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Technical note

Mechanical properties of the human gastrointestinal tract ☆

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Abstract

The tensile properties of the human esophagus, stomach, small and large bowel were examined on an Instron 1221 tensiometer. The values of maximal stress and destructive strain were the following: for esophagus—1.2 MPa and 140%, respectively, for stomach axial specimens—0.7 MPa and 190%, for stomach transversal specimens—0.5 MPa and 190%, for small bowel transversal specimens—0.9 MPa and 140% and for large bowel transversal specimens—0.9 MPa and 180%. Tests conducted on small and large bowel axial specimens permitted examination of the intestinal wall as a multi-layered structure. The mechanical properties of tested bowels in axial and transversal directions were qualitatively different. The submucosa and muscular layers condition the mechanical strength of bowel wall, while the serosa and mucosa showed no significant strength. Reproducible results were generated for cadaveric and surgically removed stomach and small intestine, which showed their mechanical properties similar under certain storage conditions. The data received could be used for monitoring of the mechanical properties of bowel wall layers under different conditions and for checking of bowel distension sequences.

Keywords: Gastrointestinal tract; Stress; Strain; Mechanical properties; Bowel wall layers

1. Introduction

Knowing mechanical properties of the hollow organs of gastrointestinal tract appears to be important for understanding their physiology, ability to withstand distension and for creating methods of joining them. Up to the present time, extensive investigations of human gastrointestinal organs mechanical behavior have been reported only in the work of Yamada (1972). The duration of the mechanically stabilized state for various human tissues was also determined by Yamada (1972), who showed that various organs of animals and human beings placed in a physiological saline solution and stored overnight at 4°C had constant strength values for different postmortem times before testing. Raikevitch (1963) and Kirpatovsky (1964) studied mechanical properties of the human small bowel. Watters et al. (1985a, b) and Buianov et al. (2000) reported on mechanical properties of the human large bowel. In the first three reports, an application of increased force was used to determine tensile strength. In Watters' work (1985) transversal samples of human colons of different ages were tested by constant strain rate method. Although, in this work, figures were not presented, evidently they were the same as in his work with rats (Watters et al., 1985a, b), and their descending parts were too short to analyze. The common problem of the methods employed in these works has been the evaluation of the bowel wall as a one-layer membrane instead of as a multi-layered construction, which it really is. Thus, there was no chance to evaluate the contribution of different layers to mechanical strength of the organ wall.

The distinguished American surgeon William Stuart Halsted was the first who tried to study the mechanical properties of the submucosa in dogs and showed its

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importance for anastomotic reliability. His work (Halsted, 1887), published more than 100 years ago, may be considered as one of the first studies on the biomechanics of intestinal junctions. Thus, while the importance of the submucosa was qualitatively established more than 100 years ago, the degree and the character of participation of the gut wall layers in supplying mechanical properties of the intestine were not demonstrated. Raikevitch (1963) and Kirpatovsky (1964) reported a 15–20% contribution of the muscular layers, a 70–75% contribution of the submucosa, and a 5–10% contribution of the serosa to the strength of the human intestinal wall. Iwasaki (Yamada, 1972) did not report on the degree of support that the wall layers give the intestine, although such data, for e.g., the esophagus, were indicated by Nonogaki F. (Yamada, 1972). In the last case, the method of testing different esophageal wall layers was not described.

In our previous study (Buianov et al., 2000), transversal and axial samples of human colons were tested by the method described below. Bimodal curves were obtained for axial tenia samples that allowed us to evaluate the bowel wall mechanical behavior as a two-layered structure.

In the present work, specimens of human esophagus, stomach, small and large bowel were examined. The data obtained for axial specimens of small and large bowel allowed us to evaluate the mechanical properties of the bowel wall layers.

2. Methods

The mechanical properties of the distal third of the esophagus, the middle parts of the stomach, the small intestine, and transversal colon, received at necropsy were examined using an Instron 1122 tensiometer. Surgically removed stomach and small intestine were also examined using the same machine. Only unaffected regions of intestine and stomach, removed during surgery (the distal intestinal end in cases of intestinal obstruction and anterior gastric wall in cases of a bleeding duodenal ulcer without pylorostenosis) were used. The cadaveric organs were taken from sudden deaths at the Pathology Department, ZIL Hospital, Moscow. The average age of the 46 subjects was 55 ± 8.5 years. The bodies had been preserved at 4°C before necropsy. The organ segments were washed and kept in physiological saline solution at 4°C and tested within 24 h.

Resected fragments of tested bowels were freed from mesenterium by dissection, cut along the mesenteric border, straightened and cut into four rectangular specimens 6–6.5 cm long and 10 mm wide. One specimen was transversal (cutting in the circular direction), another one, cut from the antimesenteric aspect, was central longitudinal specimen and two adjacent longitudinal specimens were cut from the anterior and posterior bowel wall. A similar technique was used for the esophagus. The same samples were cut from the front gastric wall in longitudinal and transversal directions.

