Towards a validated human stomach computational model

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Laparoscopic Sleeve Gastrectomy (LSG)

Aim

The aim of the research activities consists in the characterization of human gastric tissues mechanics, which is necessary to develop a reliable computational model of the human stomach. The methods of biomechanics can rationally deal with the main limits and drawbacks of bariatric surgery (the surgery that treats people affected by obesity) improving its effectiveness. In future, computational gastric models could be very useful to customize the surgical procedure on patient's medical condition, avoiding experimentation on animal model and/or preliminary clinical trials.

Materials and Methods

- Collection of human gastric samples from patients who underwent LSG at the Padova University Hospital;
- Experimental campaign involved tests on different levels: tissue level (uniaxial tensile test), sub-structural level (membrane bending test) and structural level (inflation test) (protocol and data reported in [1]);
- Constitutive formulation of gastric tissues: a fiber-reinforced hyperelastic formulation was adopted as reported in [2];
- Definition of a preliminary set of constitutive parameters by means of the inverse analysis of uniaxial tensile tests;
- Computational modelling of membrane bending tests and inflation tests. The latter involved the photogrammetric reconstruction of nine resected stomachs;
- Subsequent comparisons between experimental and computational results to upgrade and to validate constitutive parameters.

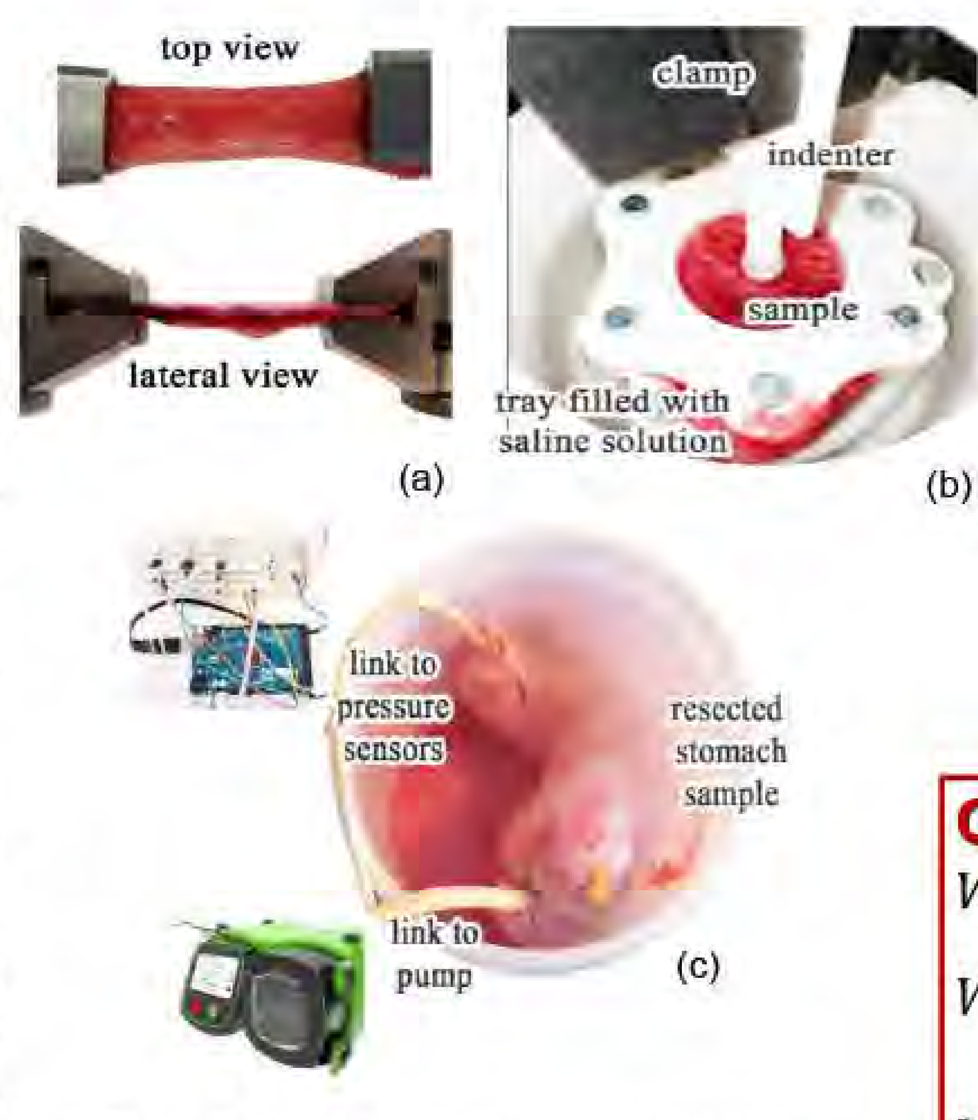

Fig.1: Tests of the experimental campaign: uniaxial tensile tests (a); membrane bending tests (b); inflation tests (c).

