Keynote: NEW TECHNOLOGIES
ARTIFICIAL INTELLIGENCE

30 August 2023

Patient-specific stomach biomechanics before and after bariatric surgery: computational models of surgical procedure

Speaker: Ilaria Toniolo, Ph.D

IFSO NAPOLI 2023

In silico modelling

Computational methods and models have outstanding potentiality (“a priori analysis”) and can describe

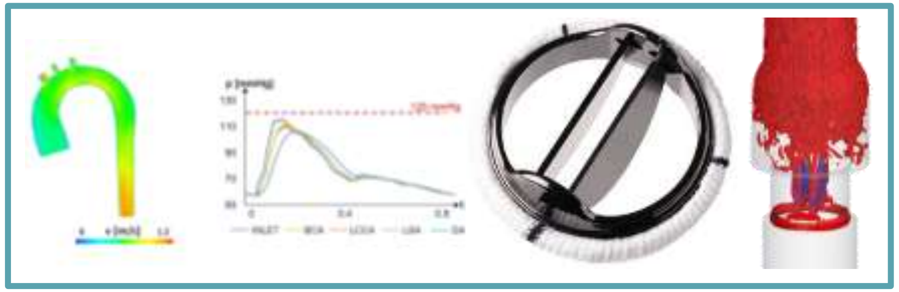
- **patient conditions**
- **surgical procedures**

without performing additional invasive tests and/or clinical trials

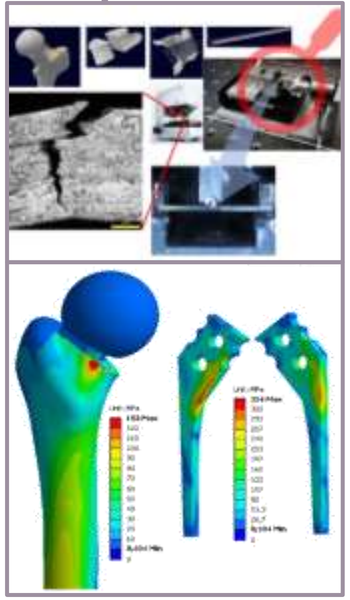
Computational models provide:

- **the strain and stress** of the biological tissues which regulate tissues mechanical, physio-mechanical and mechano-biological response
- **the prediction** of surgical efficacy, risks of failure, prostheses functionality, tissue degeneration…

Cardiovascular field

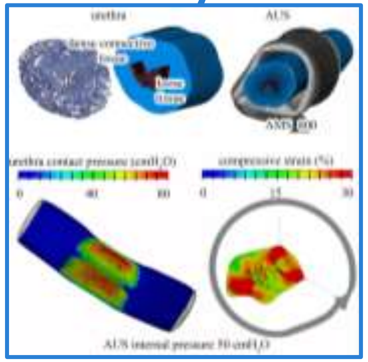


Orthopaedic field



Implantology

Urinary field



In silico modelling


bioengineering
MDPI

Review

Computational Biomechanics: In-Silico Tools for the Investigation of Surgical Procedures and Devices

Emanuele Luigi Carniel, Ilaria Toniolo and Chiara Giulia Fontanella *

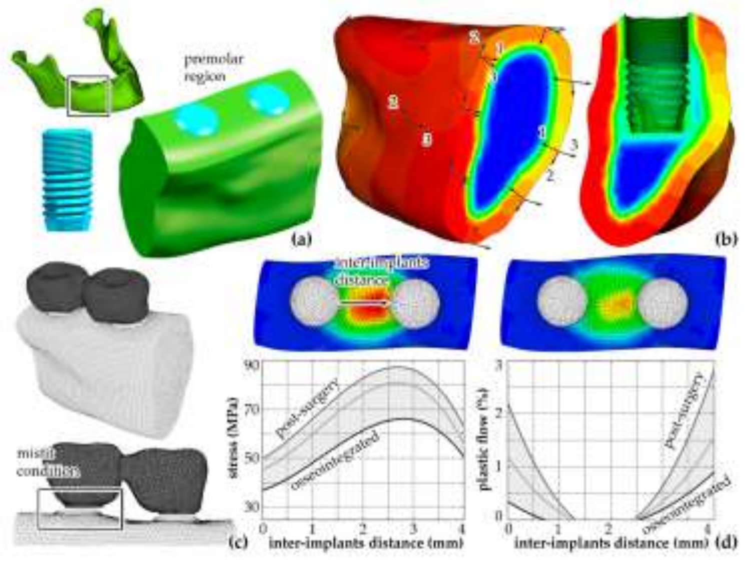
Department of Industrial Engineering, Centre for Mechanics of Biological Materials, University of Padova, I-35131 Padova, Italy; emanueleluigi.carniel@unipd.it (E.L.C.); ilaria.toniolo.1@phd.unipd.it (I.T.)
* Correspondence: chiaragiulia.fontanella@unipd.it; Tel.: +39-049-827-6754

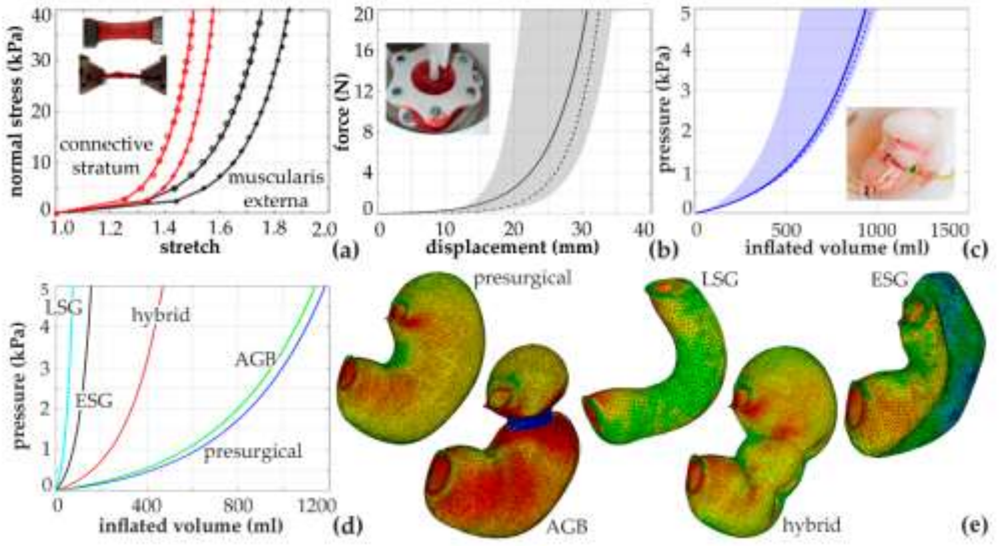
Received: 12 May 2020; Accepted: 28 May 2020; Published: 30 May 2020

check for updates

Abstract: Biomechanical investigations of surgical procedures and devices are usually developed by means of human or animal models. The exploitation of computational methods and tools can reduce, refine, and replace (3R) the animal experimentations for scientific purposes and for pre-clinical research. The computational model of a biological structure characterizes both its geometrical conformation and the mechanical behavior of its building tissues. Model development requires coupled experimental and computational activities. Medical images and anthropometric information provide the geometrical definition of the computational model. Histological investigations and mechanical tests on tissue samples allow for characterizing biological tissues' mechanical response by means of constitutive models. The assessment of computational model reliability requires comparing model results and data from further experimentations. Computational methods allow for the in-silico analysis of surgical procedures and devices' functionality considering many different influencing variables, the experimental investigation of which should be extremely expensive and time consuming. Furthermore, computational methods provide information that experimental methods barely supply, as the strain and the stress fields that regulate important mechano-biological phenomena. In this work, general notes about the development of biomechanical tools are proposed, together with specific applications to different fields, as dental implantology and bariatric surgery.

