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MODELING OF THE FASCIA-MESH SYSTEM AND SENSITIVITY ANALYSIS OF A JUNCTION FORCE AFTER A LAPAROSCOPIC VENTRAL HERNIA REPAIR

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In the paper, a simple model of the fascia-mesh system is considered to assess the junction force after a laparoscopic hernia repair. The aim of this study is to develop a cable model of the system in order to find the junction force and to distinguish the most important parameters affecting the system junction force. The cable is subjected to a pressure in the abdominal cavity and displacements of the cable edges caused by bends of the patient body. The attention is paid to the junction force sensitivity analysis with respect to initial tension of the mesh, its length and elasticity as well as fascia flexibility. All these parameters are crucial for ventral hernia repair safety. Finally, some concluding remarks important for practicing surgeons and for further more advanced study using two dimensional fascia-mesh models are presented.

Key words: biomechanics, ventral hernia repair, cable model, sensitivity analysis

Notations

H – horizontal reaction in the cable model (junction force in the fascia-mesh system)

E – Young's modulus of the mesh

A – cross-section of the cable modeling the implanted mesh

H_0 – initial junction force in the cable model

L_0 – initial length of the cable

g – distributed load in the cable model (referring to the abdominal pressure in practice)

Δ – relative planar displacement of the cable edges

Δ_m – displacement of the cable edges, resulting from elasticity of the mesh (the mesh stretch in the zone supported by the fascia)

Δ_p – displacement of the cable edges, resulting from the fascia elasticity (hernia boundary displacement)

l – length of the modeled cable span

l_s – width of the fascia and the mesh overlap

P – pressure in the abdominal cavity

F_p – resultant load of the mesh

F_n – force acting on the couple of tacks on the two opposite sides of the hernia orifice

N – number of tacks in the mesh-fascia junction

s – parameter in the sensitivity analysis, $s = L_0$, H_0, Δ_p, E

$W_{L0}, W_{H0}, W_{\Delta p}, W_E$ – sensitivity coefficients related to variations of L_0, H_0, Δp, E, respectively

$\overline{\delta H}, \overline{\delta L_0}, \overline{\delta H_0}, \overline{\delta \Delta_p}, \overline{\delta E}$ – relative variations of H, L_0, H_0, Δp, E, respectively

1. Introduction

Ventral hernias are leaks in the front wall of the abdominal cavity. They are caused by the fascia defect at some points of natural orifices (umbilicus) or scar tissue in cicatrix after previous laparotomy. Due to pressure in the abdominal cavity, intestines covered by peritoneum (creating hernia sac) are moved from the inside of the abdominal cavity to the subcutaneous space (Fig. 1). The phenomenon remains one of the most important problems in general surgical practice. Ventral hernias have been reported as a result of 0.2%-36% laparotomies, depending on type of operation, general condition of patients and comorbities (Thomas and Philips, 2002). Two different types of ventral hernia repair are performed nowadays, suture and mesh technique. The suture repair could be performed only in cases of small hernias (radius of the orifice smaller than 5 cm, e.g. umbilical hernia). There are two different approaches for the mesh technique, open and laparoscopic. The laparoscopic ventral hernia repair (LVHR) technique has revolutionized the repair of incisional hernias and appears progressively attractive contrary to open surgery. According to medical statistics, the number of recurrences is significantly smaller after the laparoscopic operation than after the open one, there are less postoperative complications and the time of postoperative recovery is shorter (Park *et al.*, 1998; Aura *et al.*, 2002; Goodney *et al.*, 2002; Eid *et al.*, 2003). During an open operation, a large incision and widespread dissection of abdominal wall components are required to prepare the space for the implant placement. In LVHR, the mesh implant is placed under the peritoneum without extended preparation and is fixed to the fascia by special tacks.

Fig. 1. Ventral hernia – external view

Despite the above mentioned advantages. the LVHR is not free of problems. Recurrences still occur (about 10%), which suggests that either the method or the materials used are not perfect (Sanchez *et al.*, 2004). During LVHR, surgeons perform their best, but use only intuition and experiences previously gained in open surgeries to place and fix the mesh correctly. In order to hold the mesh in the right position, the tacks and transabdominal sutures are used. The sutures ensure the strongest fixation, however some authors have described persistent pain of patients at the suture site, (Franklin *et al.*, 2004). On the other hand, neither the number of the tacks required for holding the mesh correctly is known, nor their optimal position on the mesh surface. It is obvious that the tacks can potentially damage human nerves and blood vessels, so their number should be reduced to a minimum. Medical knowledge itself is not suitable to solve this complex problem, therefore it becomes interdisciplinary, bringing together surgeons and engineers.

