# BIOENGINEERING AND MEDICAL-SURGICAL SCIENCES

## UNITO - Artificial Intelligence and robotic microsurgery

| | |
|---|---|
| **Funded By** | UNIVERSITA' DEGLI STUDI DI TORINO [P.iva/CF:02099550010] |

| | |
|---|---|
| **Supervisor** | AREZZO ALBERTO - alberto.arezzo@polito.it |

| | |
|---|---|
| **Contact** | |

| | |
|---|---|
| **Context of the research activity** | The project aims to create instruments for digestive tract endoluminal surgery, using robotic technologies that will allow interventions previously not possible. The main goal is to create miniaturized devices that advance inside the patient to operate in a synergistic and collaborative way. Such instruments are capable of performing surgical procedures that go beyond contemporary minimally invasive surgery. An intuitive interface will consist of advanced input devices equipped with tactile feedback and imaging screens (MRI, CT scan, fluoroscopy, US) depending on the anatomical district and clinical scenario<br>Before the RED robot (Robot for Endoscopic Dissection, A miniature robotic device applicable to a flexible endoscope for the surgical dissection of gastro-intestinal tract surface neoplasms (WO 2014147556 A1) begins its action, the environment is screened with all- optical probes, consisting of white light, multi-spectral and US sensors. Then a miniaturized inflatable operating chamber is set-up in place to keep the environment stable. Ultimately dissection begins by means of surgical manipulation<br>RED will push the boundaries of minimally invasive robotic surgery beyond the current state-of-the-art, developing solutions to perceiving and interacting with the environment for soft robots, while operating within otherwise inaccessible spaces. Our scientific objectives are<br>1- Sensing for tissue characterisation: intelligent & multimodal. Incorporate novel sensing capabilities inspired by machine learning to maximise the information content from sensors, including wide-field multispectral imaging, photoacoustic endomicroscopy and all-optical ultrasound imaging for in-situ detection and assessment of polyps/cancer<br>2- Precision microsurgery: flexible & dexterous. Introduce novel micro-surgical robot design with bimanual manipulation, ultrasound and imaging tools for precision surgery<br>3- Intervention shared control: intuitive & autonomous. Embed the surgeon in the navigation of the micro-surgical robot, creating AI-based control strategies |

| | |
|---|---|
| | The project will pursue an integrated multimodal approach to detect and treat polyps and cancer lesions in the colon<br>It is the ambition of the team to bring the project through to clinical |