Keywords: computational methods; constitutive model; dental implantology; surgery





Engineering approach in bariatric surgery

Mechanical behavior of gastric tissues

- Experimental tests on ex-vivo samples
- Proper constitutive formulation
- Model validation

$$W(\mathbf{C}) = W_m(\mathbf{C}) + W_f^{\,j}\left(\mathbf{C},\mathbf{a}_0^{\,j}\right) + W_f^{\,jk}\left(\mathbf{C},\mathbf{a}_0^{\,j},\mathbf{a}_0^{\,k}\right)$$

journal of the mechanical behavior of biomedical materials 110 (2020) 103883

Contents lists available at ScienceDirect

ELSEVIER

Journal of the Mechanical Behavior of Biomedical Materials

journal homepage: http://www.elsevier.com/locate/jmbbm

Biomechanics of stomach tissues and structure in patients with obesity

Emanuele Luigi Carniel [a,b,*], Alice Albanese [c], Chiara Giulia Fontanella [b,e], Piero Giovanni Pavan [a,b], Luca Prevedello [c], Claudia Salmaso [a], Silvia Todros [a,b], Ilaria Toniolo [a], Mirto Foletto [b,c,d]

[a] Department of Industrial Engineering, University of Padova, Italy
[b] Centre for Mechanics of Biological Materials, University of Padova, Italy
[c] IFSO Bariatric Center of Excellence, Policlinico Universitario, University of Padova, Italy
[d] Department of Surgery, Oncology and Gastroenterology, University of Padova, Italy
[e] Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy

Contents lists available at ScienceDirect

ELSEVIER

Journal of the Mechanical Behavior of Biomedical Materials

journal homepage: www.elsevier.com/locate/jmbbm

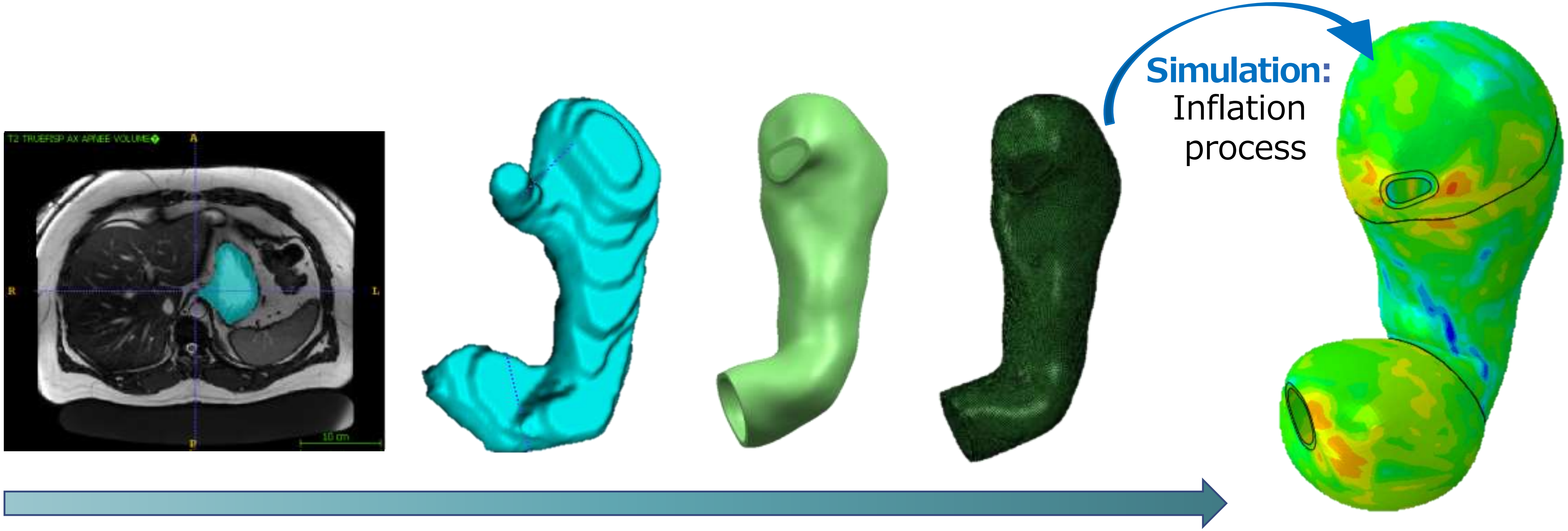
Research Paper

Coupled experimental and computational approach to stomach biomechanics: Towards a validated characterization of gastric tissues mechanical properties

Ilaria Toniolo [a,b,*], Chiara Giulia Fontanella [a,b], Mirto Foletto [b,c,d], Emanuele Luigi Carniel [a,b]

Patient-specific modelling

- Patient-specific models interpret the **geometrical conformation** and **the mechanical behavior** of a biological structure of the specific patient, aiming to optimize and customize the surgical procedure on a case-by-case basis



From MRI scans of patients

To 3D geometrical model

To 3D Finite Element model

National and International collaborations

- The following research activities started from a strong and multidisciplinary collaborations between the **University of Padova** and the **University Hospital of Padova**, and then involving numerous Italian universities (**Policlinico of Turin and Milan**) and foreign centers (**Hospital of Strasbourg and Montreal**)

Università degli Studi di Padova

dii

ICEA

Les Hôpitaux Universitaires de Strasbourg

Regione del Veneto

Regione del Veneto
Azienda Ospedale Università Padova

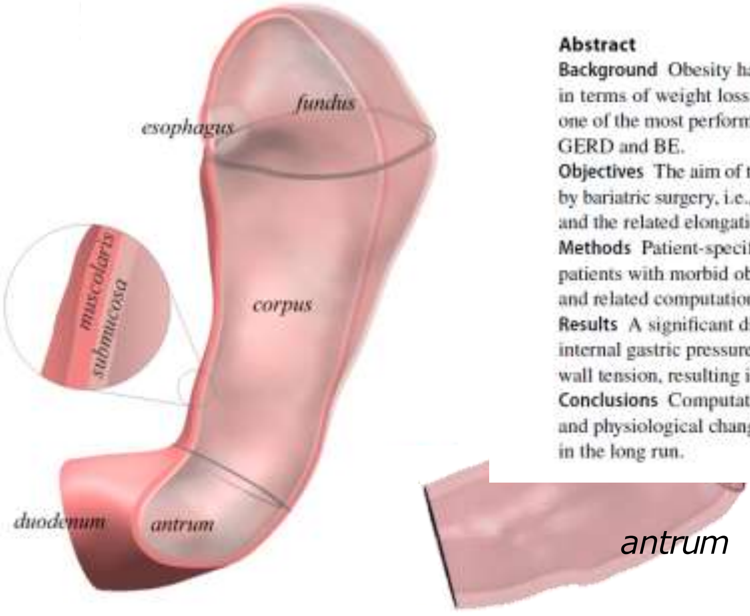
Politecnico di Torino
1859

Québec
Hôpital du Sacré-Cœur-de-Montréal

Politecnico Milano 1863

Computational evaluation of LSG

Pre-surgical model



Surgical Endoscopy
https://doi.org/10.1007/s00464-022-09233-7

Patient-specific stomach biomechanics before and after laparoscopic sleeve gastrectomy

Ilaria Toniolo[1,2] · Alice Berardo[2,3,4] · Mirto Foletto[2,5] · Claudio Fiorillo[6] · Giuseppe Quero[6,7] · Silvana Perretta[8,9,10] · Emanuele Luigi Carniel[1,2]

