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THE INFLUENCE OF GENDER ON THE ELASTIC MECHANICAL PROPERTIES OF HUMAN ABDOMINAL FASCIA

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Abstract

This study presents effects of gender on the elastic mechanical properties of human abdominal fascia according to direction of loading.

Samples from umbilical fascia (UF) have been cut along the fibres direction or perpendicular to them. The uniaxial tensile tests were performed. The mean curves of UF according to gender and direct of loading were presented. Mean values of the maximum tensile stress, stretch at maximum stress, maximum stretch ratio and elastic modulus E calculated at 5% strain were determined from the obtained stress – stretch ratio.

The differences between investigated behaviour of male and female samples were distinguished. The maximum tensile stress for female samples was 1.1 MPa at transversal direction and 2.9 MPa at longitudinal direction, while for male samples the maximum tensile stress was 0.5 MPa and 1.5 MPa accordingly. The obtained results show that there exists statistically significant differences between values of maximum stress and elastic modulus E_5 according to gender and direction of loading.

Key words: human abdominal fascia, elastic mechanical properties, gender

1. Introduction. An abdominal hernia is a significant social problem. It was reported that 88% of the patients from all repaired abdominal hernias were operated on for inguinal hernia (hernia of the groin), while 66% of the females were operated on for incisional and umbilical hernia (hernia through the umbilical ring)

[1]. The hernia becomes more prevalent with age [2]. According to data reported in [2] 27% of men and 3% of women probably will be operated on inguinal hernia after the age of 60 years.

One of the main reasons for the formation of abdominal hernia are the changed mechanical properties of the abdominal wall layers. This fact imposes investigation of their mechanical properties according to age, gender and localization. Such biomechanical studies are very useful for the purposes of diagnosis and mathematical modelling [3].

Abdominal fascia is a layer of the abdominal wall. Fascia transversalis (FT) and umbilical fascia (UF) are part of the abdominal fascia situated behind the inguinal canal and around the umbilical ring. The results from uniaxial tensile tests of herniated and non-herniated FT samples cut in transverse and longitudinal anatomical planes have been reported in [4, 5]. The determination of maximum load and distension of normal and diseased human fascia transversalis have been published in [6, 7]. The maximum load of failure for FT and other parts of the abdominal fascia were compared, but these experiments do not give any insight into the effects of gender on human abdominal fascia [7].

In this study we focus our attention on the influence of gender on elastic behaviour of human umbilical fascia because these effects have not been investigated properly yet. As far as we know only a few studies have been conducted to assess the gender related changes of mechanical properties of abdominal fascia. The article of Glassow reported about the influence of gender on the strength of human fascia transversalis while the studies of Junge et al. and Song et al. concerned the properties of the whole human abdominal wall [8–10]. Preliminary results about the influence of gender on the parameters which characterize the elastic mechanical properties of human abdominal fascia were reported in [11] but the samples were not grouped according to direction of loading.

The purpose of this study is to examine and characterize the elastic mechanical properties of human umbilical fascia according to gender and direction of loading.

2. Materials and methods. Samples from umbilical fascia harvested from 12 cadavers (8 males and 4 females) have been cut along the fibres direction (L) or perpendicular to them (direction T). The age of the donors was between 64–87 years, mean age for male group 75.4 years, and for female group 81.8 years.

The specimens were divided in two groups according to their gender and direction of loading. Thus group UFL includes 21 samples from umbilical fascia, cut along the fibres direction L, while group UFT includes 23 samples cut perpendicular to fibres direction. Harvest samples were placed in normal saline and testing occurred within 24 h. The size of each sample was between $1 \times 5 - 1 \times 7$ cm and was measured prior to investigation.

