

Measurement of Stress Relaxation During the Indentaion of Human Gastric Tissues

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Summary:

Modern gastric and bariatric surgical trends point toward the widespread use of laparoscopy and robotics. The most advanced tools of minimally invasive surgeries (MIS) now include tactile sensory feedback, motorization and other safety improvements to help surgeons achieve better patient outcomes. Neither of these are readily available in everyday cases moreover their optimization depends largely on the basic understanding of soft tissue behavior. In this work we compile a set of measurement parameters which we believe to be of outmost importance to take into consideration while carrying out compression type tissue characterizations.

Keywords: biomechanics, compression, stress relaxation, MEMS force sensor, gastric surgery

Mechanics of soft tissues

Biomechanics in general is the overlapping or interdisciplinary field of biology and physics. It can include any mechanical effect affecting a biological system, be it a single cell, blood flow or an entire body part. The sub-section of soft tissue biomechanics is a niche area with relatively few groups focusing on different tissue types, each using their own methodology [1]. Some of these measurements use derivatives of ISO standard measurements, such as different versions of ISO 527 for example. Some use systems designed for the testing of mediums with viscosity similar to soft tissues. SHORE 00 type durometers can be applicable tools. To ensure modularity and to provide more complex parametric data, we developed an indentation type tabletop measurement system and a set of modified stapler cartridges to test the application of MEMS force sensors for laparoscopic use [2].

Compression Type Tissue Testing

Uniaxial mechanical compression in one or two directions is a popular choice for tissue characterization, due to the measurement setup is robust and can be easily adopted from pre-existing systems with simple modifications for proper clamping of the sample. Similarly to polymers, the resulting stress-strain curves will have their notable points and regions such as yield strength, ultimate tensile strength, necking point, etc. Since soft tissues have viscoelastic behavior, in this case the time dependency is

also a key factor. Parameters derived from these measurements such as Young's modulus, or the time dependency of failure rate provide useful insight into individual tissue characteristics, moreover can provide clear clinical relevance [3].

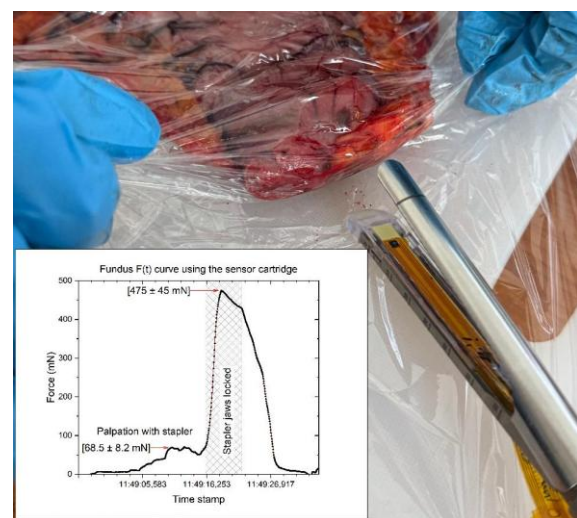


Fig. 1. Time dependent mechanical measurements made on human gastric tissue sample with MEMS force sensor integrated into laparoscopic stapler

The indentation is important, because numerous surgical maneuvers exert a compression type loading on soft tissues of the human body. Indentation type measurement systems yield force-displacement and time dependent force characteristics. While similar metrics can be attributed to these characteristics such as maximum load, relative thickness change,

cumulative force as well as Young's modulus, time dependency is often neglected. Since stress-relaxation has been defined already as an important consideration, time dependency can be important from multiple perspectives. During indentation—similarly to live surgery—tissues are not loaded to failure, but instead are exposed to transient and sustained loading conditions where time-dependent effects must be considered [4].

Results

Different artificial viscoelastic polymers were mechanically characterized by our dedicated measurement system containing self-developed 3D MEMS force sensors. The time-dependent nature of tissue response is illustrated in Fig. 2, where stress relaxation can be observed even between discrete displacement steps of the stepper motor during the compression of human gastric tissue. This highlights that viscoelastic effects are present not only during sustained loading, but also on short timescales.

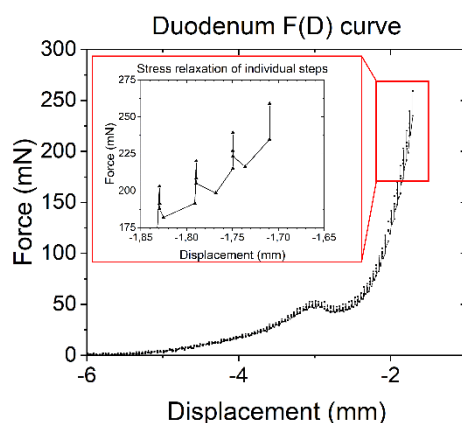


Fig. 2. Stress relaxation effect of real human duodenum sample

The measurement protocol was controlled via a custom LabVIEW interface, allowing precise definition of compression rate and hold time. Measurements were carried out with varying hold times following a force–displacement loading phase at constant compression rate. Experiments were conducted on a PDMS sample (with curing agent : elastomer ratio of 1:30) and a synthetic bowel model (Limbs & Things) used for surgical training, with dwell times of 1, 5, 15, 30, and 60 seconds.

In the artificial bowel model, a clear relaxation behavior was observed. (see Fig 3.) Following initial compression, the material exhibited a continuous decrease in counterforce at constant indenter position, confirming its viscoelastic nature. Measurable relaxation persisted throughout the full 60-second interval, and no steady-state stress value was reached within this timeframe.

As a result, the measured force depended strongly on the selected hold time. Short dwell times (1–5 s) resulted in higher, whereas longer hold times (30–60 s) yielded progressively reduced apparent force values due to the time scale of stress relaxation processes. Similar trends were observed in case the PDMS sample.

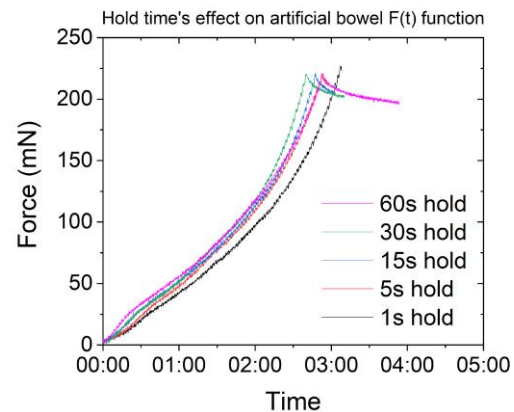


Fig.3. The effect of holding time at the end of the loading cycle of an artificial bowel sample

These findings indicate that final tissue thickness under compression is not a fixed quantity, but depends on the measurement protocol. From a clinical perspective, this introduces a trade-off between allowing sufficient time for relaxation and maintaining a feasible procedural duration, suggesting that standardized hold times may be required for consistent intraoperative assessment. Ongoing work will extend this analysis by systematically investigating the effect of compression rate on tissue response and apparent stiffness.

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