Received: 2 November 2021 / Accepted: 29 March 2022

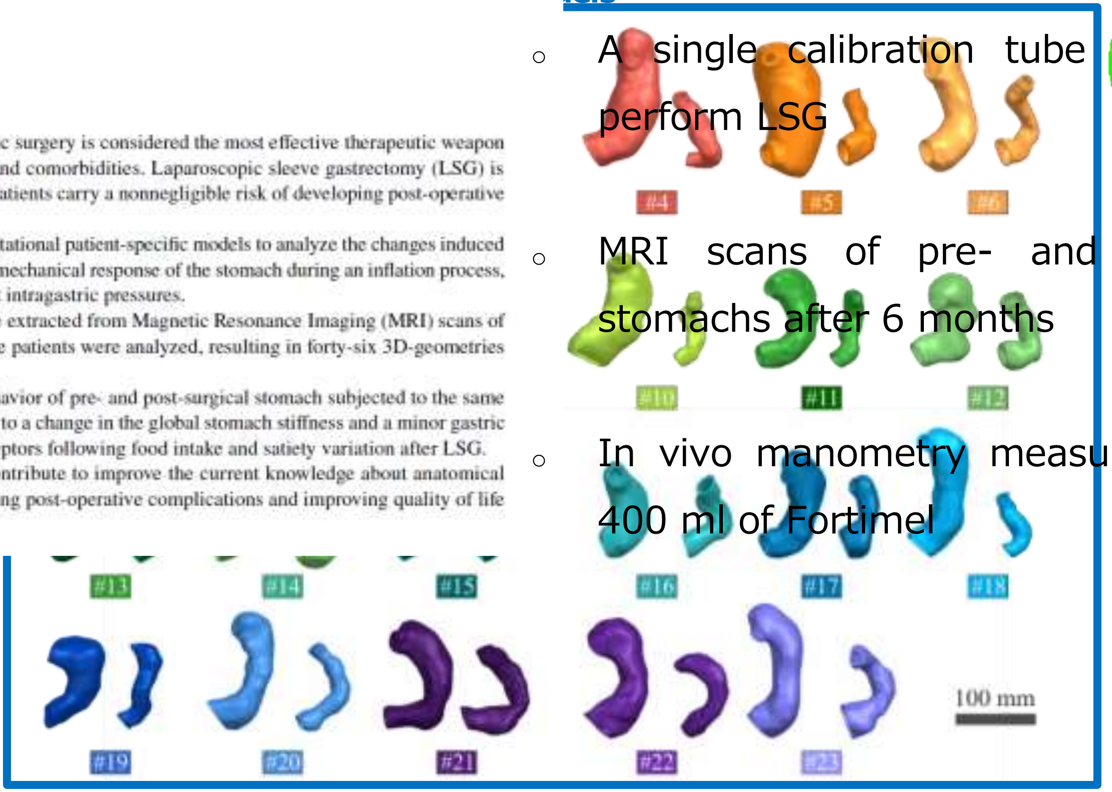
Abstract
Background Obesity has become a global epidemic. Bariatric surgery is considered the most effective therapeutic weapon in terms of weight loss and improvement of quality of life and comorbidities. Laparoscopic sleeve gastrectomy (LSG) is one of the most performed procedures worldwide, although patients carry a nonnegligible risk of developing post-operative GERD and BE.
Objectives The aim of this work is the development of computational patient-specific models to analyze the changes induced by bariatric surgery, i.e., the volumetric gastric reduction, the mechanical response of the stomach during an inflation process, and the related elongation strain (ES) distribution at different intragastric pressures.
Methods Patient-specific pre- and post-surgical models were extracted from Magnetic Resonance Imaging (MRI) scans of patients with morbid obesity submitted to LSG. Twenty-three patients were analyzed, resulting in forty-six 3D-geometries and related computational analyses.
Results A significant difference between the mechanical behavior of pre- and post-surgical stomach subjected to the same internal gastric pressure was observed, that can be correlated to a change in the global stomach stiffness and a minor gastric wall tension, resulting in unusual activations of mechanoreceptors following food intake and satiety variation after LSG.
Conclusions Computational patient-specific models may contribute to improve the current knowledge about anatomical and physiological changes induced by LSG, aiming at reducing post-operative complications and improving quality of life in the long run.

Cohort info and surgical procedure:

5.5, age

- A cohort of 23 patients with morbid obesity (BMI= 41.9 ± 5.5, age 36 ± 10) who underwent LSG
- A single calibration tube was used to perform LSG
- MRI scans of pre- and post-surgical stomachs after 6 months
- In vivo manometry measurements after 400 ml of Fortimel

nths
lels



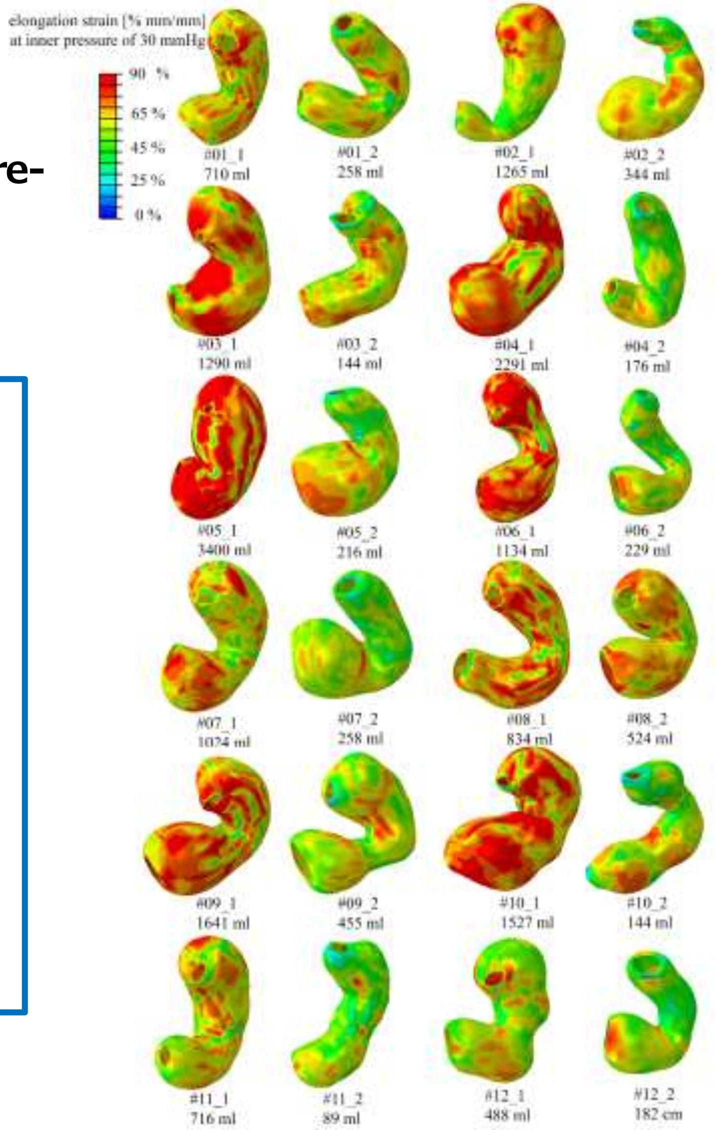
Inflation process to **analyze food intake**