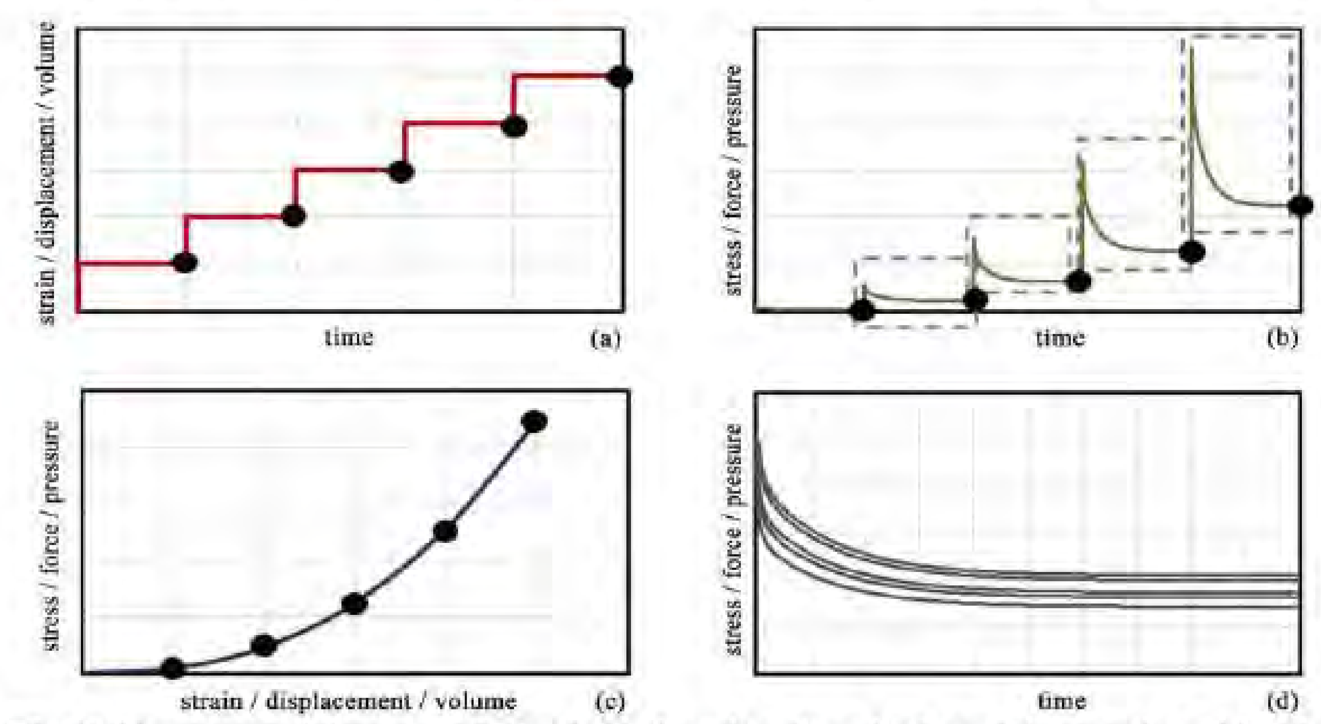

Fig.2: Experimental protocol: Applied stimulus-time history (a), monitored loading action-time data (b), computed equilibrium loading action-applied stimulus data (c) and relaxation phenomena (d)

Constitutive Formulation: Strain energy function

$$W(C) = W_m(C) + W_f(C, a_0, b_0)$$

matrix contribution

$$W_m(C) = -p(J-1) + \left[\frac{C_1}{\alpha_1}\right]\{exp[\alpha_1(I_1 - 3)] - 1\}$$

fibers' contributions

$$W_{fa}(I_4) = \left[\frac{C_4}{\alpha_4^2}\right]\{exp[\alpha_4(I_4 - 1)] - \alpha_4(I_4 - 1) - 1\}$$

$$W_{fb}(I_6) = \left[\frac{C_6}{\alpha_6^2}\right]\{exp[\alpha_6(I_6 - 1)] - \alpha_6(I_6 - 1) - 1\}$$