Longitudinal and transversal specimens of all organs mentioned above except the esophagus were tested. For all tested organs, curves for the central axial sample and adjacent axial samples were identical and differed only by the greater stress values for the central sample. The results of central sample tests are presented in this work. Because of technical difficulties in testing very short transversal esophageal specimens, we were not able to get repeatable results for this direction. Thus, for the esophagus, only data for axial specimens are presented.

In the middle part of the small intestine and stomach, the folds of the mucosa greatly influence the thickness measurements. Thus, the thickness of a specimen for these organs was measured between two working parts of micrometer gauge (10 mm in diameter each) after cutting off the mucosal folds. The folds of the cadaveric esophagus were not cut-off. Each specimen was fixed in upper and lower pneumatic clamps of the tensiometer in such a way that the distance between the clamps (the initial length of the specimen $\{L_0\}$) was 25 mm. This L_0 was considered as "standard". The pressure in clamps was maintained at the level of 3 atm. Testing was carried out by upward movement of the clamp attached to the cross-head away from the fixed lower clamp. In every case, the strain rate was constant 2λ/min. (loading velocity 50 mm/min).

Strain was expressed through the stretch ratio $\lambda = l/l_0$, where l_0 is the initial length (the distance between the clamps of the testing machine), and l is the current length. We were not able to precisely describe sample thickness during testing to determine true stress value in a sample. To measure stress, an engineering stress value was taken, representing the ratio of the current load to the initial sample cross-sectional area.

Fifty cadaveric esophagus specimens were tested. Cadaveric small intestine was tested in 363 cases: 181 specimens were longitudinal and 182 transversal. Operating material was tested in 98 cases: 51 longitudinal specimens and 47 transversal. Cadaveric stomach was tested in 100 cases: 50 specimens were longitudinal and 50 transversal. Operating material was tested in 60 cases: 30 longitudinal specimens and 30 transversal. Cadaveric large intestine was tested in 150 cases: 100 specimens were longitudinal (50 specimens of haustra and 50 specimens of tenia) and 50 transversal.

The results for intestinal wall turned out to be more interesting for us, so the small bowel samples were tested additionally. Twenty-four transversal and 24 longitudinal 10 mm wide small bowel cadaveric specimens with $L_0 = 25$ mm were then tested at constant strain rates

0.04λ and 20λ (the loading velocity 1 and 500 mm/min, respectively). Twelve 10 mm wide cadaveric small bowel longitudinal specimens with L_0 increased to 75 mm were tested. For these "long" 75 mm specimens, strain rate was 1.3λ (the loading velocity 100 mm/min).

We used preconditioning (10 cycles at 30% strain) before the main testing. No recovery period was allowed between preconditioning and testing. This technique resulted in the shortening of the 0–B (zero–B) interval for all tested organs (see Figs. 6 and 7) and did not influence other data in the diagrams.

Mechanical properties were tested in air at room temperature for no longer than 45 s making dehydration a negligible factor. In case of 0.04λ/min strain rate, the sample was constantly moistened by physiologic saline solution at room temperature.

Because of regular structure of the small intestine wall, we considered it a most appropriate material for histological examination to determine the relationship between the bowel wall mechanical properties and its morphological changes. At points, corresponding to the definite strain level, the histological structure of 20 longitudinal and 20 transversal intestinal specimens was examined.

2.1. Statistical methods

The experimental results allowed us to use parametric tests and were expressed as mean $\pm$ SD. Analysis of variance was used to detect significant difference. In case of significance, data were evaluated in pairs by a multiple comparison method of Student—Bonferrony (Glantz, 1994). The difference was regarded as significant when $P<0.05$.

In the diagrams, standard deviation is indicated only for points of extrema.

3. Results

The mean thickness of a specimen was equal to 2.450 ± 0.75, 0.950 ± 0.20, and $1.080\pm0.25\,\text{mm}^2$ for cadaveric esophagus, cadaveric and for surgically removed small intestine, respectively. For stomach it was 1.85 ± 0.52, 1.95 ± 0.85, and 0.910 ± 0.37 mm for cadaveric, surgically removed tissue and for cadaveric large bowel, respectively.

The curves, obtained during the testing of the material, had one (Figs. 1–4 and 6) or two (Figs. 5 and 7) maxima. In the former case, there was initial length of slow non-linear growth of stress, maximum and long and smooth decreasing of stress to 0. The curves of intestinal and large bowel axial samples (Figs. 5 and 7) had two maxima. There was initial length of slow non-linear growth of stress, linear length of significant stress increase, first maximum and abrupt drop of stress almost to 0. Further, long and smooth decreasing of stress followed, which, on reaching the second maximum, changed by the same smooth and long decreasing of stress to 0.