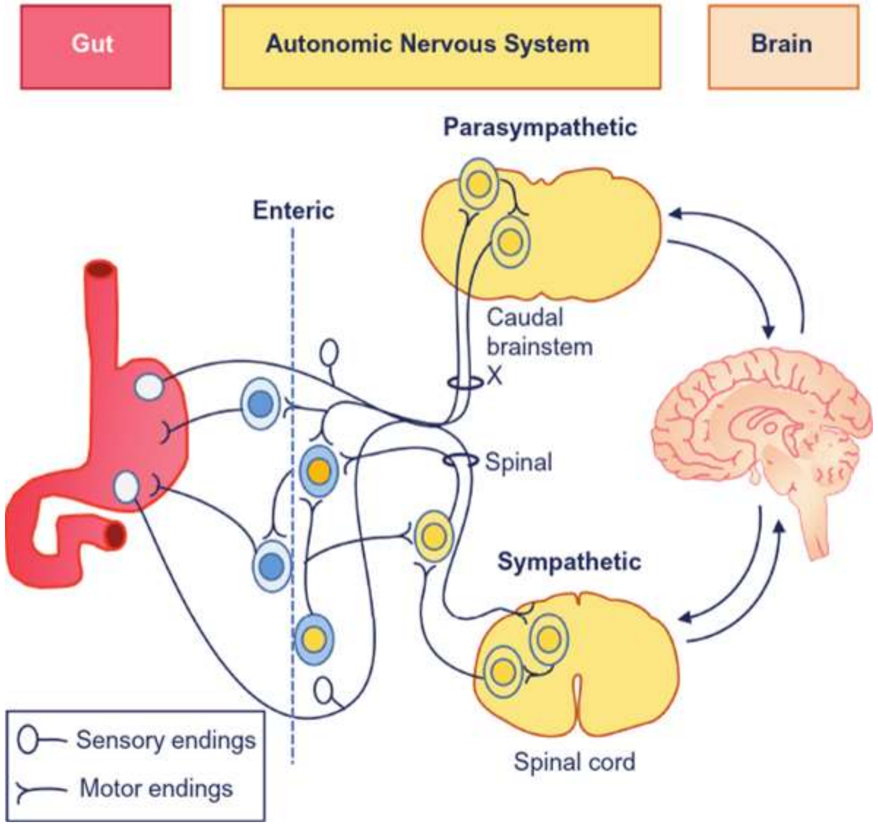
LSG modelling - Results

- High inter-sample variability
- **Higher** elongation strain in **pre-surgical** than post-surgical stomachs

LSG affects the mechanical response of the stomach

At 30 mmHg pressure, a decrease of 13% of elongation strain after LSG

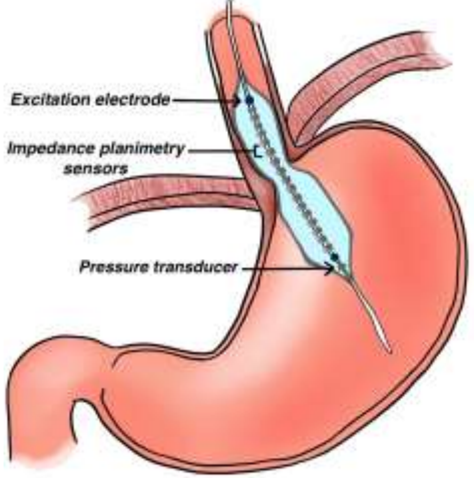




LSG modelling - Results

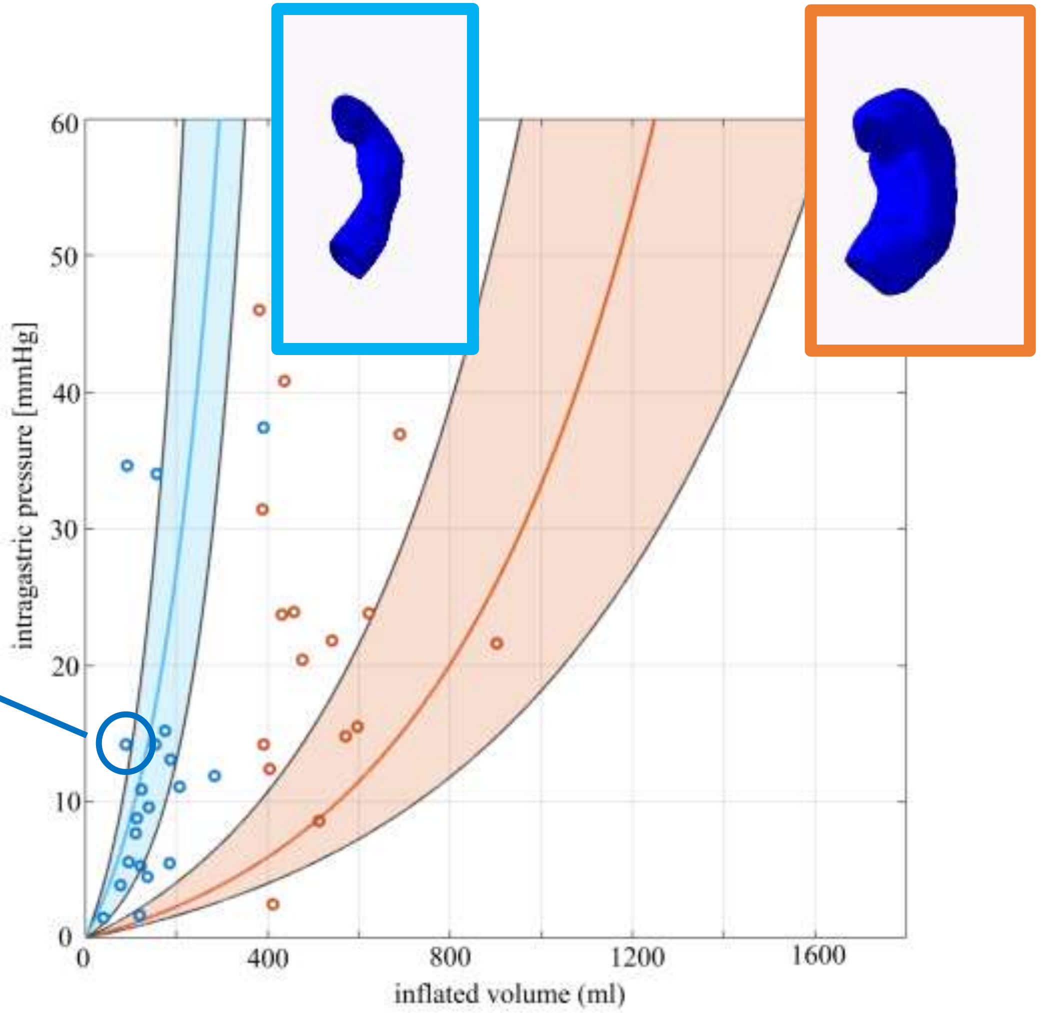
- Wide volume-pressure curves behaviour
- **Post-surgical stomachs** appear to be **stiffer** than pre-surgical ones (less volume, higher pressurisation)
- **Good agreement** between **computational results** and **in vivo experimental manometry** measurements

