Women with incorrect pelvic floor statics: A biomechanical answer to the mechanical loading of the vagina-endopelvic fascia complex

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Abstract

OBJECTIVE: This work focuses on finding method for detecting the elementary mechanical characteristics of the vagina-endopelvic fascia complex, aimed at providing results for use in optimizing solutions for stability defects of the pelvic floor.

MATERIALS AND METHODS: Two experiments have already been carried out that have enabled monitoring of the reaction of tissue complex samples to a selected load. The elastic properties of samples under a simple pull load were evaluated. The monitored property in the first experiment was the maximum reference tension at the moment of rupture of the sample in relation to the non-deformed section. We evaluated data from measurements on 11 samples within the scope of the first experiment.

For data processing from the second experiment we used a linear-elastic model of the sample, formed by parallel connection of basic mechanical elements – springs – that represented the endopelvic fascia and the vaginal wall. The relevant rigidities were used for a description of their properties. Five samples were used for this experiment.

RESULTS: An important discovery was that the endopelvic fascia tears apart after a longer period of time than the vaginal wall during the pull test. The results show considerable variability among individuals, but the pattern of curves is similar in all test cases. In all measured data we found a rigidity increase zone, a maximum rigidity zone and a gradual rigidity decrease zone before terminal damage in the response.

CONCLUSIONS: The results presented here show quite broad interindividual variability of the mechanical properties of the vaginal wall-endopelvic fascia complex. It appears that the mechanical properties of the tissue complex change with number of pregnancies, and are affected by diseases, by physical load or by the presence of other factors, e.g. obesity.

INTRODUCTION

Defects of pelvic floor statics are a frequent cause of female mortality, and are a serious health and social-economic issue. According to Olsen *et al.* (1997), there is an 11% accumulated risk of the need for surgery ut to the age of 70 years, and a 30% risk of a need for repeat surgery within a period of 5 years after the initial operation. Clinical symptoms of defects include urinary incontinence, faecal evacuation disorder and impaired intercourse experience (dyspareunia). All these states are non-lethal, but they have a serious impact on quality of life, employment opportunities and the chance to form satisfactory relationships.

The main causes are vaginal delivery injuries, a chronic increase in abdominal pressure (obesity, cough), and ageing processes. These causes lead to changes in the mechanical properties of both the vaginal suspension apparatus – the endopelvic fascia, and the vaginal wall itself (Cruikshank 2003; Otcenasek 2001; Urdzik *et al.* 2007). The mechanical properties of these tissues have been examined only very marginally until now, and some relevant biomechanical characteristics are virtually absent in the literature.

The objective of this work is therefore to find a method for reliably defining the elementary biomechanical parameters of the vaginal wall and endopelvic fascia complex, and for recording their development in relation to selected parameters (impact of loading type, chronic illness, obesity, gravidity, etc.)

MATERIAL AND METHOD

<u>*Characteristics of the tested set*</u>

Due to the complicated setting of the endopelvic fascia, there is no way to perform rigidity testing throughout its course. The best access is from the area of the rectovaginal septum, where a sample piece of tissue can be gathered during a standard scheduled operation, without any risk for the patient. All samples used in our experiment were collected during operations performed as "posterior vaginoplasty" for clinical reasons.

The samples were prepared as necessary for a therapeutic solution of the diagnosis. Immediately after they had been collected, they were fixed on a cork bed, immersed into a physiological solution and stored at a temperature of 4–7 °C. Before the measurements were made, the samples were standardised to a cuboid shape (for dimensions, see Table 1). The measurements were performed as soon as possible after collection (6–48 hours).

<u>*Measurement protocol*</u>

The experimental data was detected in the biomechanical laboratory at the Czech Technical University in Prague. The samples were fixed in jaws of CTU's own construction, with thrust of 5 MPa (see Figure 1).

The experiment was performed on the MTS 858 Mini Bionix machine, according to the following protocol:

- load type: simple tension
- load direction: caudal-cranial,
- loading speed: 20 mm/min

- the liquid ratio in the total volume of the sample was not monitored before, during and after the test
- the sample was not moistened during the test

- the properties of the sample were stabilized by 10 loading cycles, using a force of 0 N to 4 N (Figure 2, encircled area)

- in the actual test, the inserted value was the stretching

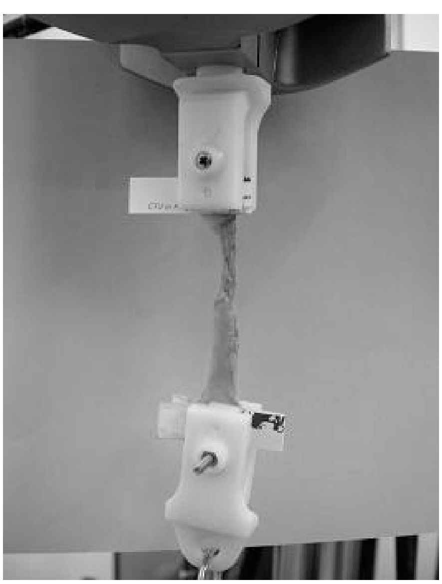

Fig. 1. Fixed sample.