| | |
|---|---|
| **Objectives** | applications. From a clinical requirement starting point, progress will involve the integration of newly created methods and techniques, culminating in intensive prototype testing in M20 and benchmarking and evaluation in the human cadaver lab in M24. We will work on new techniques and materials for 3D printing of realistic anatomical models, such as soft and inflatable multi-layered organs like the bowel, based on DICOM databases of patients with confirmed disease. This will exclude the use of wet and in vivo animal labs, not only for ethical reasons but also because, in anatomical terms, no animal colons are truly comparable to human colons. In the project follow-up, we will focus on acquiring funds for clinical validation, to establish REDtechnology as a benchmark on a global scale.<br>This will be a joined activity of mixed research groups made up of clinicians and engineers.<br>WP1 — Inflatable Operating chamber (in collaboration with QMUL)<br>We will create a stable operating chamber that can be deployed within the colon positioned at the identified target polyp site, carry out precise surgical intervention. This will be achieved by a transferable, inflatable operating chamber, made of a pre-shaped double-layered, fenestrated balloon which will be inflated at the site of the lesion to lodge itself stably within the colon and its structural elements will be stiffened using an approach based on granular jamming.<br>T1.1 Operating chamber design (M1–M12), reconfigurable inflatable granular- jammable structure, integrating microsurgical arms<br>T1.2 Operating chamber fabrication (M5–12), identifying suitable materials/particles biocompatible with endoluminal environment<br>T1.3 Chamber deployment and microsurgical manipulator reconfiguration tests (M12–M20), experimental assessment and evaluation<br>WP2 — Sensing for tissue characterisation: intelligent & multimodal (in collaboration with KCL)<br>We will design probes for wide-field multispectral imaging, photoacoustic and ultrasound microscopy. Multispectral imaging will identify tumour boundaries for resection guidance. Photoacoustic microscopy will provide label-free tumour staging, while all-optical ultrasound will provide deep-structure information to facilitate robot control. Machine learning will address long-standing challenges in sensor analytics to generate detection tools that leverage multimodal information to effectively screen large areas.<br>T2.1 Photoacoustic endomicroscopy and all-optical ultrasound (M1–M12), to develop a real-time system.<br>T2.2 Sensorised robotic probe design (M13–M20), articulated concentric robotic probes integrated with highly sensitive contact sensing<br>T2.3 Multimodal imaging and sensing (M13–M20), wide-field multi-spectral imaging to ensure improved tissue characterisation<br>WP3 — Precision surgery: flexible & dexterous<br>For challenging high-precision tissue manipulation, our system will incorporate a miniaturised super-flex design capable of reconfiguration and bimanual operation, while visual servoing combined with intelligent control will permit high-precision sub-mm accuracy. A chip-on-tip-based stereo vision system will incorporate both white light and multispectral imaging for clear visualisation of submucosal structures and microvasculature. The miniaturisation of foldable tools will allow sufficient dexterity for oncologically-safe excision of polyps and cancer lesions.<br>T3.1 Microsurgical robot hardware architecture design (M1–M12), architecture robot design<br>T3.2 Evaluation of structural functionality (M13–M16), to ensure interoperability of its subcomponents<br>WP4 — Intervention shared control: intuitive & autonomous (In collaboration |

| | |
|---|---|
| | with UNINA-CREATE)<br>Active control of soft growing robots and supervised autonomous execution of surgical tasks is the big new challenge in robotics. Our shared control architecture will use interaction with the colon to control the growth and retraction of the soft robot while mitigating the possibility of buckling. AI-based strategies will allow control of the interaction between miniaturised tools and the environment to enable supervised autonomous polyp dissection and suturing.<br>T4.1 Guardian AI for safe advanced control of the whole robot system (M1–M16), an AI-based guardian system for surgery.<br>T4.2 Automatic dissection of polyps and suturing with the microsurgical robot (M1–M20) exploiting motion tracking algorithms<br>WP5 — System integration and validation<br>A robot with integrated sensors and effectors will be prepared for intensive testing and comparative evaluation. The study will investigate the feasibility and performance of the concept for complete colon exploration and local excision in realistic environments.<br>T5.1 Fabrication of phantom organs (M1–M12), 3D printed, based on DICOM databases of patients with confirmed disease.<br>T5.2 Execution of the experimental studies in realistic MIS environment (M13– M24):<br>· Ex vivo animal labs using bowel tracts of swine models inserted into phantoms, for all tests related to dissection of simulated polyps.<br>· Tests on human cadavers to verify the advancement of the robot in a human model, after tests in 3D printed human colon models.<br>· In vivo assessment of the function of the multimodal probe in patients diagnosed with benign or malignant rectal neoplasms, under general anaesthesia, just before local excision by Transanal Endoscopic Microsurgery, after approval of the Local Ethical Committee. |

| | |
|---|---|
| **Skills and competencies for the development of the activity** | The candidate is expected to be graduated in Bioengineering and to have previous experience with robotics and computer assistance for endoluminal applications (e.g., endoscopy and/or endovascular procedures). In particular, the ideal candidate should have previous experience with at least one of the following areas of robotic surgery: 1) Force/shape sensing, 2) Simulation frameworks (e.g., SOFA), 3) Medical image acquisition and processing (e.g., MRI, CT), 4) Control and Automation, 5) AI/Machine learning.<br>Scientific publications and conference/workshop participation related the topic of this fellowship represent a plus.<br>Free keywords<br>Endoluminal robotics, force/shape sensing, Simulation, Medical imaging, Autonomous control and manipulation, Intervention shared control |