Results

- The inverse analysis of uniaxial tensile tests (Fig. 3) led to preliminary set of equilibrium hyperelastic parameters;

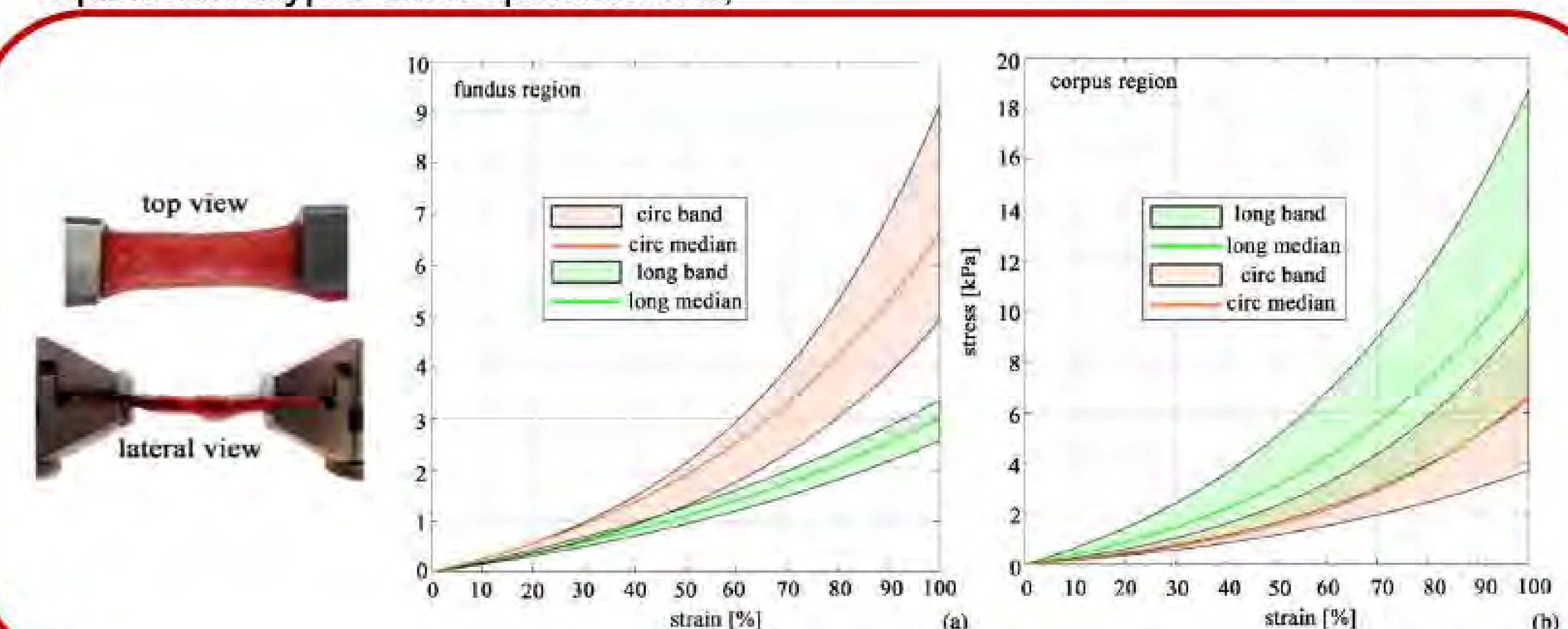

Fig.3: Results of the uniaxial tensile test, for fundus (a) and corpus region (b).

- The computational investigation of membrane bending tests (Fig. 4) further upgraded the quality of the parameters (Table I);

Region	Layer	C_1^{∞} [kPa]	α_1^{∞} [-]	C_4^{∞} [kPa]	α_4^{∞} [-]	C_6^{∞} [kPa]	α_6^{∞} [-]
Fundus	submucosa-mucosa layer	0.15	1.05	3.3	0.96	3.7	1.11
	muscularis stratum	0.15	1.05	5.2	0.68	7.1	0.70
Corpus	submucosa-mucosa layer	0.15	1.05	3.00	1.80	3.00	1.68
	muscularis stratum	0.15	1.05	10.09	0.24	9.70	0.23

Table I: Constitutive parameters from the analysis of the different experimental tests on human stomach tissues and structures.