Experimental points from in vivo manometry



Post-LSG configuration

Pre-surgical configuration

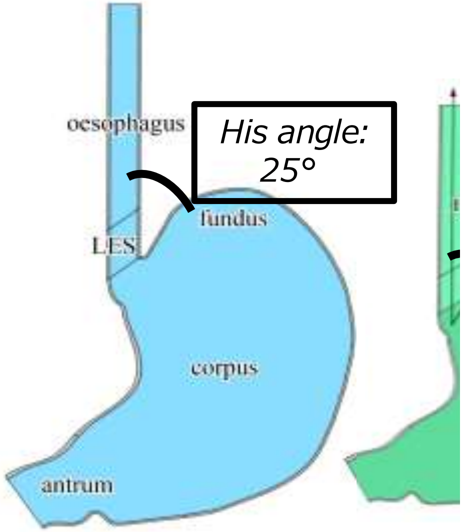


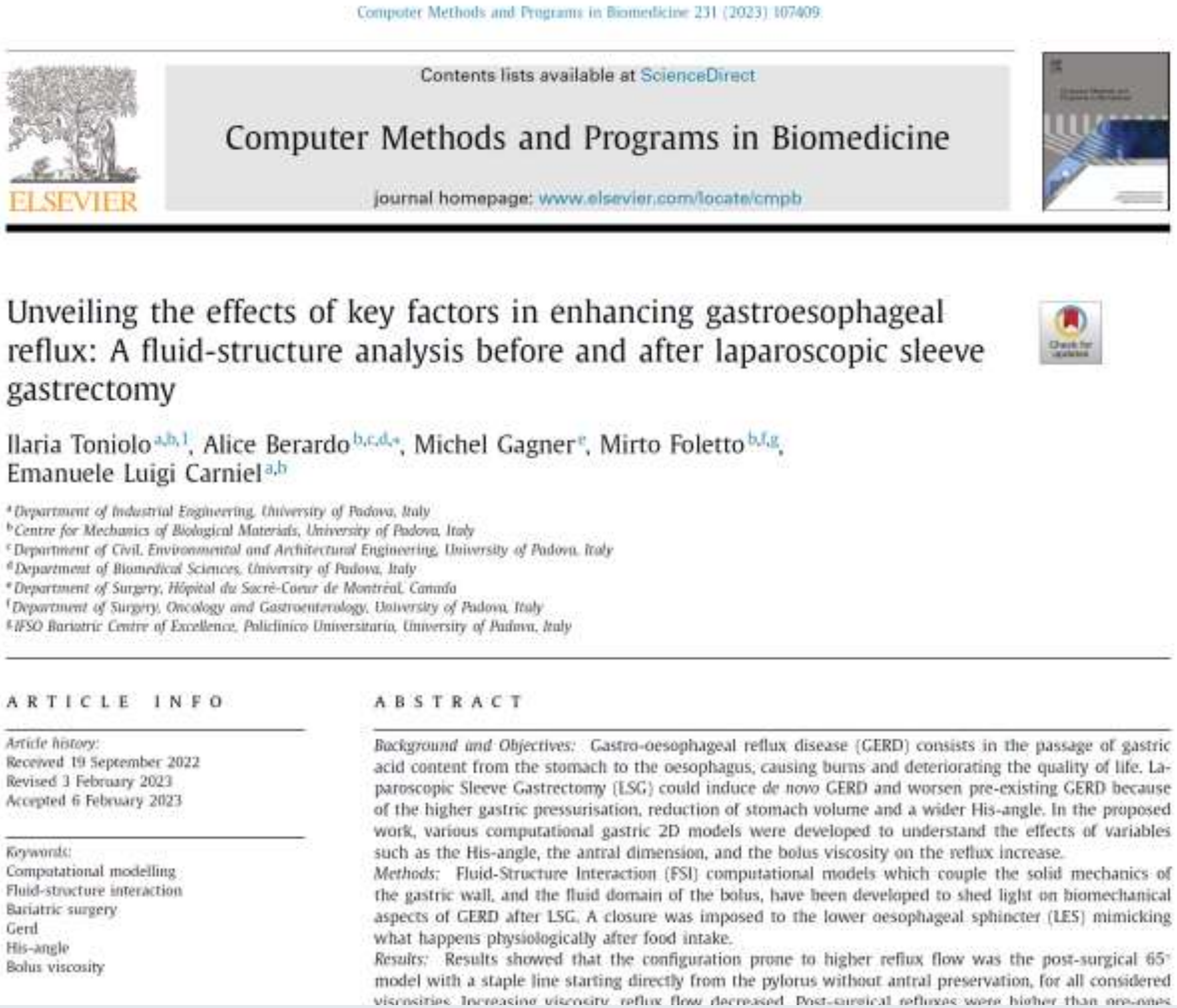
GERD and LSG – Fluid-Structure Interaction analysis

- **Challenge**: mechanical quantification of the gastric reflux after LSG respect to His angle amplitude and antrum preservation

Geometries (case studie

- **four** His angles (25
preservation and thre




Computer Methods and Programs in Biomedicine 231 (2023) 107409
Contents lists available at ScienceDirect
Computer Methods and Programs in Biomedicine
journal homepage: www.elsevier.com/locate/cmpb

Unveiling the effects of key factors in enhancing gastroesophageal reflux: A fluid-structure analysis before and after laparoscopic sleeve gastrectomy

Ilaria Toniolo[a,b,1], Alice Berardo[b,c,d,*], Michel Gagner[e], Mirto Foletto[b,f,g], Emanuele Luigi Carniel[a,b]

[a] Department of Industrial Engineering, University of Padova, Italy
[b] Centre for Mechanics of Biological Materials, University of Padova, Italy
[c] Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy
[d] Department of Biomedical Sciences, University of Padova, Italy
[e] Department of Surgery, Hôpital du Sacré-Coeur de Montréal, Canada
[f] Department of Surgery, Oncology and Gastroenterology, University of Padova, Italy
[g] IFSO Bariatric Centre of Excellence, Policlinico Universitario, University of Padova, Italy

ARTICLE INFO

Article history:
Received 19 September 2022
Revised 3 February 2023
Accepted 6 February 2023

Keywords:
Computational modelling
Fluid-structure interaction
Bariatric surgery
Gerd
His-angle
Bolus viscosity

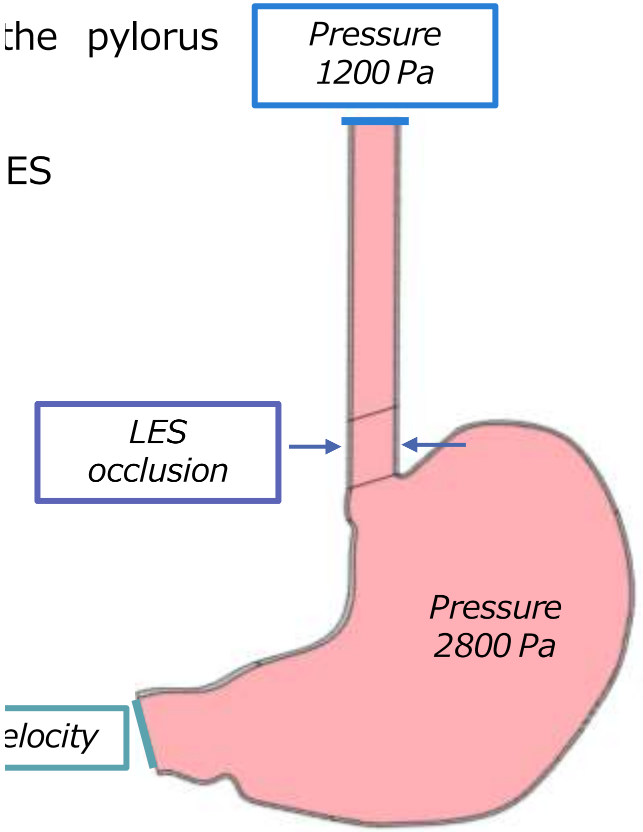
ABSTRACT

Background and Objectives: Gastro-oesophageal reflux disease (GERD) consists in the passage of gastric acid content from the stomach to the oesophagus, causing burns and deteriorating the quality of life. Laparoscopic Sleeve Gastrectomy (LSG) could induce de novo GERD and worsen pre-existing GERD because of the higher gastric pressurisation, reduction of stomach volume and a wider His-angle. In the proposed work, various computational gastric 2D models were developed to understand the effects of variables such as the His-angle, the antral dimension, and the bolus viscosity on the reflux increase.
Methods: Fluid-Structure Interaction (FSI) computational models which couple the solid mechanics of the gastric wall, and the fluid domain of the bolus, have been developed to shed light on biomechanical aspects of GERD after LSG. A closure was imposed to the lower oesophageal sphincter (LES) mimicking what happens physiologically after food intake.
Results: Results showed that the configuration prone to higher reflux flow was the post-surgical 65° model with a staple line starting directly from the pylorus without antral preservation, for all considered viscosities. Increasing viscosity, reflux flow decreased. Post-surgical refluxes were higher than pre-ones

pressure to
...mach

the pylorus

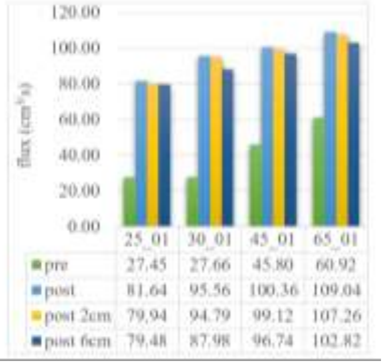
ES



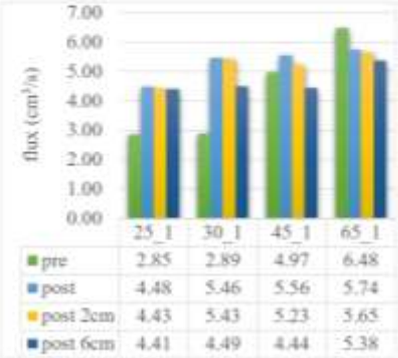
GERD and LSG – Results

- Configuration promoting **higher reflux flow** was **post-surgical 65° without antral preservation**
- Post-surgical refluxes were higher than pre-ones and decreased at the increasing of the distance between the stapler line and pylorus

