20th European Mechanics of Materials Conference - EMMC20
Florence, Italy | May 27th-29th, 2026
www.emmc20.unifi.it

Experimental investigation of the human stomach wall – focus on its inelastic properties

Clarissa S. Holzer-Stock[1], Francesca Bogoni[2], Sara Mohaddes[3], Michael Schweighofer[4], Christian Viertler[5], Gerhard A. Holzapfel[6]

[1] Graz University of Technology, Austria. clarissa.holzer@tugraz.at
[2] Graz University of Technology, Austria. bogoni@tugraz.at
[3] Vienna University of Technology, Austria. e12307545@student.tuwien.ac.at
[4] Krankenhaus der Barmherzigen Brüder Graz, Austria. Michael.Schweighofer@bbgraz.at
[5] Medical University of Graz, Austria. christian.viertler@medunigraz.at
[6] Graz University of Technology, Austria. holzapfel@tugraz.at

Paper ID: 436
Symposium S11: Mechanics of biological materials & biomechanics

Abstract

Partial gastrectomies, the surgical removal of a portion of the stomach, have proven effective for the resection of gastric lesions and long-term weight loss in patients suffering from obesity. In these interventions, the segments are dissected and sealed using staplers by (i) radially compressing the gastric walls, (ii) pushing parallel bands of metal staples through the tissue, and (iii) cutting the compressed wall adjacent to the staple lines. Previous studies on single-step stress-relaxation tests suggested that the human gastric wall requires a few seconds to minutes to asymptotically reach a state of equilibrium [1]. This reported relaxation behavior is likely the basis for the improved staple formation and reduced leakage after the application of a pre-fire waiting period between compression and stapling [2]. Given the inelasticity of gastric tissue, the separation of the equilibrium response and dissipative phenomena is crucial. Since rate-dependent effects can occur even at low deformation rates, the assumption of quasi-stationarity is often inadequate, and continuous loading protocols hardly yield the equilibrium response [3]. For this reason, we compressed the gastric wall uniaxially along its radial direction using two different loading protocols: (i) a continuous cyclic test followed by a single-step relaxation test, and (ii) a cyclic

stepwise relaxation test. Comprehensive histological examinations complemented our mechanical investigations. In particular, adjacent samples from the main regions, i.e., fundus, body, and antrum, of 16 human stomach resectates (8 male, 8 female) were mechanically tested to assess region-specific and sex-dependent differences and to relate these to the underlying microstructure. The continuous cyclic loading protocol revealed hysteresis between loading and unloading, notable softening between primary and secondary loading, and, unlike the idealized Mullins effect observed for rubber-like materials, a mismatch between the unloading and subsequent reloading of the samples. Furthermore, despite the comparatively low stretch rate, stress relaxation was consistently observed. However, with the second loading protocol, we observed hysteresis on the equilibrium response and a dependence of the amount of stress relaxation on the applied deformation during the loading cycle. These properties were differently pronounced between gastric regions and are likely related to the respective gastric wall architecture. In particular, more inelastic phenomena were measured in the fundus compared to the distal regions, which could be attributed to its higher amount of connective tissue and the smaller, less interwoven muscle bundles. Interestingly, more than 75% of leakages after sleeve gastrectomies occur at the staple line in the fundus [4].

Keywords:

Human stomach wall Gastric mechanics Radial compression Viscoelasticity Histology

References:

[1] C. S. Holzer-Stock et al., A biomechanical comparativestudy of passive stomach tissue from pigs and humans, ActaBiomater. 200 (2025) 265–282.doi:10.1016/j.actbio.2025.05.013.

[2] S. Nakayama et al., The importance of precompressiontime for secure stapling with a linear stapler, Surg.Endosc. 25 (2011) 2382–2386. doi:10.1007/s00464-010-1527-7.

[3] F. Bogoni et al., On the experimental identification ofequilibrium relations and the separation of inelasticeffects in soft biological tissues, J. Mech. Phys. Solids193 (2024) 105868. doi:10.1016/j.jmps.2024.105868.

[4] T. Oshiro et al., Treatments for staple line leakageafter laparoscopic sleeve gastrectomy, J. Clin. Med. 12(2023) 3495. doi:10.3390/jcm12103495.