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Characterization of Gastric Tissue Samples with MEMS Force Sensor Based Indentation method

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Summary:

Considering the actual requirements in laparoscopic as well as robotic surgical practices and the advancements in utilisation of artificial intelligences in data analysis and decision making, the need for tissue mechanical analysis is greater than ever. However, the necessary data is still hard to acquire due to the existing gap between medical and engineering professionals in daily practice. Since the chosen methods of tissue characterization vary widely, we designed our measurement setup so that it resembles clinical practice as closely as possible. [1] In our cooperation with the Uzsoki Hospital, we present the results of our measurement system developed for gastrointestinal tissue characterization. We aim this as a pioneer project to form a basis for larger, more targeted data collection to improve medical professionals' decision-making during surgical procedures.

Keywords: mechanical tissue characterization, indentation, gastric, biomechanics

Background, Motivation an Objective

While laparoscopic surgeries are some of the most routine procedures today, postoperative complications can still arise and though advanced robotics are precise and beneficial, improvements of surgical tools are still in high demand. Probably the most critical aspect in need of developments is the quantitative assessment of the surgeon's tactile feedback. [2] To provide researchers and medical engineers accurate data regarding tissue properties systematic and controlled measurements with a large sample size are needed. A MEMS force sensor based [3] indentation type tissue mechanical analyser have been developed and deployed at the Surgery and Onco-surgery Ambulance of Uzsoki Hospital in Budapest. In our current pilot study, we demonstrate the capability of our system for ex-vivo tissue thickness measurement at a clinically relevant force range. Furthermore, post-processing the force-displacement data provided by the sensor and supported with the metadata acquired about the patient and tissue condition, forms a promising foundation for AI-supported decision-making algorithms. Our preliminary results demonstrates that the tissue analytical system would be integrated into a laparoscopic stapler, offering real-time data on tissue characteristics, and potentially providing decision-making support to surgeons during surgery.

Measurement System and Methodology

Our measurement setup integrates the MEMS piezoresistive 3D force sensor developed by HUN-REN CER's Microsystems Lab [3]. The setup applies the indentation method previously defined by Egorov et al. [4]. Since the medical objective of our long-term work is to adopt our tissue characterisation methodology in laparoscopic devices, indentation is the corresponding solution to mimic the compression type deformations emerging during laparoscopic gastric surgeries.

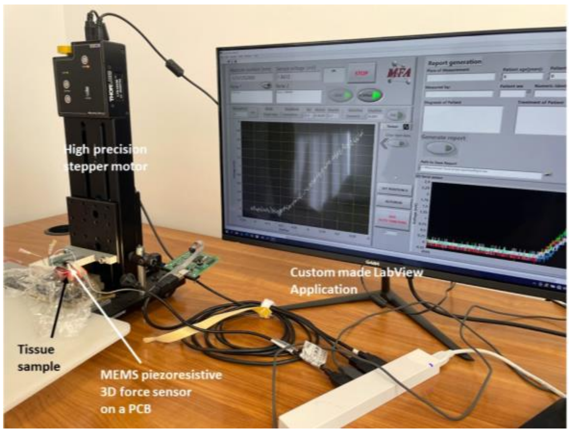

Fig. 1. Indentation type measurement system at the Uzsoki Hospital.

The measurement system is driven by a custom made LabView application and records the force-displacement curve during controlled compression of the examined tissue. The force information is provided by the MEMS piezoresistive 3D force sensor while the accurate deformation is generated by a high precision stepper motor. The setup is quite robust for ex-vivo field experiments, although the sensor itself can be easily integrated into a laparoscopic jaw according to its form factor.

The tissue samples were mostly cancerous gastric leftovers which were removed during resection. The contact points of the sensor were chosen to be either on a tumorous (but measurable) region or near the sectioned and stapled line. Measurements on the anatomically important healthy regions were also executed for comparison the mechanical characteristics different tissue status. The majority of our measurements focused on different session of the colon, such as the transversum, the sigmoideum and the rectum, with additional samples obtained from the pancreas and the stomach. The experiments were accomplished under ethical authorization number IV/174- 2 /2022/EKU.

Results

A total of 42 ex vivo measurements have been implemented on 30 human tissue samples to date. Two representative experimental force – displacement functions are demonstrated in in *Figure 2.* They represent the diverse tissue biomechanical properties associated with different medical conditions.

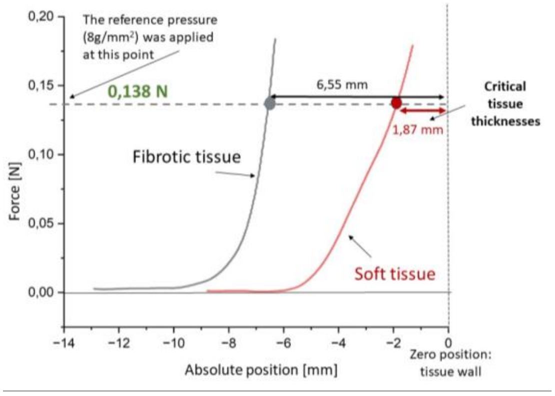

Fig. 2. Force-displacement curve of two pancreas samples

Considering the *F(d)* curve, the compressed tissue thickness can be determined from the displacement detected at the critical force value to be reached for optimal stapling during surgical procedure. The conventional pressure value between the stapler's jaws is considered to be 78,4 mN/mm^{2}in clinical practice. The detected critical force value corresponding to this pressure can be calculated as 138 mN considering the sensor's geometry.

Outlook

Accurate determination of the optimal thickness of the compressed tissue prior to stapling would represent a significant advancement in laparoscopic surgery. Moreover, the data obtained from the force – displacement measurements contain a wealth of relevant information regarding tissue biomechanics also. By extracting relevant parameters (such as uncompressed tissue thickness, Young-moduli, and others) from these datalines and analysing them with consideration medical metadata regarding patient vital signs, tissue condition and pathology, surgeons can establish a deeper understanding of how various pathological conditions affect tissue biomechanics and surgical results. With this background knowledge, these smart devices will be able to refine onsite surgical decision support during laparoscopic gastrointestinal surgeries.

Discussion

Testing different samples provided valuable insight on how these measurements can be carried out on a large scale by medical personnel. We are continuously refining both the software and user interface accordingly. This study demonstrates the ability to measure compressed tissue thickness and reveal clinically relevant differences in tissue characteristics, such as significant change in the biomechanical properties of a highly inflamed tissue compared to a healthy one. Based on our experiences, a handheld, laparoscope-like measurement system is to be developed for efficient large quantity data gathering. Critical feature is the precise laparoscope geometry compatible for usage in surgical environments.

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