Fig. 1 and Table 1 represent the data and the diagram of the mechanical testing of axial specimens of human cadaveric esophagus. The diagram is presented by the curve with one maximum.

Tables 2 and 3 and Figs. 2 and 3 represent the data and diagrams of the mechanical testing of human cadaveric and surgically removed transversal and axial stomach specimens. The diagrams for both directions are presented by one maximum curves.

Tables 4 and 5 and Figs. 4 and 5 represent the data and diagrams of the mechanical testing of human cadaveric and surgically removed transversal and axial specimens of large bowel. One maximum curves were generated for both directions of haustra, whereas for

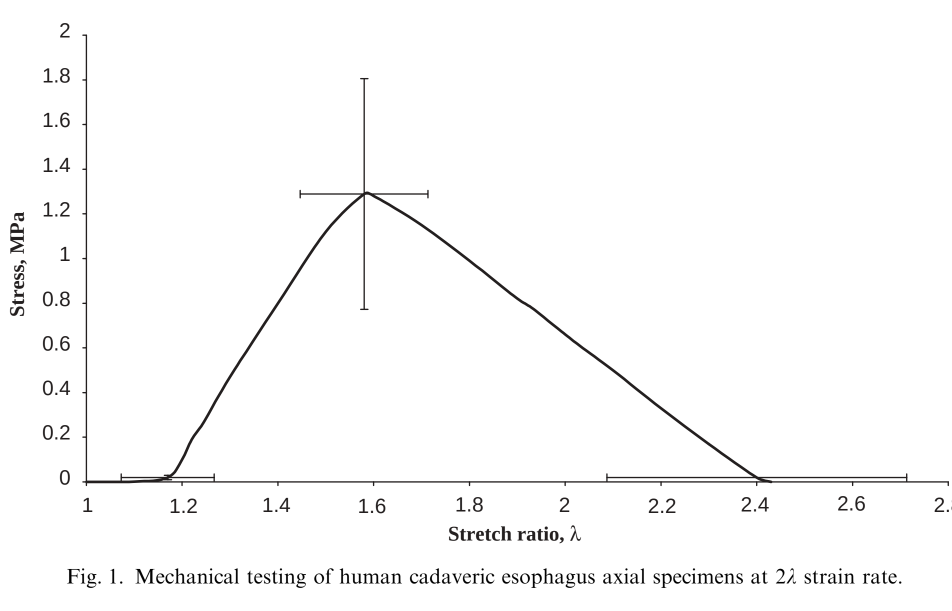

Fig. 1. Mechanical testing of human cadaveric esophagus axial specimens at 2λ strain rate.

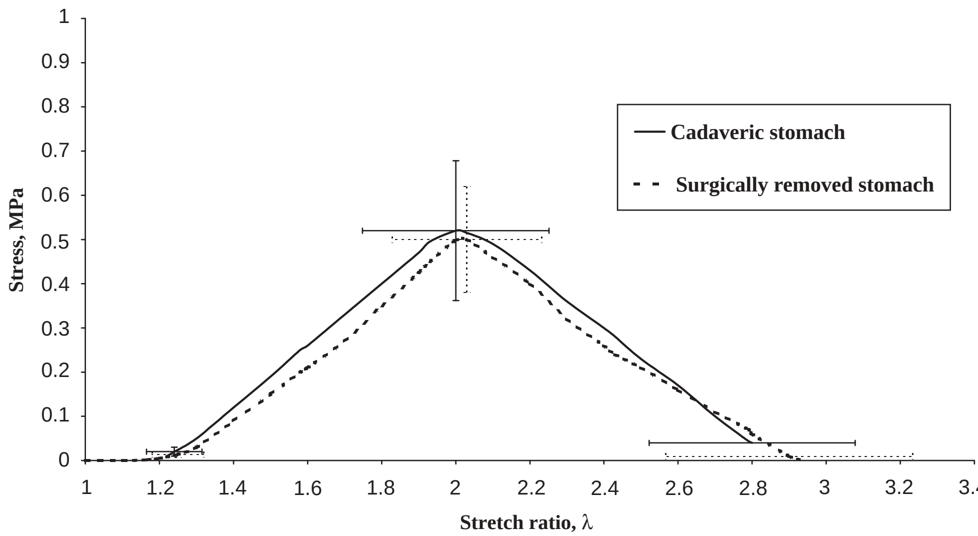

Fig. 2. Mechanical testing of human cadaveric and surgically removed transversal stomach specimens at 2λ strain rate.