Tab. 1. Basic parameters of samples

Sample	Dimensions [mm]	Section [mm^2]
1	31.0 × 3.5 × 6.3	108.5
2	39.0 × 3.0 × 6.0	117.0
3	34.0 × 12.0 × 6.0	408.0
4	31.0 × 7.5 × 3.5	232.5
5	19.5 × 8.1 × 4.6	151.4
6	32.7 × 7.3 × 3.3	238.7
7	39.9 × 10.0 × 3.2	399.0
8	39.3 × 11.0 × 4.1	432.3
9	39.1 × 9.2 × 3.5	359.7
10	38.0 × 10.3 × 3.0	391.4
11	45.0 × 9.0 × 4.5	405.0

A sample response with sampling frequency of 10 Hz was detected in both experiments.

There was constant air humidity of about 60–80%, and the temperature in the laboratory was within the range of 24–26 °C.

Data processing and evaluation

The objective of the experimental data processing was to find the maximum tension at the moment when the sample ruptured (Figure 2, fascia rupture), and to discover any trend in changes in the mechanical properties of the sample related to the deformation.

During data processing, the tissue was considered to be a linear-elastic material, with regard to its detected response to the load course (Figure 2).

Determining the tension at the moment when the sample ruptures

Data from 11 measurements was processed for this evaluation (Table 1).

The evaluation was performed using the following expression:

$$\sigma = \frac{F}{A_0}\ , \qquad (1)$$

where $\boldsymbol{\sigma}$ is relative tension (related to the non-deformed section), $\boldsymbol{F}$ is force at the moment of rupture, and $\boldsymbol{A_0}$ is a section of the non-deformed sample.

Monitoring the behaviour of mechanical properties in relation to stretching of the samples

Five samples were used in this part of the research task.

The monitored parameters for an evaluation of the development of the mechanical properties of the sample in relation to stretching were the rigidities of the individual components (fascia and vaginal wall). Data from sample loading until destruction was used for processing (Figure 3).

The curve was divided into multiple parts with a linearized course. The parts are marked with ordinal numbers in Figure 3.

Slight vacillations in the measured course (Figure 3, black encircled area) that show stretching without a further increase in the presumed force may be interpreted, e.g. as moments where there was some minor fault in the tissue that had no influence on the overall stability of the response of the tested sample.

A major breakthrough in the course of the response of the sample was the rupture of the vaginal wall (Figure 3, white encircled area).

The subsequent course of the graph (Figure 3, laps 8 and 9) was then formed only by the endopelvic fascia response. The moment at which the vaginal wall ruptured and then the endopelvic fascia also ruptured was well detectable even in a synchronous video recording of the experiment.

The individual parts (No. 1–9, see Figure 3) were interlaced with lines the directions of which were the monitored parameter.

A rigidity evaluation resulted from the schemes in Figure 4.

For an evaulation of the rigidity, an analogy of regression line equations and a rigidity-defined linear spring description was used:

Linear spring description equation:

$$F = K\Delta l, \qquad (2)$$

where $\boldsymbol{K}$ [N/mm] is spring rigidity, $\boldsymbol{F}$ [N] is force in effect, and $\boldsymbol{\Delta l}$ [mm] is stretching.

Regression line equation:

$$y = ax + b, \qquad (3)$$

where $\boldsymbol{a}$ is direction (determines line tilt) and $\boldsymbol{b}$ is an absolute element (determines the position of the line relative to the given axial system).

Comparing the two expressions (2, 3), can we write the following:

$$F \approx y;\ \Delta\, l \approx x;\ \boldsymbol{K} \approx \boldsymbol{a}$$

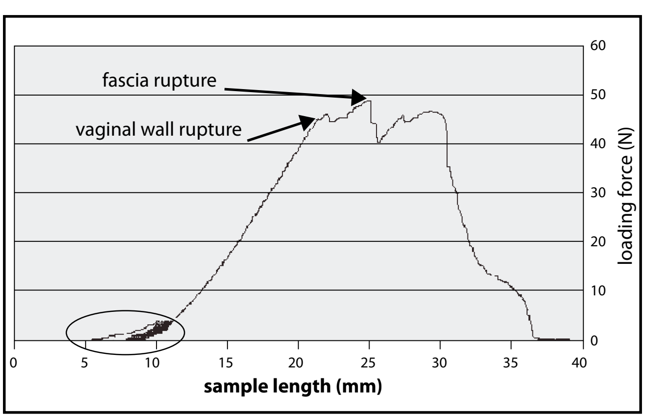

Fig. 2. Relation of force F and stretching Δl (an example).

