structures, leading to the elaboration of detailed 3D models for surgical planning, focusing on Prostate and Kidney cancer. Another key endpoint of the study is predicting the surgical difficulty and potential risks, allowing proactive planning, and generating personalized surgical plans, including optimal incision sites, and target definitions. This can enable virtual surgical simulation, enabling

Objectives	surgeons to practice complex procedures and optimize their approach. Further, predicting postoperative outcomes can help to support patient selection and elaborate personalized informed consent. In this setting, the surgeon is asked to provide careful feedback and correct errors made by integrated AI systems, proposing the correct solutions to engineers in a detailed multidisciplinary teamwork setting. This forms the basis of error-based learning. During the intraoperative phase, the framework aims to integrate AI-guided robotic surgery into clinical practice by analyzing real-time data from robotic systems, such as live augmented reality video streams. This integration overlays critical information—segmented anatomical structures and planned surgical trajectories—directly onto the operative field, facilitating precise instrument tracking and guidance. Ultimately, the goal is to assist surgeons in navigating complex anatomical regions and accurately identifying tissues. The detailed plans generated preoperatively by deep learning models that directly inform the AI algorithms would enhance precision and adherence to the intended surgical strategy. Integrating preoperative insights with intraoperative guidance is a key strength of this framework. Although substantial challenges persist regarding data availability, model validation, interpretability, and regulatory approval, this study's learning-based framework may contribute significantly toward advancing personalized, safer, and ultimately more effective minimally invasive patient-specific surgical procedures. The project will be developed at MITIC center at the University of Turin, and at UniTO, PoliTO and other international facilities.

Skills and competencies for the development of the activity	The project requires diverse competencies and effective collaboration within a multidisciplinary team. As a translational medicine initiative, both surgical and non-surgical expertise are necessary. Essential skills include proficiency in image analysis techniques, familiarity with 3D image processing and visualization, and knowledge of robotic kinematics and dynamics. Additionally, a thorough understanding of ethical considerations associated with AI in healthcare - particularly bias, transparency, and accountability - is crucial for the project's completeness. Medical degree and clinical experience in urology is mandatory.