The first, pioneer study on this subject was published by Śmietański *et al.* (2007). Tension tests of the porcine fascia – prosthetic mesh system were described in that paper. A failure force for various kinds of tacks and implants in different configurations was identified. The manner of the connection of the two mediums, the fascia and the mesh were proved to be the weakest element of the system. The authors concluded that the kind of tissue-implant connection along with the junction force was crucial as far as the ventral hernia recurrence was concerned.

In this paper, the authors present a next step to understand the behaviour of the fascia – mesh system. The aim of the study is to develop a first simple model of the system in order to distinguish most important parameters affecting the junction force of the system and to outline future studies. A cable model is proposed for this purpose (see Fig. 2). The influence of the crucial parameters of the model on the junction force is studied by means of sensitivity analysis. A preliminary study on this subject was presented by Szymczak *et al.* (2009).

The research refers to the following materials which are commonly used in the surgical practice in LVHR: Dual Mesh© (Gore&Asc., USA) and the Protac© (Covidien Inc., France) tacks. The Dual Mesh is a biocompatible material (extended polytetrafluoroethylene – e PTFE). Due to its antiadhesive properties it can be placed in the peritoneum and stay in the direct contact with the intestines and other abdominal solid organs. The Protac tacks are convenient as far as their mechanical and homeostatic properties are concerned (they allow suturing via vessels due to pressure inside of the tack – spiral form). For that kind of junction the failure load has been experimentally estimated as $H = 9.05\,\mathrm{N}$ (see Śmietański *et al.*, 2007).

2. Cable model of internal mesh

In this analysis, the hernia with a circular orifice is considered. It is repaired by a mesh fixed to the fascia by tacks placed in several points in a semi-circular order (there is no practical possibility to distribute tacks in a uniform order). Two kinds of the orifices have been modeled, with stiff or flexible edges. The mesh and the fascia have a joint connection in several points in a circular order (see Fig. 2a). Because in practice it is not possible to tighten the mesh with the same force in every direction, the following extreme situation is considered. There exists one strip of the mesh between two tacks on the opposite sides of the orifice, which is tightened most (see Fig. 2a). The mesh is

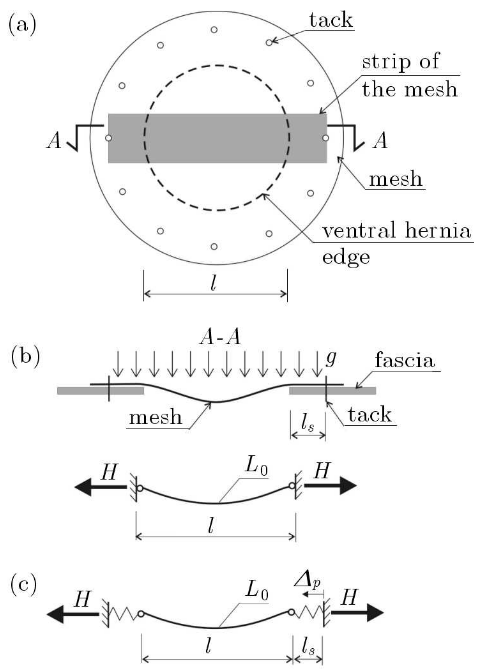

Fig. 2. Mathematical model of the fascia-mesh system; (a) scheme of the fascia-mesh junction with one strip distinguished for further cable model, (b) cable model with stiff supports, (c) cable with support springs representing an elastic mesh in the support zone as well as with displacements of cable edges related to the flexible edges of the hernia

subjected to a uniformly distributed load derived from the abdominal pressure. Additionally, due to bends of the patient body, the elongation in the maximum strain direction arises and should be taken into consideration. Under such a load and elongation, the distinguished strip will be stressed most and the junction force reaches its maximum value. If this strip does not fail, the whole mesh does not either. Such assumptions allow us to reduce a 2-dimension problem to a 1-dimension cable.