- The reliability of the hyperelastic framework was assessed by performing the computational analysis of insufflation tests (Fig. 5).

Sub-structural tests: membrane bending tests

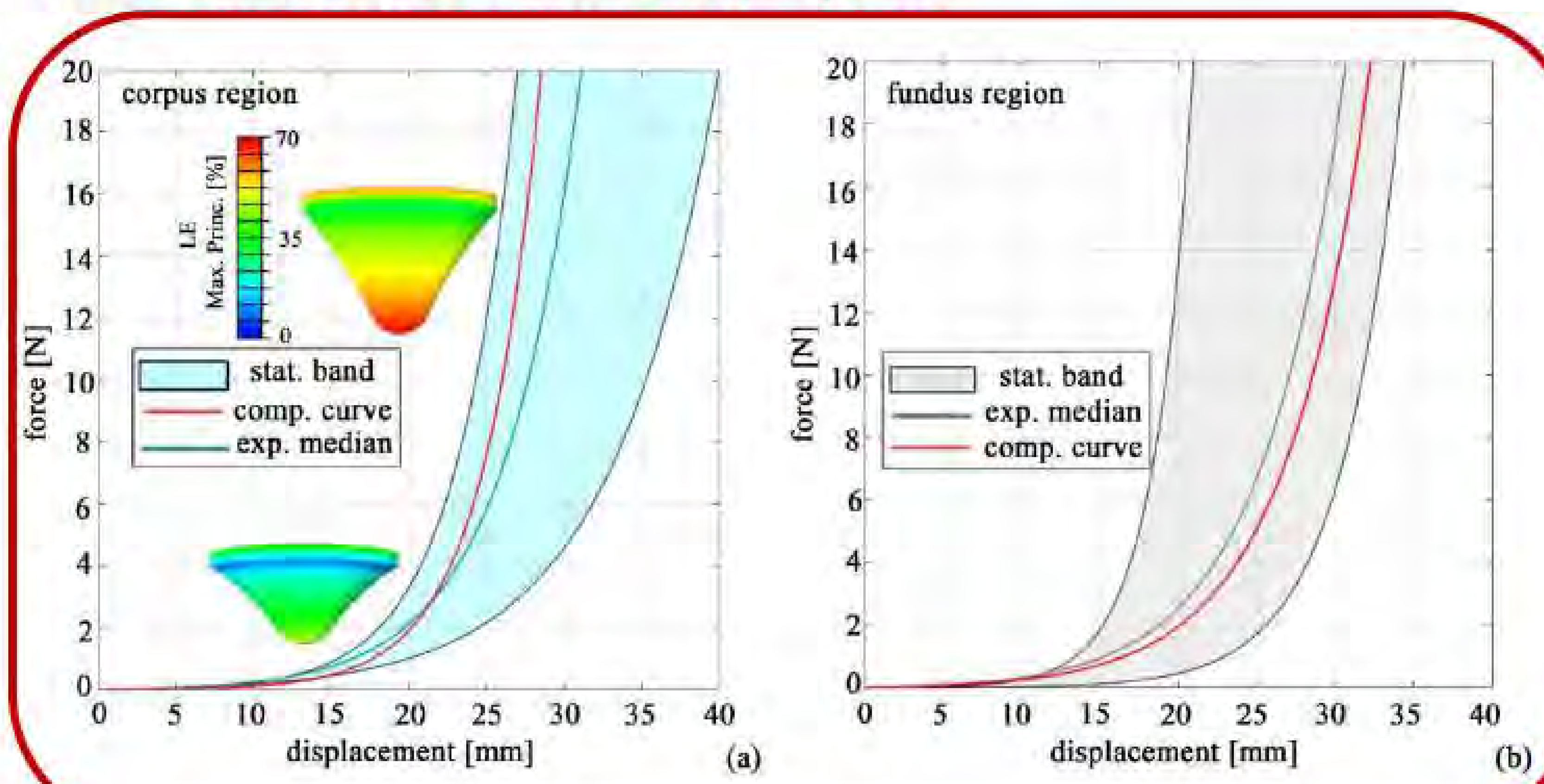

Fig.4: Inverse analysis of sub-structural level membrane bending tests.