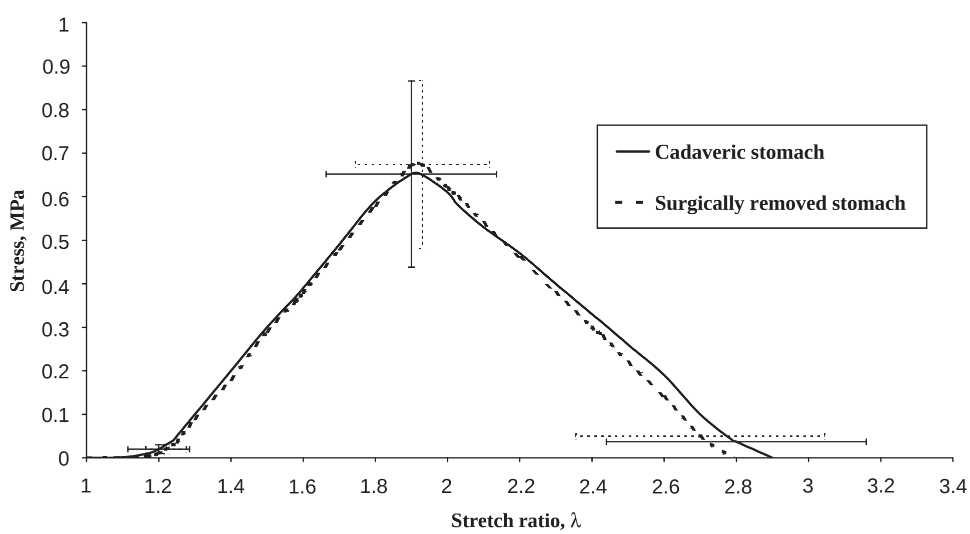

Fig. 3. Mechanical testing of human cadaveric and surgically removed axial stomach specimens at 2λ strain rate.

tenia one maximum curve was obtained for transversal and two maxima curve for longitudinal direction. Tables 2–7.

Tables 6 and 7 and Figs. 6 and 7 represent the data and diagrams of the mechanical testing of human cadaveric and surgically removed transversal and axial specimens of small intestine. One maximum curves were generated for transversal and two maxima curve for longitudinal direction.

Our understanding of such a behavior of the material are given in the section Discussion.

Transversal intestinal specimens were histologicaly examined in points 1–4 (Fig. 6) before and after strain–stress testing. Before testing five intact layers of the small bowel were observed on microslides. After testing the following became evident:

At point 1, the mucosa, submucosa and external muscular layer remained intact. Irregularities of the serosa and internal muscular layer were observed. At point 2, mucosa and submucosa were intact, but full rupture of the serosa and both muscular layers was found. At point 3, full rupture of the serosa and both muscular layers was found, the mucosa was intact, the submucosa was fragmented inside, but without complete ruptures. At point 4, results were very similar to those of point 3, but occasionally complete ruptures of the submucosa were found. The mucosa was intact and still folded. At point 5, a full burst of the intestinal wall

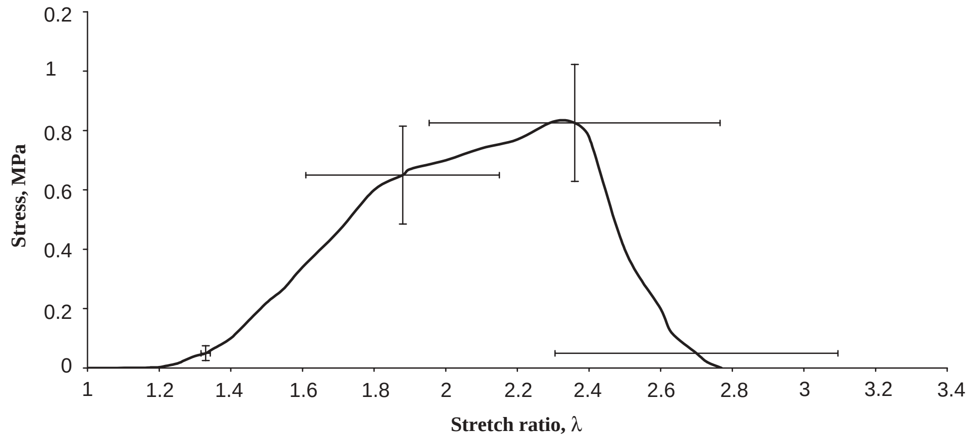

Fig. 4. Mechanical testing of human cadaveric large bowel transversal specimens at 2λ strain rate.