2.1. Equilibrium equation of cable subjected to distributed loads

Let us consider a cable hanging on two supports on the same level as it is shown in Fig. 2. The cable is subjected to an arbitrary uniformly distributed load g. A general situation, in which a horizontal relative displacement of the supports Δ and an initial horizontal reaction H_0 occur, is considered. Since the cable flexural stiffness is omitted the bending moment in deflected position of the cable should be equal to zero, and hence the cable deflection

$$y = \frac{[M]}{H} \tag{2.1}$$

where H is the horizontal reaction and $[M]$ denotes the bending moment due to the distributed load g for the simply supported beam. The bending moment $[M]$ is expressed as

$$[M] = \frac{1}{2} g l^2 x \Big(1 - \frac{x}{l}\Big) \tag{2.2}$$

where l describes the horizontal distance between the supports.

Total length of cable L can be written by formulae accounting for the relative horizontal displacement $\varDelta$ of the supports

$$L = l - \varDelta + \frac{1}{2} \int\limits_0^{l-\varDelta} \Big(\frac{dy}{dx}\Big)^2 \, dx \tag{2.3}$$

Using Eqs. (2.1) and (2.2) in Eq. (2.3), we arrive at the relation

$$L = l\Big(1 - \frac{\varDelta}{l} + \frac{g^2 l^2}{24H^2}\Big) \tag{2.4}$$

On the other hand, the cable length is equal to its initial length L_0 plus its elongation $\varDelta L$ caused by the cable force increase $N - N_0$

$$\varDelta L = L - l = \int\limits_{L_0} \frac{N - N_0}{EA} \, ds \approx \frac{H - H_0}{EA} L_0 \tag{2.5}$$

where EA is the axial stiffness of the cable.

Substitution of Eq. (2.5) into Eq. (2.4), after some algebra, leads to the equation for calculating the supports reaction sought

$$H^3 + H^2\Big(-H_0 + \varDelta \frac{EA}{L_0}\Big) - \frac{EA}{L_0} \frac{g^2 l^3}{24} = 0 \tag{2.6}$$

where H denotes the horizontal reaction of the cable, E stands for Young's modulus of the cable material, A – the cable cross-section, H_0 – initial horizontal reaction originating from the initial tightening of the mesh, L_0 – initial cable length, g – uniformly distributed load (referred to the abdominal pressure), $\varDelta$ – relative horizontal displacement of the cable edges, l – length of the cable span. Thermal effects are neglected in the calculations.

2.2. Mesh modeling

Let us consider $\varDelta$ as a resultant displacement of the following two, $\varDelta_m$ connected with the elasticity of the mesh, which represents an extension in the radial direction of this part of the mesh, which is supported by the fascia (the mesh and the fascia overlap on a width l_s, marked in Fig. 2a) and $\varDelta_p$ resulting from the elasticity of the fascia and being a displacement of the hernia edges. Then, from (2.6), the following formula is obtained

$$H^3 + H^2\Big(-H_0 + (\varDelta_m + \varDelta_p)\frac{EA}{L_0}\Big) - \frac{EA}{L_0}\frac{g^2l^3}{24} = 0 \tag{2.7}$$

The elasticity of the mesh is represented by a linear spring of length l_s, appropriate to the mesh and the fascia overlap (see Fig. 2a,c). The force H causes the spring elongation by $\varDelta_m$. From the unit load method $\varDelta_m = Hl_s/(EA)$, which leads to final equation

$$H^3 \underbrace{\Big(1 + \frac{l_s}{L_0}\Big)}_{B} + H^2 \underbrace{\Big(-H_0 + \varDelta_p\frac{EA}{L_0}\Big)}_{C} - \underbrace{\frac{EA}{L_0}\frac{g^2l^3}{24}}_{D} = 0 \tag{2.8}$$

In order to simulate situations for various ventral hernias, with stiff or elastic edges, one decided to study three kinds of models:

- **M1 model – the cable with stiff support** – presented in Fig. 2b

  This is the simplest model, representing an ideal situation in vivo, in which the hernia orifice created in connective tissue is stiff and the mesh is fixed to the edges of the orifice.

- **M2 model – the cable with elastic support** – presented in Fig. 2c

  The springs in the supports of the cable represent elasticity of the mesh in a region supported by the fascia, so the model describes the natural situation after mesh implantation. The hernia orifice is stiff in this model so displacements of its edges are not possible ($\varDelta_p = 0$).

- **M3 model – the cable with elastic supports and displacement of the support** – presented in Fig. 2c

  This model represents the most general situation, in which the ventral hernia orifice is not stiff, its edges can displace and also the mesh elasticity in the supported by the fascia zone is considered.