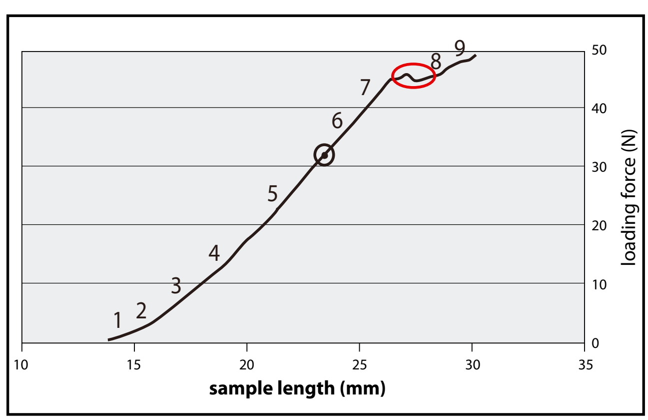

Fig. 3. Dividing the curve into linear parts (an example).

This implies that a calculation of the direction of the regression line defines the rigidity of the monitored sample or a part of the sample.

Taking into account the real setting of the two tissue structures in the samples (Figure 4), we created a complete model of the tested samples by joining the two rigidities in parallel. This is described by the following force balance equation:

$$F_{FP} = F_P + F_F, \qquad (4)$$

where $\boldsymbol{F_{FP}}$ is the force recorded by the detection head of the testing device, $\boldsymbol{F_P}$ is the reaction force determined by the properties of the vaginal wall, and $\boldsymbol{F_F}$ is the force determined by the endopelvic fascia.

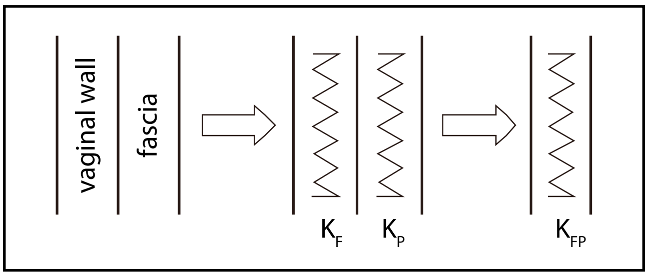

Fig. 4. Biomechanical model vaginal wall + fascia.

Using relation (2), equation (4) can be modified for an intact complex to the form:

$$K_{FP}\,\Delta l = K_F \Delta l + K_P \Delta l, \qquad (5)$$

From relation (5), we can formulate an expression for vaginal wall rigidity:

$$K_P = K_{FP} - K_F\,. \qquad (6)$$

Taking into account the data available from the experiments, this relation can be used for defining the rigidity of the vaginal wall at the moment of rupture (Figure 3, red marked area), when the rigidity of the endopelvic fascia itself is known (Figure 3, parts 8 and 9).

RESULTS

Eleven samples is not enough to enable us to process the results with statistical quality, but they enable a comparison related to the anamnesis data of the women in the experiment.

Determining the tension at the moment when the samples rupture

The tensions reached when the sample (Table 2) was destroyed were calculated using relation (1). This is is the relative tension related to non-deformed sample sections.

In Table 2,"relative tension" spanning from 0.39 MPa to 1.7 MPa is detected.

We can express the following conclusions:

Women who have never delivered, or who have delivered by means of an operation, fall into the group with the highest sample tension (Table 2, samples 4, 6, 10). In the anamnesis of such women there is also no record of chronic disease leading to a long-term increase in abdominal pressure. Mostly these are women in perimenopause, who have a comparatively high social position and do not perform physically demanding work.

Women with multiple deliveries or who have delivered a foetus with a high birth weight (Table 2, sample 7, 9) and women with serious obesity (Table 2, samples 1, 2, 11) fall into the group with the lowest relative tension values.

Monitoring the behaviour of mechanical properties related to sample stretching

Calculated values of the rigidities of the samples and their individual components – vaginal wall and endopelvic fascia – are displayed in Tables 3, 4 and 5.

Based on measurement course analysis and a comparison of the calculated rigidities, we can state that:

The vaginal wall endures less stretching than the endopelvic fascia. This conclusion is valid for all our experiments performed so far, irrespective of patient anamnesis.

The rigidity of the sample increases with deformation, and after reaching the maximum it decreases while heading for rupture (Figure 4). The course has concave characteristics and is visible on all tested samples.

After rupture of the vaginal wall, the rigidity of the endopelvic fascia decreases with increasing deformation (Figure 5). This decrease can be considered linear with satisfactory precision.