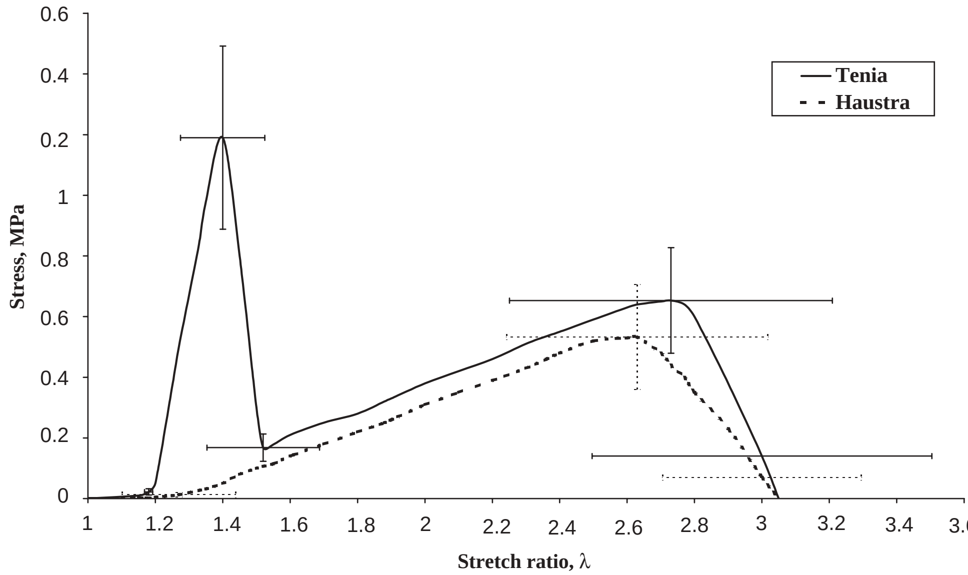

Fig. 5. Mechanical testing of human cadaveric large bowel axial specimens at 2λ strain rate.

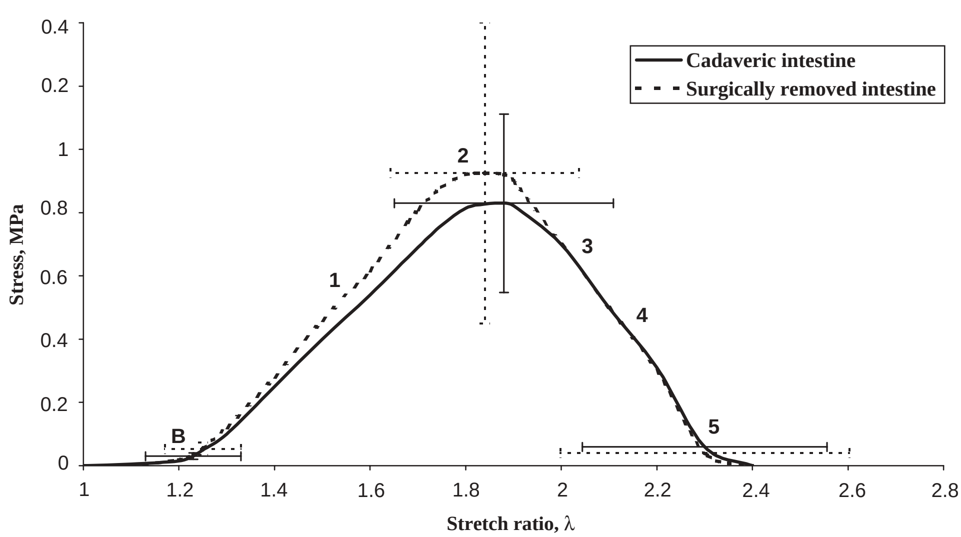

Fig. 6. Mechanical testing of human cadaveric and surgically removed transversal specimens of small intestine at 2λ strain rate. Points of histological examination are indicated by Figs. 1–4. Parameters of the diagram: B—strain level at which sharp increasing of stress begins. This point is described by the value of λ_{beg}. 1–4—points of the histological examination.