3. The data

It can be noticed that the value of the force H in Eq. (2.8) depends on 8 quantities. Four of them: A, g, l and l_s have constant values in the analysis, because they are related to the assumptions about the model (dimensions and loads). The latter four quantities: L_0, H_0, Δ_p, E are difficult to specify in practical cases, thus in this study they take approximate (starting) values with some dispersion, and they are considered as the parameters of the problem. The importance of the parameters to the junction force is investigated by means of the sensitivity analysis, which allows us to identify the most significant elements in the study. Below the starting value for each quantity is defined.

The constant values of the analysis are described at first. The assumed hernia radius is equal to $r = 0.05\,\mathrm{m}$, so the cable span $l = 0.1\,\mathrm{m}$. The overlap of the hernia and the mesh is $0.04\,\mathrm{m}$, which is typical in practice, so $l_s = 0.04\,\mathrm{m}$. From the practical point of view, the width of the strip of the mesh which is considered in the cable model equals $0.015\,\mathrm{m}$ ($0.015\,\mathrm{m}$ is the maximum distance between tacks to prevent the incarceration of the bowels among the tacks), so the cross section of the strip $A = 0.015 \cdot 0.0009 = 1.35 \cdot 10^{-5}\,\mathrm{m}^2$. An extreme load acting on the mesh is derived from the critical pressure in the abdominal cavity $P = 270\,\mathrm{mmHg}$ ($35\,997\,\mathrm{Pa}$) appearing during postoperative cough (Twardowski *et al.*, 1986). This uniformly distributed load of one selected strip of the mesh is given as $g = F_n/l$, where $F_n = 2F_p/N$ is a force acting on a couple of tacks on two opposite sides of the hernia, N is the total number of tacks and $F_p = P\pi r^2$. Thus, for the assumed hernia geometry the pressure is equal to $g = 148.80\,\mathrm{N/m}$.

Secondly, the parameters of the sensitivity analysis are specified. The initial junction force H_0 is taken as 10% of the failure load identified by Śmietański *et al.* (2007) in the experiment, so $H_0 = 1\,\mathrm{N}$. As far as L_0 is concerned, $L_0 = 1.05l$ seems to be a reasonable value. Since mechanical properties of the implant are not available, Young's modulus of the mesh has been identified in an experiment. The considered Dual Mesh is not reinforced by any textile or fiberglass. A one-dimensional stretching test in a range of extension 0-1 mm with a constant increment has been performed. It is assumed that this range of elongation refers to a real situation. Dimensions of a measurement base of the specimen are $50\,\mathrm{mm} \times 80\,\mathrm{mm}$. The edge 80 mm has been cut in the direction of strongest resistance of the mesh to elongation and the specimen has been stretched in this direction. That kind of experiment represents exactly the modeled strip of the mesh. The Zwick Roell testing machine (see Fig. 3) has been used. It has been assumed that the elongation of the specimen is equal to the position of the machine crosshead. Such an approach is compatible with the European Code EN ISO 1421 Rubber- or plastics-coated fabrics – Determination of tensile strength and elongation at break'. The obtained nearly linear stress-strain relation allowed one to specify Young's modulus of the implant as $E = 10.77\,\mathrm{MPa}$. For comparison, Young's modulus of PTFE coated textile membranes used for coatings in building industry equals 420 MPa (see e.g. Minami *et al.* 1992; Kuwazuru and Yoshikawa 2004). Again, due to lack of information about the elastic properties of the fascia, the authors had to identify Δ_p experimentally. In this approach, Δ_p is related to displacement of some points of the fascia during human movement. The monitored points are tacks visible on Roentgen photos of a patient after LVHR. The boundary displacement Δ_p equals the average displacement of the tacks toward the centre of the ventral hernia measured as the difference of tacks positions during maximal inhalation and exhalation. Exemplary Roentgen photos in such a situation are presented in Fig. 4. The displacements are specified with a reference to the Protac tack dimensions: 2 mm height and radius of 3 mm. Thus Δ_p is estimated as $0.005\,\mathrm{m}$.

Fig. 3. One-dimensional stretching test of Dual Mesh (WL Gore) on the Zwick Roell testing machine

The following ranges of parameter variability are considered: $E \pm 50\%$, $L_0 \pm 10\%$, $H_0 - 100\%$, $+400\%$ and $\Delta_p \pm 50\%$ in relation to the starting values, described above. The ranges relate to the authors' uncertainties about the starting value of each parameter. The starting value of each quantity present in Eq. (2.8) and the parameter variability are listed in Table 1.