DISCUSSION

Thanks to their easy repeatibility, the results produced so far provide a way to create a relatively simple methodology for examining the tested tissue.

The first part of the experiment determined the highest tension that was reached. This was used as a quantifier for an evaluation of tissue quality. The selected method appears to be appropriate. Formally, however,

Tab. 2. Rupture tension.

Sample No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Tension [MPa]	0.85	0.74	0.68	1.10	0.72	1.20	0.48	1.10	0.39	1.70	0.32

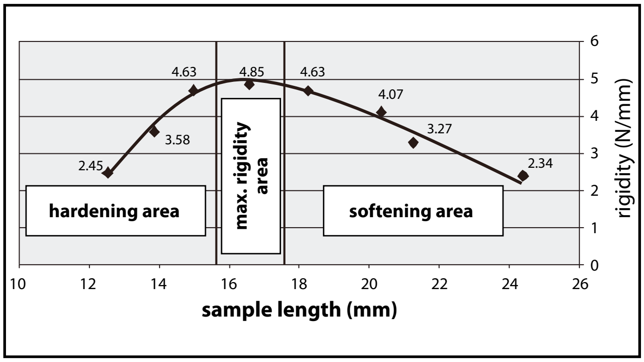

Fig. 4. Rigidity – stretching prolongation relation of fascia + vagina complex (an example).

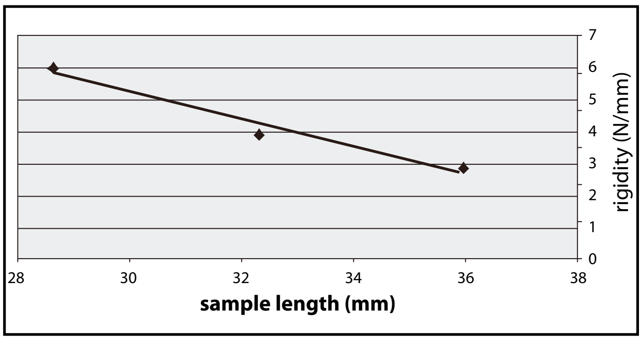

Fig. 5. Dependency of fascia rigidity on prolongation after vaginal wall rupture (an example).

Tab. 3. Rigidity of the complete sample.

Lap	Sample 1 N/mm	Sample 2 N/mm	Sample 3 N/mm	Sample 4 N/mm	Sample 5 N/mm
1	2.41	1.64	1.1	2.45	5.88
2	4.27	2.25	2.15	3.58	5.50
3	5.79	3.06	2.97	4.63	5.44
4	7.39	3.52	3.65	4.85	3.54
5	6.66	3.16	4.52	4.63	
6		3.34	4.70	4.07	
7		3.15	4.44	3.27	
8		2.41	4.30	2.44	

Tab. 4. Rigidity of endopelvic fascia.

Lap	Sample 1 N/mm	Sample 2 N/mm	Sample 3 N/mm	Sample 4 N/mm	Sample 5 N/mm
1	5.96	2.27	2.42	2.02	2.64
2	3.94	1.34	1.75	0.93	1.01
3	2.86				

Tab. 5. Rigidity of the vaginal wall at the moment of rupture.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
N/mm	0.70	0.14	1.88	0.43	0.90

there is some inaccuracy in this calculation, because the peak reaction force was reached due to deformation of the endopelvic fascia only (the vaginal wall had already been destroyed in all cases – Figure 3, area marked in red). Further research will focus on improving this calculation, so that it can be used for real tension calculations in both tissue structures of the tested samples.

The second part of the experiment monitored changes in the mechanical properties caused by increasing deformation. Both tissue structures in the samples were modeled as linear-elastic materials defined by rigidities. Even when using such a simple model, it is obvious that the mechanical properties of the samples are very variable during loading. One of the major objectives of further work in this area is to add a mathematical of the development description of the monitored rigidities (Figures 4 and 5). For a reliable definition of the trend in changes in the rigidity endopelvic fascia, it is necessary to perform more detailed measurements of the area after rupture of the vaginal wall.

CONCLUSIONS

The results presented here show quite broad interindividual variability in the mechanical properties of the vaginal wall – endopelvic fascia complex. It appears that the mechanical properties of this tissue complex change with number of pregnancies, and are affected by diseases, by physical load or by other factors, e.g. obesity. It would be interesting to find out to what extent, if at all, these changes are reversible.

The work that we have done so far has opened many more questions for processing in further research. The results presented here are the first part of a more extensive study of the mechanical properties of the vaginal wall – endopelvic fascia complex, focused on optimizing approaches aimed at dealing with defects in the stability of the pelvic floor.

ACKNOWLEDGEMENT

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