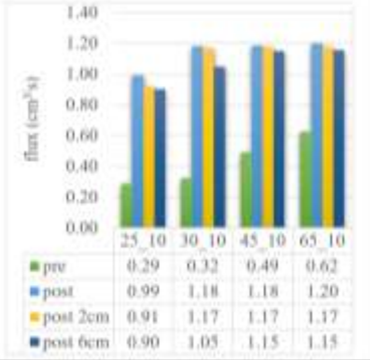
increasing viscosity of the bolus



	25_01	30_01	45_01	65_01
pre	27,45	27.66	45.80	60.92
post	81,64	95.56	100.36	109.04
post 2cm	79,94	94.79	99.12	107.26
post 6cm	79,48	87.98	96.74	102.82



	25_1	30_1	45_1	65_1
pre	2.85	2.89	4.97	6.48
post	4.48	5.46	5.56	5.74
post 2cm	4.43	5.43	5.23	5.65
post 6cm	4.41	4.49	4.44	5.38



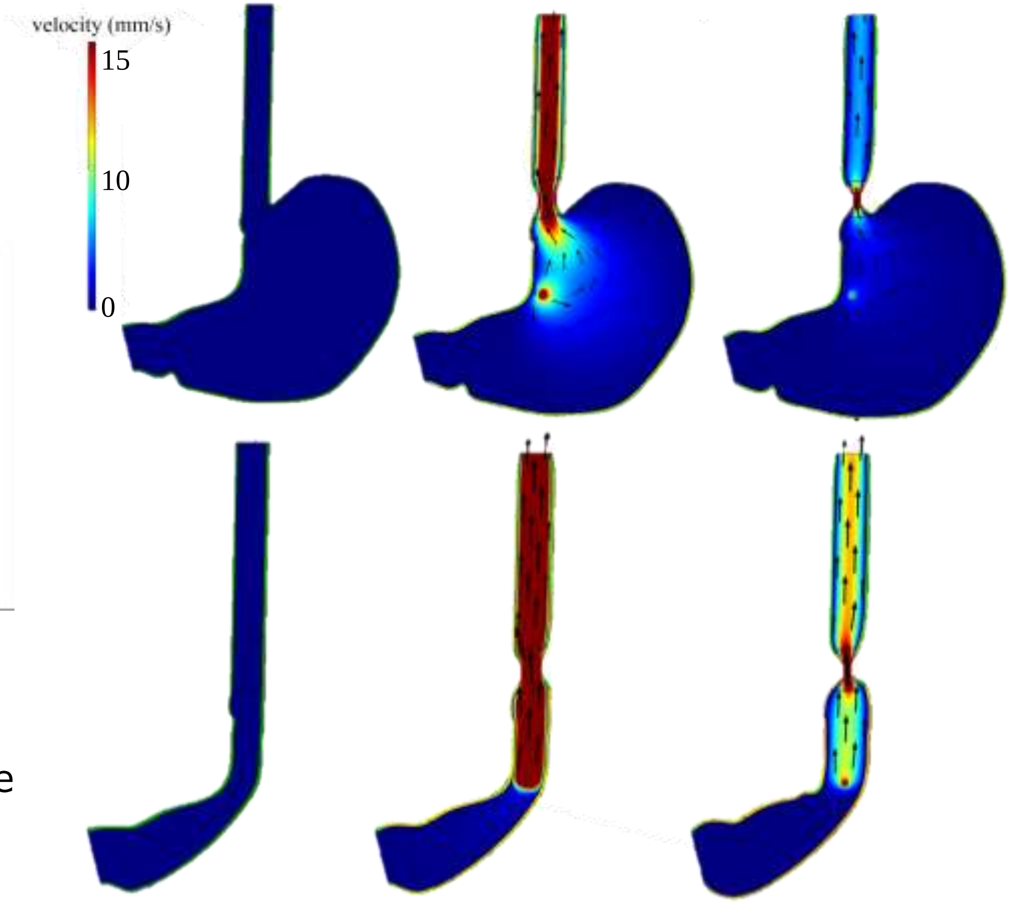
	25_10	30_10	45_10	65_10
pre	0.29	0.32	0.49	0.62
post	0.99	1.18	1.18	1.20
post 2cm	0.91	1.17	1.17	1.17
post 6cm	0.90	1.05	1.15	1.15

Take-home message:

good practice: maintenance or the decrease of His's angle and preserving part of the antrum after LSG

Colormaps

His angles 45° and **stapler line very close to pylorus**

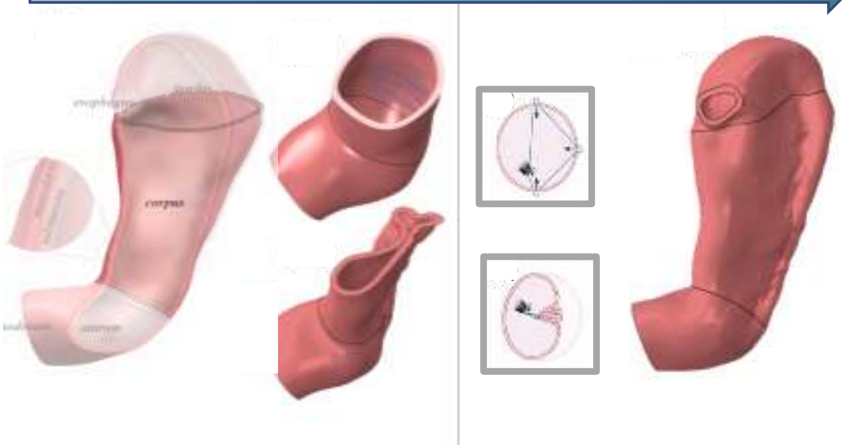


Computational evaluation of ESG

Cohort info and surgical procedure:

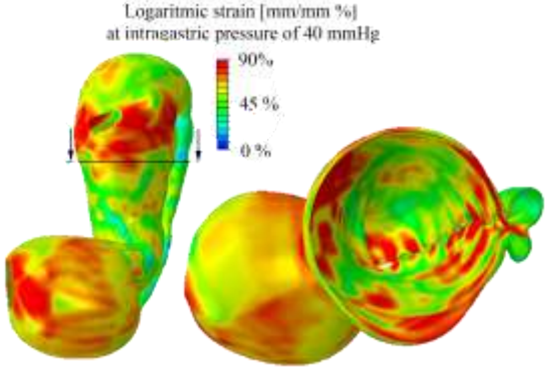
- A cohort of 12 patients with obesity (BMI=38.19 ± 4.51 kg/m^2 , age 40.75 ± 9.49 years) who underwent ESG
- MRI scans of pre- and post-surgical stomachs after 6 months

Part1: Simulation of ESG procedure



- Wire features to simulate the sutures' pattern (according to the procedure performed at Hospital of Strasbourg)
- Connector displacement to simulate the sutures' closing

Part2: Simulation of food intake



- Gastroesophageal and gastroduodenal junctions were fixed
- Fluid cavity interaction in the internal region of the stomach
- Pressure of the cavity: from 0 to 5 kPa
- Software: Abaqus Explicit 2018