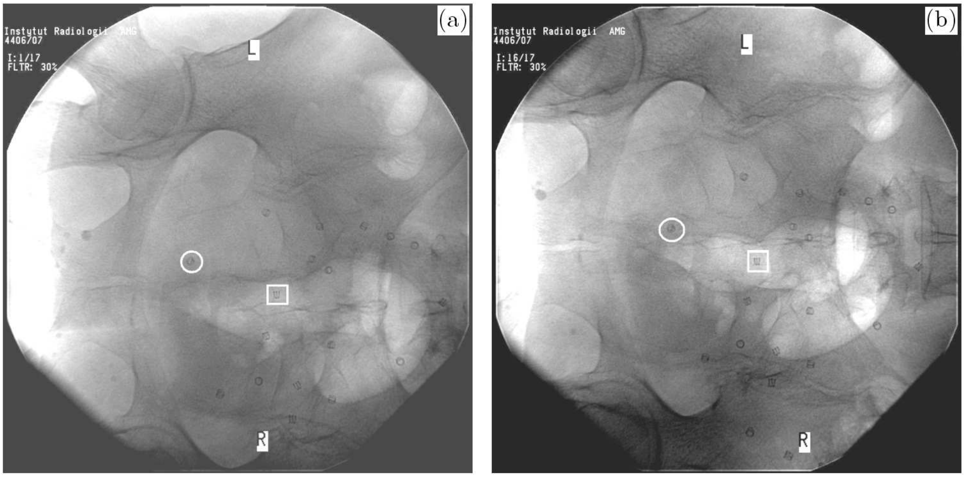

Fig. 4. Roentgen photos of a patient after LVHR: (a) position of the tacks at maximal inhalation, (b) position at maximal exhalation. One example of the tack displacement is marked by a square frame and the second by a circle

Table 1. Constant values and parameters of the sensitivity analysis

Constans			
A [m^2]	g [N/m]	l [m]	l_s [m]
$135 \cdot 10^{-5}$	148.8	0.1	0.04
Parameters – starting values and dispersions			
E [MPa]	L_0 [m]	H_0 [m]	Δ_p [m]
$10.77 \pm 50\%$	$0.105 \pm 10\%$	$1 - 100\%, +400\%$	$0.005 \pm 50\%$

4. Sensitivity analysis

Sensitivity analysis is a powerful tool in engineering design (see for example Haug at al. 1986). Some applications are also described by Szymczak (1998). In this research, the importance of each parameter to the junction force H is assessed.

Let the term s represent a parameter. A derivative of the left hand side of formula (2.8) with respect to the parameter s is specified

$$3H^2\frac{dH}{ds}B + H^3\frac{dB}{ds} + 2H\frac{dH}{ds}C + H^2\frac{dC}{ds} - \frac{dD}{ds} = 0 \tag{4.1}$$

and then the derivative dH/ds sought is arrived

$$\frac{dH}{ds} = \frac{-H^3\frac{dB}{ds} - H^2\frac{dC}{ds} + \frac{dD}{ds}}{3H^2B + 2HC} \tag{4.2}$$

Small variations are assumed, so $dH = \delta H$, $ds = \delta s$ and

$$\delta H = \frac{-H^3\frac{dB}{ds} - H^2\frac{dC}{ds} + \frac{dD}{ds}}{3H^2B + 2HC}\delta s = w_s\delta s \tag{4.3}$$

where w_s is the sensitivity coefficient of the force H with respect to the parameter s.

Relative variations take the form

$$\frac{\delta H}{H} = w_s\frac{\delta s}{s}\frac{s}{H} \qquad \rightarrow \qquad \overline{\delta H} = w_s\frac{s}{H}\overline{\delta s} = W_s\overline{\delta s}$$

The following formulae represent the variations of the force H related to the variations of subsequent parameters s

$$\begin{aligned}
s = L_0: \qquad & \overline{\delta H} = \frac{H^3 l_s + H^2\Delta_p EA - \frac{EAg^2l^3}{24}}{L_0H^2\Big[3H\Big(1+\frac{l_s}{L_0}\Big) + 2\Big(-H_0 + \Delta_p\frac{EA}{L_0}\Big)\Big]}\overline{\delta L}_0 = W_{L0}\overline{\delta L}_0\\
s = H_0: \qquad & \overline{\delta H} = \frac{-H_0}{3H\Big(1+\frac{l_s}{L_0}\Big) + 2\Big(-H_0 + \Delta_p\frac{EA}{L_0}\Big)}\overline{\delta H}_0 = W_{H0}\overline{\delta H}_0\\
s = \Delta_p: \qquad & \overline{\delta H} = \frac{-\frac{EA}{L_0}\Delta_p}{3H\Big(1+\frac{l_s}{L_0}\Big) + 2\Big(-H_0 + \Delta_p\frac{EA}{L_0}\Big)}\overline{\delta\Delta}_p = W_{\Delta p}\overline{\delta\Delta}_p\\
s = E: \qquad & \overline{\delta H} = \frac{-H^2\Delta_p EA + \frac{EAg^2l^3}{24}}{L_0H^2\Big[3H\Big(1+\frac{l_s}{L_0}\Big) + 2\Big(-H_0 + \Delta_p\frac{EA}{L_0}\Big)\Big]}\overline{\delta E} = W_E\overline{\delta E}
\end{aligned} \tag{4.4}$$