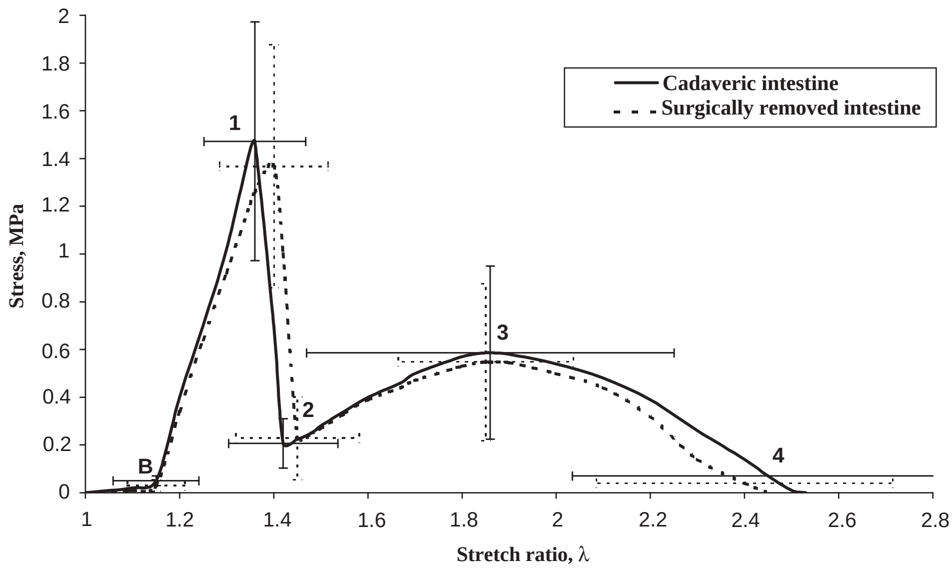

Fig. 7. Mechanical testing of human cadaveric and surgically removed axial specimens of small intestine at 2λ strain rate. Parameters of the diagram: B—strain level at which sharp increasing of stress begins. This point is described by value of λ_{beg}. 1, 2, 3—points of the histological examination.

Table 1
Cadaveric esophagus stress–strain parameters, longitudinal specimens

Parameter	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)
Value	16.71 ± 9.97	143.4 ± 31.34	1.289 ± 0.517	57.65 ± 13.35

occurred. Bursting of the mucosa macro- and microscopically occurred with the bursting of the last filaments of the submucosa.

Axial intestinal specimens were histologicaly examined at chosen points on a curve "B-1-2-3-4" (Fig. 7) before and after strain–stress testing. On microslides five intact layers of the small bowel were observed before testing. After testing the following was found:

At point 1, only the mucosa and submucosa were intact. Full destruction of the serosa and both muscular layers took place. At point 2, the picture was very similar to that of point 1—intact mucosa and submucosa, full rupture of the serosa and both muscular layers. At point 3, mucosa was intact and remained folded, submucosa was fragmented inside, but without complete ruptures. At point 4, a full burst of the intestinal wall occurred. The mucosa tore immediately after the breaking of the last filaments of the submucosa, not rendering observable resistance.

The results obtained for "standard" (10×25 mm) axial samples tested at the strain rate 2λ/min were identical to those for "long" (75×10 mm) axial samples tested at 1.3λ/min.

The curves obtained for specimens of both directions tested at strain rates 0.04λ, 2λ and 20λ/min were qualitatively and quantitatively very similar. The strain values for "standard" specimens points of extremum tested at different loading velocities were practically identical for both directions. The stress values for specimens of both directions were larger at strain rate 20λ/min, and smaller at 0.04λ/min, if compared with tests at 2λ/min. However, these differences were insignificant (Tables 8 and 9).

4. Discussion

As the living abdominal organs are inaccessible for mechanical testing, the practical sources of them are surgical and necropsy material. In the work presented, mechanical properties of the cadaveric and surgically removed specimens of the gastrointestinal tract wall on different levels were studied at constant strain rate.

The values for tensile strength of the axial and transversal samples of small and large bowel in the works of Yamada (1972) and Watters et al. (1985a, b) were very similar to ours. Differences were noticed only for maximal stress of esophageal wall (1.2 MPa in our work (Fig. 1) as compared to 0.6 MPa in the work of Yamada).

According to our data, the diagrams of the transversal and axial specimens testing of cadaveric and surgically removed stomach are practically identical (Figs. 2 and 3). The diagrams of the transversal specimens testing of cadaveric and surgically removed intestines are very similar (Fig. 6). Strain values are virtually the same, and stress values differ insignificantly. Tensile strength of the cadaveric gut is below of that of the operating gut, but for the surgically removed and cadaveric gut the scatter ranges of properties mostly overlap. This fact indicates that stress and strain characteristics of the wall of

Table 2
Cadaveric and surgically removed stomach stress–strain parameters, transversal specimens

	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)
Cadaveric stomach	24.03±7.47	190,48±27.79	0.52±0.16	99.62±25.16
Surgically removed stomach	25.1±6.98	194.55±33.36	0.5±0.12	103.12±20.23
Level of significance	>0.5	>0.5	>0.5	>0.5

Table 3
Cadaveric and surgically removed stomach stress–strain parameters, longitudinal specimens

	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)
Cadaveric stomach	20.12±8.55	189.42±36,03	0.65±0.21	90.45±23.61
Surgically removed stomach	21.7±5.62	178.93±34.39	0.67±0.19	93.3±18.57
Level of significance	>0.2	>0.2	>0.5	>0.5

ε_{beg}—strain level at which sharp increasing of stress begins, ε_{fin}—level of failure strain, σ_r—stress maximum, ε_r—strain level, corresponding to the stress maximum.