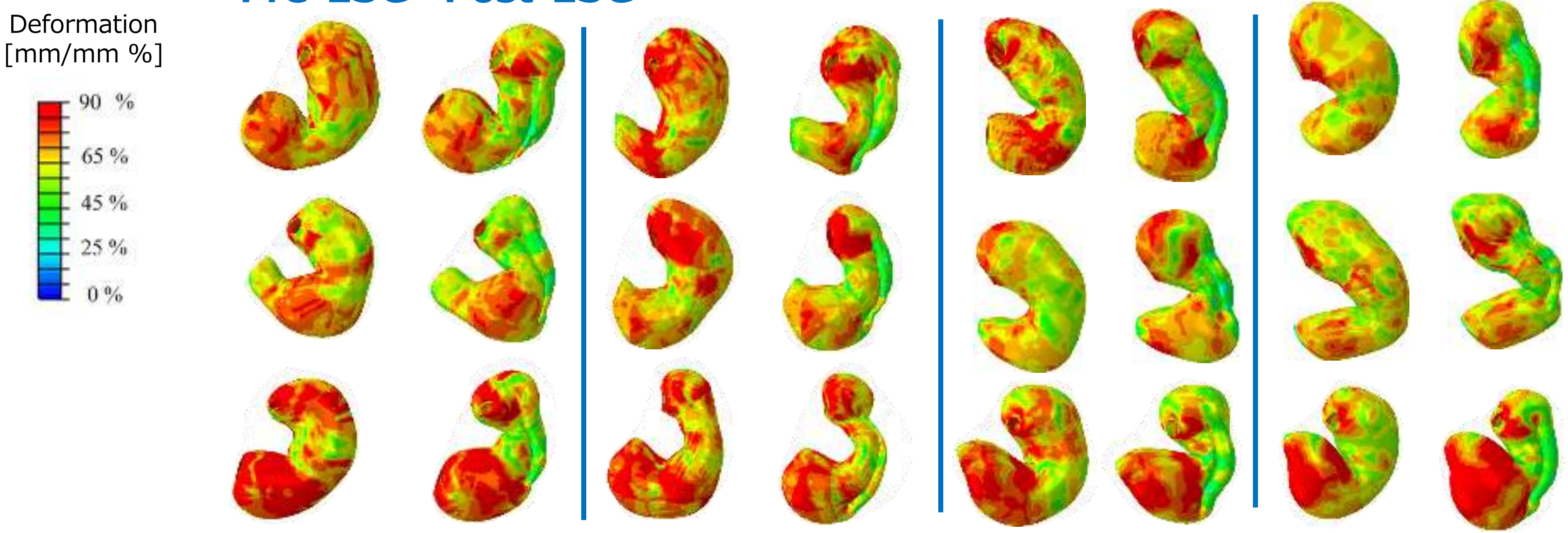
Virtual solid models

ESG modelling - Results

- High inter-sample variability
- **Higher** elongation strain in **pre-surgical** than post-surgical stomachs
- The corpus region is less inclined to deformation because of the presence of the suture that limit the displacement

ESG affects the mechanical response of the stomach by a decrease of 3% of elongation strain

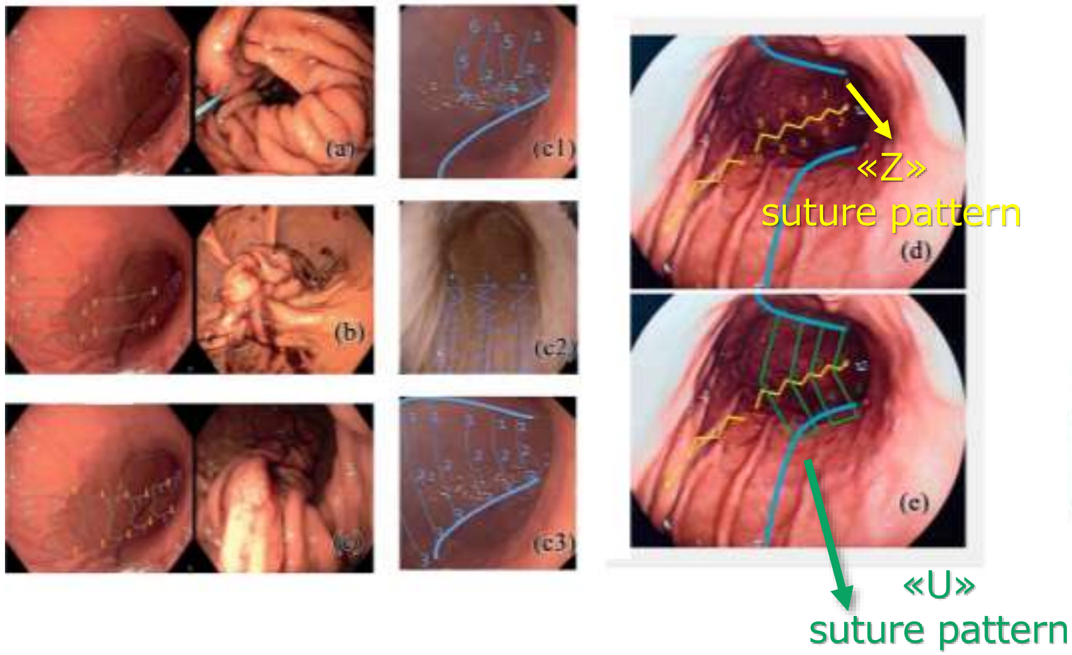
Pre-ESG Post-ESG



ESG sutures modelling – Case Study

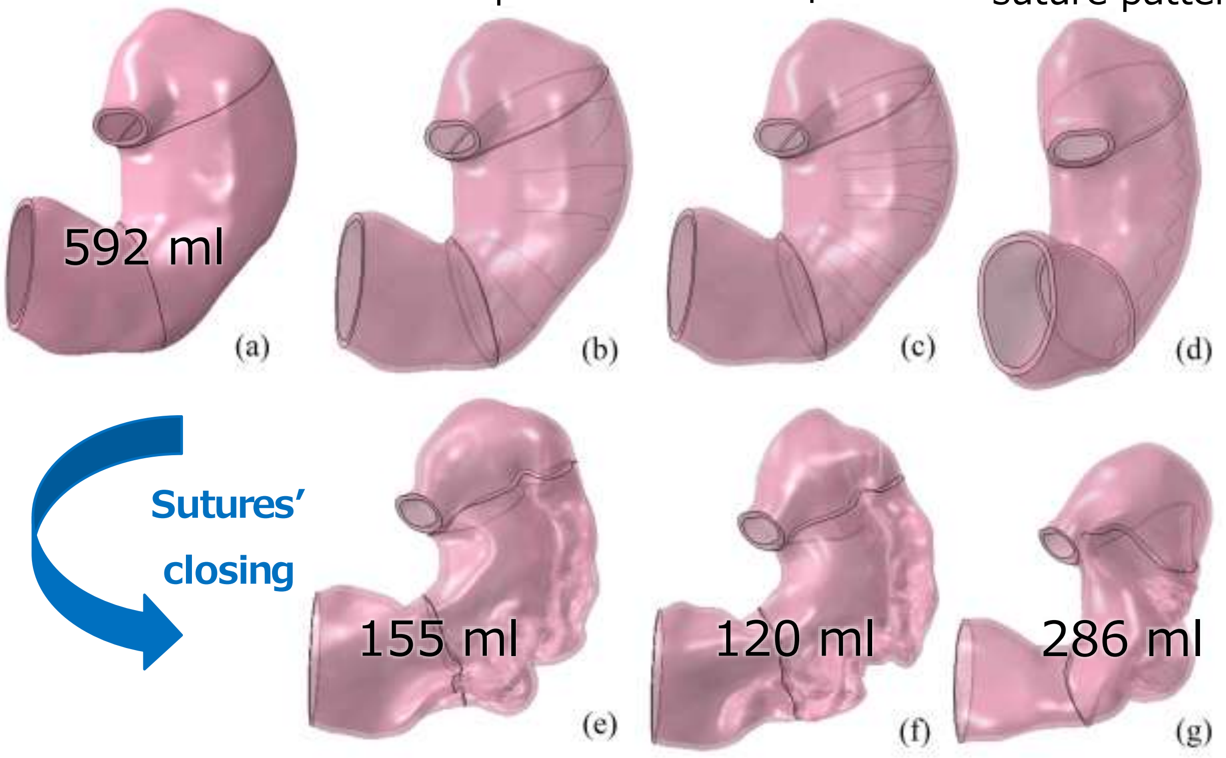
- **Challenge**: mechanical evaluation of the different sutures' patterns aiming at identifying the best compromise in terms of volumetric reduction and tubulisation duration, avoiding excessive biological tissues stress