where W_{L0}, W_{H0}, $W_{\Delta p}$, W_E are relative sensitivity coefficients related to relative variations of L_0, H_0, Δ_p and E, respectively. The sensitivity coefficients express the importance of each variation of parameter in the calculation of the junction force.

5. Results

There are three solutions to equation (2.8), but only one of them is real for the values written in Table 1. The highest value of the searched junction force has been obtained for M1 model, $H_{\mathrm{M1}} = 11.194\,\mathrm{N}$. The same force in M2 model has been calculated as $H_{\mathrm{M2}} = 9.991\,\mathrm{N}$. The lowest junction force $H_{\mathrm{M3}} = 8.503\,\mathrm{N}$ has been achieved for M3 model. These results are comparable with the experimentally determined failure load of the fascia-mesh connection $H = 9.05\,\mathrm{N}$, see Śmietański *et al.* (2007).

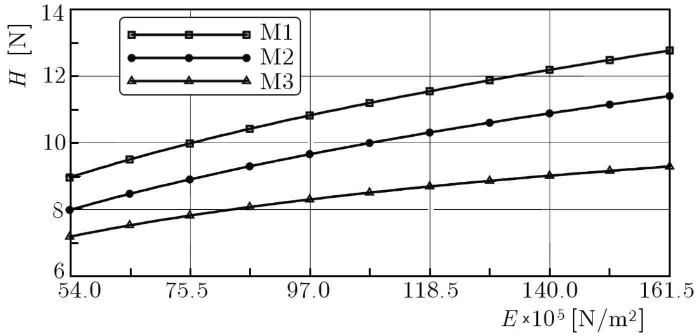

Fig. 5. Junction force H in M1, M2, M3 models vs. Young's modulus E

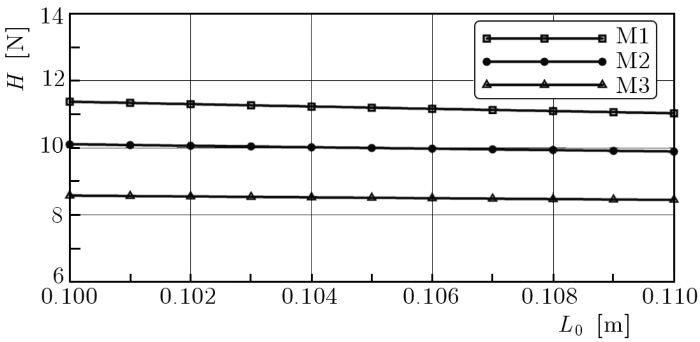

Fig. 6. Junction force H in M1, M2, M3 models vs. initial cable length L_0

In Figs. 5, 6, 7, 8, direct influence of each parameter variability on the force H is presented. In the diagrams, only one parameter is changing in the range described in Table 1, while the other parameters are constant and equal to their starting values. Those graphs prove that in the assumed range the change of Young's modulus E causes relatively big changes of the junction force, while changes of the cable length L_0 do not affect H significantly. Changes of the other two parameters: H_0 and Δ_p implicate moderate changes of H. These results are similar in each of the three models.