Uniaxial tensile tests were performed. From the obtained load-elongation relationships Lagrangian stress-stretch ratio curves were prepared. The Lagrangian

stress T_L was calculated as the force F divided by the undeformed initial cross-sectional area of the specimen S and stretch ratio λ was defined as $\lambda = L/L_0$, (L_0 is the initial length of the specimens, L is the sample length after elongation). The mean curves were obtained using the arithmetic mean of Lagrangian stress for the values of stretch ratio λ.

The following mechanical parameters, which characterize elastic response of human abdominal fascia, were determined: maximum tensile stress $T_{\max}$, stretch at maximum stress $\lambda^{T\max}$, maximum stretch ratio $\lambda_{\max}$ and elastic modulus E_5 defined as a ratio of the Lagrangian stress T_L and 5% strain. Comparison between the defined parameters was accomplished by means of Mann–Whitney test. A significance level of $p < 0.05$ was chosen.

3. Results. The results obtained from tensile tests of umbilical fascia are presented in Fig. 1 and Fig. 2, comparing the elastic mechanical behaviour of male and female samples in both directions. The curves of the female group consist of nearly linear part up to maximum stress with one peak, while the curve which describes the longitudinal direction of the male group is nonmonotonic – there exist two peaks (Fig. 1). Such behaviour was reported in our previous study for fascia transversalis [11, 12].

Differences between the mean curves for male and female samples are clearly distinguished. The mean stress-strain curve of the female samples is higher than that of the male curve at both directions. The maximum tensile stress at longitudinal direction for the female curve is 2.9 MPa and for the male curve – 1.5 MPa. At transversal direction the maximum tensile stress is 1.1 MPa for the female curve and 0.5 MPa for the male curve (Table 1).

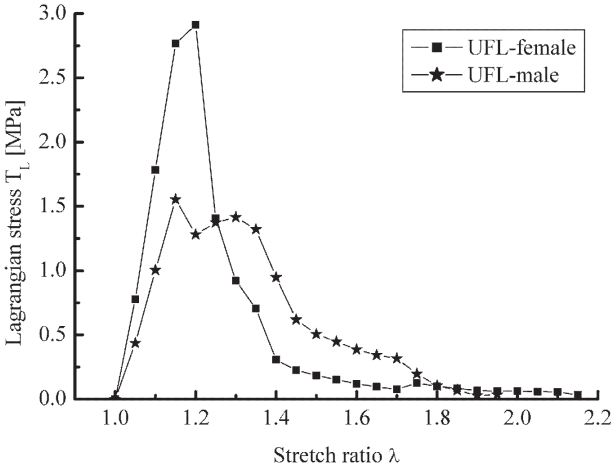

Fig. 1. Lagrangian stress-strain relationships between male and female samples cut in longitudinal direction L (number of female samples – 12, number of male samples – 9)

Table 1

Mean values of elastic parameters

Type of fascia	T_{max}, MPa	$\lambda^{T\,max}$	λ_{max}	E_5, MPa
UFL-male	1.5 ± 0.4	1.14 ± 0.33	1.95 ± 0.03	8.6 ± 0.8
UFL-female	2.9 ± 0.8	1.2 ± 0.1	2.15 ± 0.02	16.08 ± 0.20
UFT-male	0.5 ± 0.1	1.4 ± 0.3	2.22 ± 0.09	2.8 ± 0.5
UFT-female	1.1 ± 0.3	1.3 ± 0.3	2.05 ± 0.02	2.8 ± 0.7

Stress-strain relationships of umbilical fascia show also that female samples are stiffer than male samples in longitudinal direction. The value of elastic modulus E_5 for the female curve is 16.08 MPa and for the male curve is 8.6 MPa. A shift of female stress-strain curves to the left in longitudinal direction indicates that fact (Fig. 1). In transversal direction the coincidence of curves shows that at physiological strain (which is up to 5%–7% for abdominal fascia) elasticity of umbilical fascia according to gender is identical (Fig. 2) but above that deformation the male and female curves reveal different elastic behaviour. For both directions stretch at maximum stress $\lambda^{T\,max}$ changes in the range 1.14–1.40 and maximum stretch ratio λ_{max} between 1.95 and 2.22 (see Table 1).