Structural tests: inflation tests

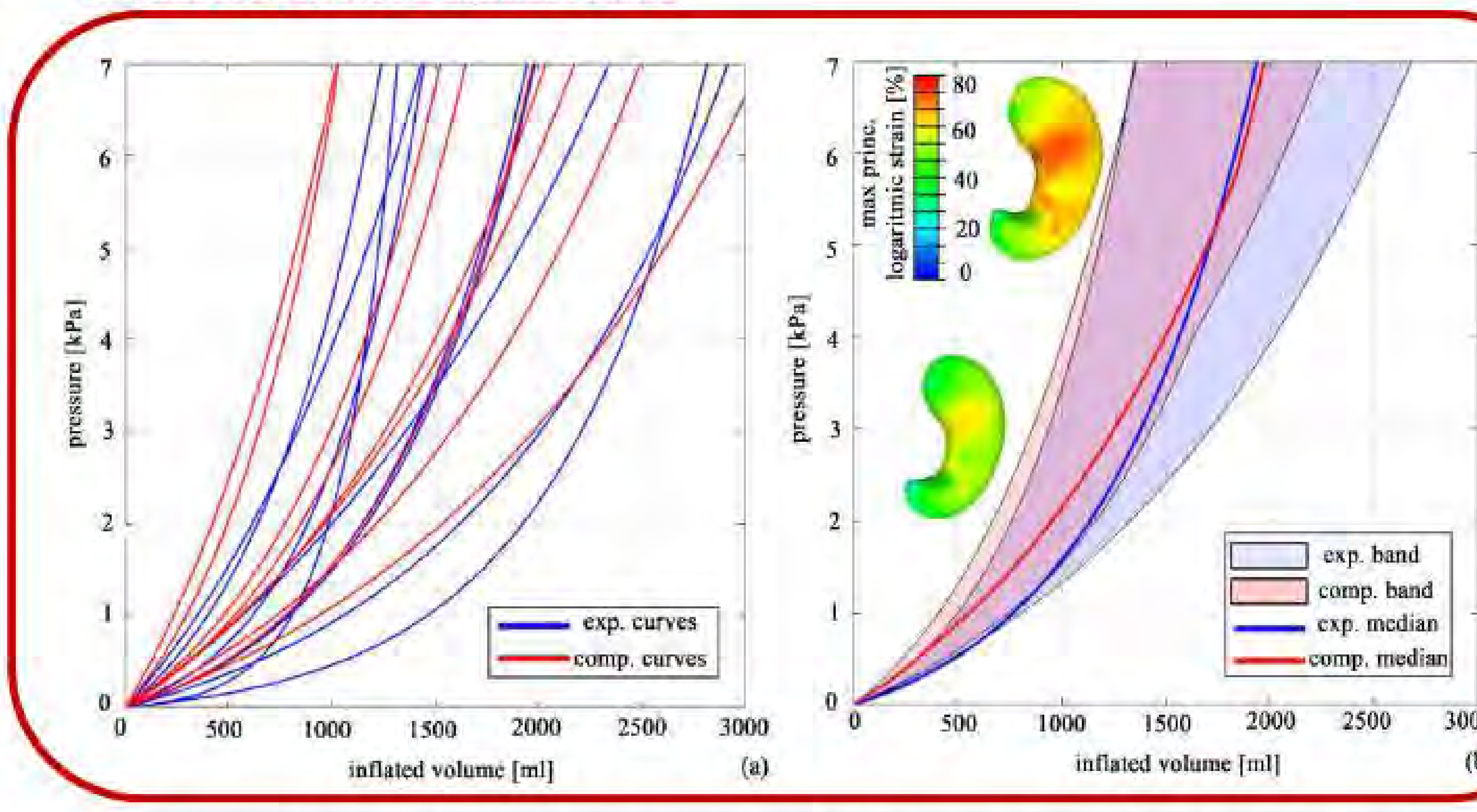

Fig.5: Comparison of computational and experimental results from insufflation tests at the structural level

Discussion

The experimental campaign's results permitted to define and upgrade a fibre-reinforced hyperelastic constitutive framework. The good agreement between experimental and model results confirmed the reliability of the investigations and the strength of the proposed approach.

Biomechanics and reliable computational models could be useful tools to improve bariatric surgery effectiveness and to develop new and innovative procedures avoiding animal experimentations and clinical trials [3,4].

References

[1] Carniel et al., "Biomechanics of stomach tissues and structure in patients with obesity", 2020.
[2] Fontanella et al., "Computational models for the mechanical investigation of stomach tissues and structure". 2019.
[3] Salmaso et al., "Computational Tools for the Reliability Assessment and the Engineering Design of Procedures and Devices in Bariatric Surgery",2020.
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