The effect of variations of the parameters upon the junction force variation is investigated also in the sensitivity analysis. The change of the junction

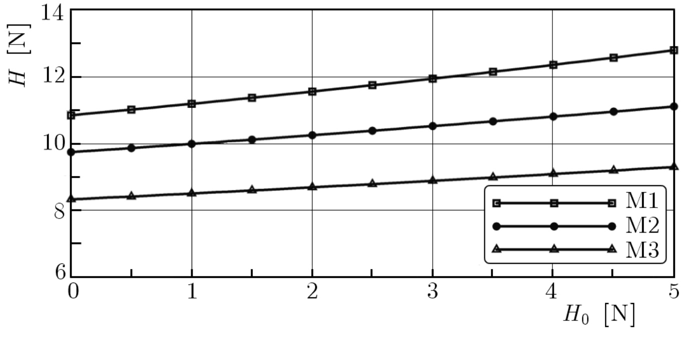

Fig. 7. Junction force H in M1, M2, M3 models vs. initial junction force H_0

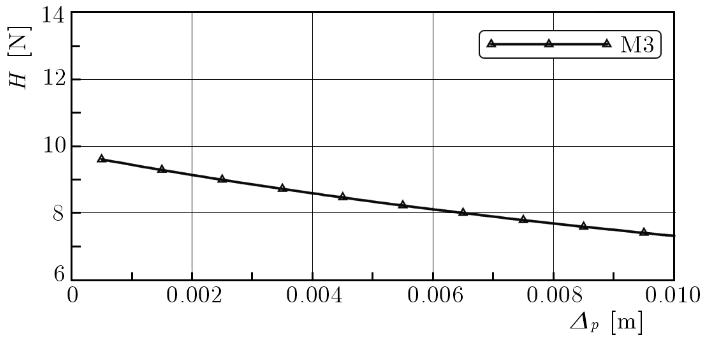

Fig. 8. Junction force H in M3 model vs. displacement of hernia edges Δ_p

force with respect to a parameter is described by sensitivity coefficients in the following manner, the higher is the absolute value of the sensitivity coefficient related to the parameter, the higher is change of the junction force. Negative values of the coefficient indicate a decline of the junction force due to higher values of the mentioned parameters.

In this study, the sensitivity coefficients have been calculated for four changeable parameters in the range described in Section 3. The tendencies of the coefficient values observed are similar in every model, so only results for M3 one are presented. In Figs. 9-12, the sensitivity coefficients for the discussed range of the four parameters E, L_0, H_0, Δ_p are given. In calculations concerning each coefficient, three parameters have constant values equal to their starting values, while the fourth, which is of interest, is changeable. In Figs. 9-11, the highest absolute values of the relative sensitivity coefficients W_E and little lower values of W_{L0} are observed. That proves the highest importance of values E and L_0 in calculations of H. Similar situation is observed in Fig. 12, but only for the hernia boundary displacements $0.0005\,\mathrm{m} < \Delta_p < 0.0065\,\mathrm{m}$.

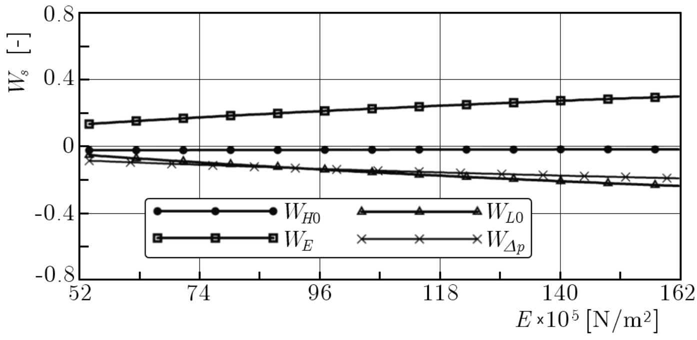

Fig. 9. Relative sensitivity coefficients calculated for M3 model vs. Young's modulus E

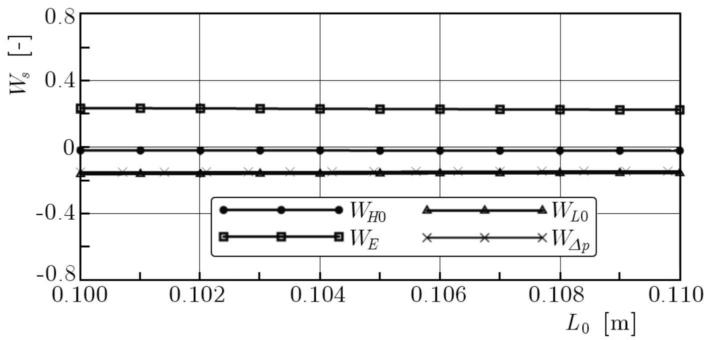

Fig. 10. Relative sensitivity coefficients calculated for M3 model vs. initial cable length L_0