The Mann–Whitney test was applied to determine the existence of statistically significant differences between values of the parameters from groups of samples. Although the differences in both investigated directions could clearly be observed according to gender (Fig. 1 and Fig. 2) they are not statistically significant. The obtained results show that there exist statistically significant differences only between values of maximum stress and elastic modulus E_5 calculated for male and female samples in longitudinal direction ($p < 0.05$).

4. Discussion. The effects of gender on elastic mechanical behaviour of human abdominal fascia were investigated. The data revealed the differences in both investigated directions according to the gender (Figs 1 and 2) but they are statistically significant only between values of maximum stress and elastic modulus E_5 calculated for male and female samples in longitudinal direction.

The study of Glassow presented the strength of the posterior wall of the inguinal canal in male and female [8]. He reported that posterior wall of the inguinal canal in women is obviously stronger than that of men. Investigating elastic mechanical properties of umbilical and transversalis human abdominal fascia we proved that it can be considered as a tissue, which mechanical properties are not affected by localization [12]. This was the reason to suggest that not only the female transversalis fascia but also umbilical fascia is stronger than male fascia from the same localization. The results confirmed this hypothesis.

Junge et al. [9] showed that the anterior abdominal wall of women is more distensible than the same layer of men. They measured the distension of the

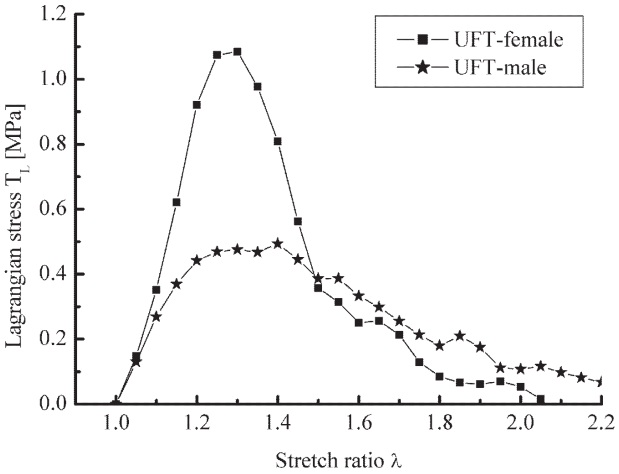

Fig. 2. Lagrangian stress-strain relationships between male and female samples cut in transversal direction T (number of female samples – 12, number of male samples – 9)

abdominal wall stretching it at a 2–24 N in horizontal, vertical and oblique directions. The resulting mean distension at 16 N showed that the elongation in vertical direction was $23 + 7\%$ for male and $32 + 17\%$ for female. Our results supported that elongation in longitudinal direction for the female group is higher than that in the male group.

Song et al. [10] investigated elasticity of male and female abdominal wall during inflation in vivo. Stress-strain relationships of the abdominal wall showed that the male wall is stiffer than the female wall over 3% strain which is different from our results. At the beginning of this study it was supposed that our results would confirm Song's results qualitativly. However, since the mechanical properties of the umbilical fascia were obtained using cadaver's samples this was most probably the main reason our findings to differ from those reported in [10].

The presented study has some limitations. The obtained results described elastic properties of donors in the range 64–87 (mean 75 years for male and 81 years for female samples), which means that the conclusions cannot be applied for the biomechanical properties of young people.

5. Conclusions. The results highlighted the effects of gender on elastic mechanical behaviour of the human abdominal fascia. Statistically significant differences were obtained for the values of maximum stress and elastic modulus E_5 calculated for male and female samples in longitudinal direction. Further experiments with this type of fascia are necessary to describe the influence of gender on elastic properties of young donors. The results may provide the possibility of choosing the proper brand of hernia mesh for patients from different age.

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