Table 4
Cadaveric large bowel stress–strain parameters, transverssal specimens

Parameter	ε_{beg} (%)	ε_{fin} (%)	σ_{r1} (MPa)	ε_{r1} (%)	σ_{r2} (Mpa)	ε_{r2} (%)
Value	33.29±13.0	176.66±39.48	0.645±0.165	87.85±27.0	0.826±0.197	135.98±40.58

ε_{beg}—strain level at which sharp increasing of stress begins, ε_{fin}—level of failure strain, σ_{r1}—the first stress maximum, ε_{r1}—strain level corresponding to the first stress maximum, σ_{r2}—the second stress maximum, ε_{r2}—strain level corresponding to the second maximum.

Table 5
Cadaveric large bowel stress–strain parameters, longitudinal specimens

	ε_{beg} (%)	ε_{fin} (%)	σ_r (Mpa)	ε_r (%)	σ_a (MPa)	ε_a (%)	σ_b (Mpa)	ε_b (%)
Tenia	18.42±12.09	205.49±50.4	1.188±0.302	40.94±12.5	0.168±0.045	52.43±16.72	0.652±0.174	173.45±47.85
Haustra	27.12±16.8	205.65±29.48					0.533±0.173	162.78±38.75
Level of significance	<0.005	>0.5					<0.001	>0.2

ε_{beg}—strain level at which sharp increasing of stress begins, ε_{fin}—level of failure strain, σ_r—the first stress maximum, ε_r—strain level corresponding to the first stress maximum, σ_a—stress minimum, ε_a—strain level corresponding to the stress minimum, σ_b—the second stress maximum, ε_b—strain level corresponding to the second maximum. For the the haustra σ_b and ε_b are the values of the single maximum.

Table 6
Cadaveric and surgically removed gut stress–strain parameters, transversal specimens

	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)
Cadaveric gut	23.3±10.0	138.9±25.59	0.83±0.28	87.93±22.97
Surgically removed gut	25.56±7.89	138.39±30.23	0.92±0.48	84.02±19.73
Level of significance	>0.1	>0.5	>0.05	>0.2

ε_{beg}—strain level at which sharp increasing of stress begins, ε_{fin}—level of failure strain, σ_r—stress maximum, ε_r—strain level, corresponding to the stress maximum.

cadaveric and surgically removed human guts are comparable in a circular direction.

As can be seen from the Figs. 5 and 7, the tensile diagrams $\sigma(\lambda)$ for longitudinal (axial) specimens of small intestine and tenia look unusual as there are two maxima. The first maximum is narrow and nearly four times as high as the second one, which is broad and low.

In Fig. 7, the diagrams of the mechanical testing of the axial specimens of intact cadaveric and surgically removed intestines are presented. The summary diagrams are very similar. Strain values are practically the same, stress values differ insignificantly. For axial specimens we discovered that tensile strength of the surgically removed gut was lower compared to that of

Table 7
Cadaveric and surgically removed gut stress–strain parameters, longitudinal specimens

	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)	σ_a (MPa)	ε_a (%)	σ_b (MPa)	ε_b (%)
Cadaveric gut	15.92±9.14	153.14±41.57	1.472±0.499	36.76±10.77	0.208±0.104	41.52±11.56	0.586±0.362	86.71±38.97
Surgically removed gut	15.36±6.14	145.88±31.51	1.368±0.508	39.37±11.54	0.229±0.173	44.83±13.12	0.548±0.329	85.76±18.6
Level of significance	>0.5	>0.2	>0.2	>0.1	>0.2	>0.1	>0.5	>0.5

ε_{beg}—strain level at which sharp increasing of stress begins, ε_{fin}—level of failure strain, σ_r—the first stress maximum, ε_r—strain level corresponding to the first stress maximum, σ_a—stress minimum, ε_a—strain level corresponding to the stress minimum, σ_b—the second stress maximum, ε_b—strain level corresponding to the second maximum. All the data, presented in Tables 1–7, were obtained at 2λ strain rate.

Table 8
Stress–strain parameters of the cadaveric gut tested at different velocity of loading, transversal specimens

Parameter strain rate	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)
2λ/min	23.3±10.2	140.2±27.4	0.84±0.31	88.02±23.12
0.04λ/min	22.7±11.1	138.7±28.1	0.81±0.36	88.1±24.0
20λ/min	24.21±12.8	141.1±30.0	0.89±0.41	87.9±23.7

There were no significant differences in values for all parameters.