→ Proposing a standardisation in ESG performance

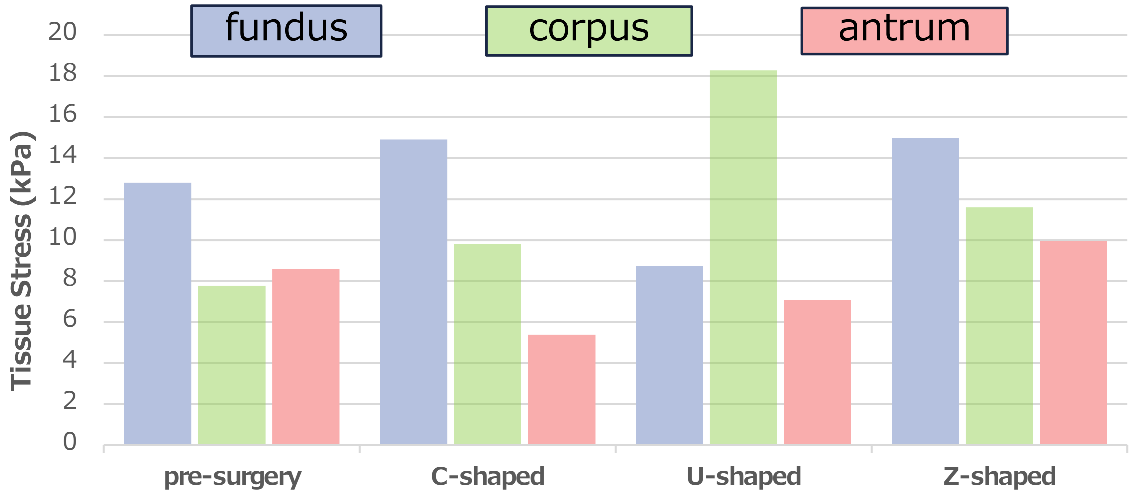


a Pattern "band" aiming to increase distensibility of the fundus. b Gastric "volume reduction." c Pattern "dams" aiming to slow down gastric emptying. Different types of endoscopic suture patterns used in ESG-Apollo. Images (c1) (TBp), (c2) (Lp) and (c3) (TMp).

Computational modelling



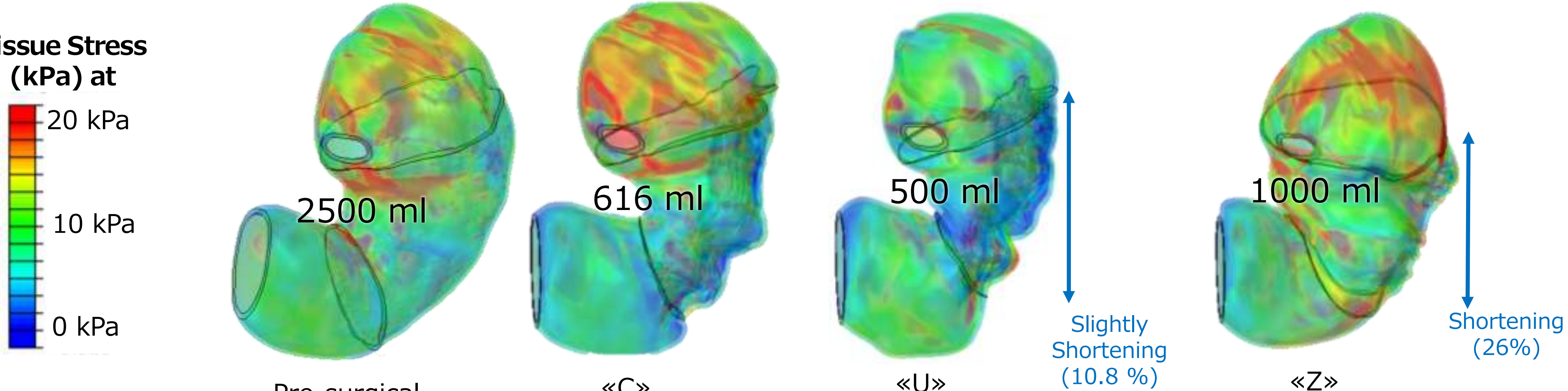
ESG sutures – Results



Potentialities of computational models

In silico a priori analyses changing the number of sutures, the positioning and the patterns to enhance the deformation in the most-populated-by-mechanoreceptors stomach locations

Tissue Stress (kPa) at



Pre-surgical stomach

«C» suture pattern

«U» suture pattern

«Z» suture pattern

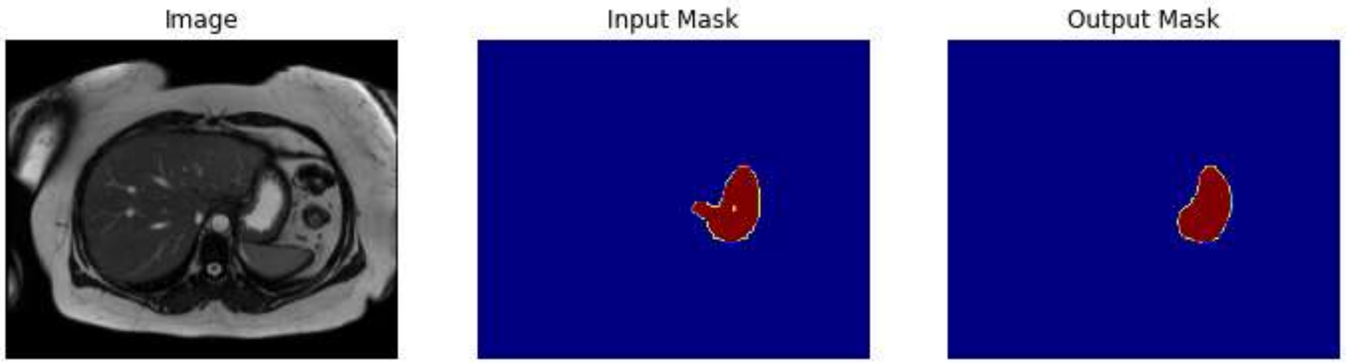
ON GOING ACTIVITIES:

- **Development of a neural-network to automatically provide the Total small bowel length** supported by a **national research foundation** *"Progetti di Rilevante Interesse Nazionale (PRIN) "* in collaboration with La Sapienza University (Prof. Gianfranco Silecchia, Roma) and University of Federico II (Prof. Mario Musella, Naples)

- **Development of a neural-network to automatically segment Stomach** supported by a **national research foundation** *"Fondazione Cassa di Risparmio di Padova e Rovigo"*

Aim is to develop a **computational clinical tool** that **automatically:**

- **generates the patient-specific stomach model** from MRI
- **proposes the optimal post-surgical configuration**
- **suggests the sutures' pattern** in case of ESG
- **forecasts the surgical success**



ON GOING ACTIVITIES:

- The high potentiality of computational models can improve surgical outcomes and offer a rational and mechanical comparison among the several surgical procedures

- We need a **large database** of abdominal MRIs to **train and validate the neural networks/artificial intelligence** for the detection of the stomach

If would like to **participate** into this multi-center research project, do not hesitate to contact ilaria.toniolo@unipd.it

Your contribution will consist of sharing anonymized MRIs where the stomach is visible and complete (Normal-weight subjects or Bariatric subjects, before and/or after bariatric procedures)

ON GOING ACTIVITIES:

Thank you for your attention!

Keynote: NEW TECHNOLOGIES
ARTIFICIAL INTELLIGENCE

30 August 2023

Patient-specific stomach biomechanics before and after bariatric surgery: computational models of surgical procedure

Speaker: Ilaria Toniolo, Ph.D

IFSO
NAPOLI
2023