Table 9
Stress–strain parameters of the cadaveric gut tested at different velocity of loading, longitudinal specimens

Parameter strain rate	ε_{beg} (%)	ε_{fin} (%)	σ_r (MPa)	ε_r (%)	σ_a (MPa)	ε_a (%)	σ_b (MPa)	ε_b (%)
2λ/min	15.88±10.1	149.12±51.17	1.482±0.528	37.18±11.24	0.224±0.108	42.24±13.01	0.594±0.398	84.2±41.12
0.04λ/min	15.62±10.24	147.27±48.81	1.379±0.6	35,87±13.5	0.218±0.124	39.4±14.2	0.574±0.382	82.8±40.24
20λ/min	15.48±11.0	146.5±57.76	1.501±0.612	36.81±13.1	0.236±0.150	41.6±14.09	0.692±0.411	82.4±38.82

There were no significant differences in values for all parameters.

the cadaveric gut, but the scatter ranges of properties of the surgically removed and cadaveric gut generally overlap. This fact means that stress and strain characteristics of cadaveric and surgically removed human guts wall in longitudinal direction are comparable.

Our results in testing small and large bowel axial specimens show that studying strain–stress curves obtained by the method used allows us to consider the intestinal wall a multi-layered structure. Testing of axial specimens demonstrated the mechanical properties of the layers of the bowel wall, i.e. the capacity of different tissues to bear different deformation and stress.

The cause of the two maxima in the diagrams of the axial bowel specimens tested is the heterogeneity of mechanical properties along its thickness. Tests showed the difference in the mechanical properties of the submucosa and muscularis, and the weakness of the adhesive connections between them in an axial direction. At the beginning of the strain on the gut strip, a rupture of the serosa occurs. This rupture is registered macro- and microscopically, because a dynamometer with the scale of 1000 g was unable to record this event. At interval B-1-2, the muscularis and submucosa begin to work. Point 1 and the fall to point 2 correspond to the moment of the rupture of the muscular layer. The following interval 2–4 with the stress maximum in point 3 corresponds only to the work of the submucosa. There was no indication of mechanical properties of the mucosa on the diagram.

Evidently, because of strong adhesive connections between the intestinal submucosa and muscularis in transversal direction, one maximum curves were generated and represent summarized properties of these layers.

Mechanical strength of the bowel wall is determined by the submucosa and muscular layers. The serosa and mucosa have no significant strength. The moment of rupture of these layers was never registered on the diagrams. The values for the maximal strength of the muscular layer were usually 3–4 times larger than that of the submucosa. At the same time, the submucosa could withstand deformations 4–5 times greater than muscularis could. As it was mentioned, stress–strain curves are presented for the thickness of the specimen at the onset of testing. We were not able to precisely determine sample thickness during testing. Theoretically, the decrease in thickness should be considerable—approximately three- to four-fold—because of rupturing of the muscularis and straightening of the submucosa.

The data can be explained on the basis of what is known about the structure of the intestinal wall. Normal serosa is a layer of mesothelium cells on the thinnest irregular connective tissue membrane. The thickness of the serosa under light microscopy is usually not more than 50 μm (Ross et al., 1995). The thickness of the mucosa under light microscopy is much larger—approximately 500–1000 μm (Ross et al., 1995). However, it has no significant strength as its cell mass is many times greater than that of the stroma. Smooth muscles are containers of colloid liquid connected to each other, which explains the ability of the muscle layer to withstand significant stress but only for a short duration. The main framework of the submucosa is collagen fiber bundles arranged as a mobile lattice (Gabella, 1987; Komuro, 1988). This structure explains the ability of the submucosa to resist significant mechanical impacts.

The study of strain–stress curves, generated during the testing of gastrointestinal specimens in conditions of constant strain rate, revealed the following facts.

By the method used, bimodal curves were generated for axial specimens of small bowel wall and tenia region of large bowel wall. This permits investigation of mechanical properties of the bowel wall layers. For stomach and esophagus, curves with one maximum were generated for both directions.

The mechanical properties of cadaveric and surgically removed stomach and small intestine were similar under definite storage conditions.

The mechanical properties of small and large bowel in axial and transversal directions were qualitatively and quantitatively different, whereas there were no significant differences in the results for axial and transversal strips for the stomach.

The mechanical strength of the intestinal wall is conditioned by the submucosa and muscular layers, while the serosa and mucosa show no significant strength. Mechanical stability of the gut wall, its strength and ability to resist intensive deformations of long duration, is conditioned by the submucosa.

The results presented could be of interest, not only from academic, but also from practical point of view. It is possible to monitor experimentally the mechanical properties of the bowel wall layers under different conditions, in healing process, after transplantation or distension. In our work (Buianov et al., 1999), using the method described here the participation of the bowel wall layers in supplying of the intestinal wall strength was shown for intact and sutured gut. Regular structure and well-defined differences in mechanical properties of axial and transversal specimens of the intestinal wall could make it an ideal material for modeling the mechanical behavior of the intestinal anastomosis.

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