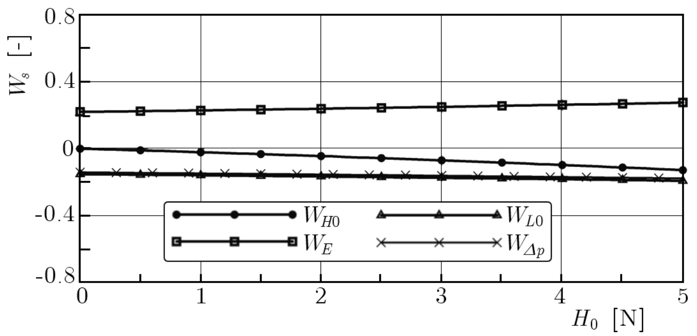

Fig. 11. Relative sensitivity coefficients calculated for M3 model vs. initial junction force H_0

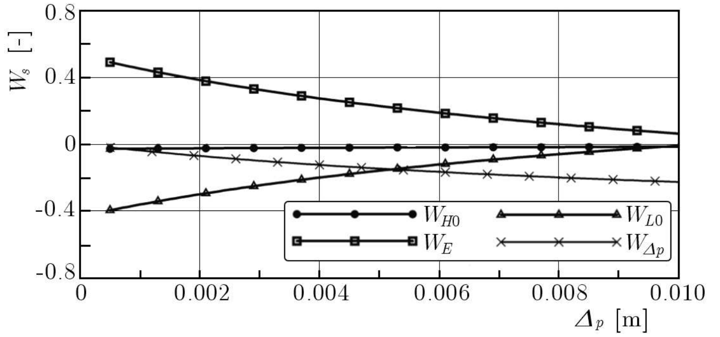

Fig. 12. Relative sensitivity coefficients calculated for M3 model vs. displacement of hernia edges Δ_p

If the displacement is higher, $0.0065\,\mathrm{m} < \Delta_p < 0.01\,\mathrm{m}$, the role of the parameter Δ_p becomes dominant. In each diagram, the coefficients W_{H0} have the smallest values, which practically means that for calculating the exact value of the junction force the accurate identification of H_0 is not a priority.

6. Discussion

The presented study is the first one of that kind in which the junction force in the fascia-implant system in a laparoscopic ventral hernia repair problem is calculated. The authors have conducted an analytical investigation and identified the most significant factors influencing the junction force. This is important for the future research orientation, when a more complex mathematical model of the system will be made. At present, a few following conclusions may be drawn.

1. The presented cable model and its parameters determined by the authors represents a real intraoperative situation well, because the calculated junction force is comparable to the experimentally determined failure load.

2. To calculate the exact value of the junction force, it is important to know an appropriate value of Young's modulus of the mesh or, in general, a constitutive model of the mesh material. This requirement is proved by the highest values of the sensitivity coefficients W_E, among others, and by the biggest changeability of the junction force H for different values of Young's modulus E.

3. The next important problem is proper modeling of the hernia orifice with appropriate boundary conditions. The authors' future study, related to a more complex model will be oriented to the identification of mechanical properties of the fascia.

4. The initial force in the mesh (H_0) reveals little significance to the junction force. Introducing a specific value of the initial force to the mesh during implantation is a quite difficult surgical problem, so this fact brings more convenience for operating doctors.

5. Current stage of knowledge allows us to present two remarks, specifically for practicing surgeons:

   - The higher Young's modulus of the mesh, the higher the junction force in the analyzed system – this observation may be helpful in the mesh selection for a given hernia orifice.
   - The smaller the force of initial mesh tension (H_0), the smaller the final junction force in the analyzed system, what is important from a practical point of view because surgeons can pay less attention to the mesh tightening, which simplifies the operation process.

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Modelowanie układu powięź-siatka i analiza wrażliwości siły połączenia po laparoskopowej operacji przepukliny brzusznej

Streszczenie

W pracy rozpatrywano prosty model układu powięź-siatka do oszacowania siły połączenia siatki z powięzią po laparoskopowej operacji przepukliny brzusznej. Celem pracy jest zastosowanie modelu cięgna do wyznaczenia siły połączenia tego układu oraz do wyznaczenia najważniejszych parametrów mających wpływ na siłę połączenia implantu z powięzią. W tym celu zastosowano analizę wrażliwości siły połączenia

względem wariacji początkowej siły rozciągającej siatki, jej długości i modułu sprężystości oraz podatności powięzi. Cięgno jest obciążone ciśnieniem wewnątrz brzusznym oraz przemieszczeniami jego końców wywołanymi skłonami ciała pacjenta. Wszystkie podane wyżej parametry są istotne dla bezpieczeństwa operacji przepukliny. W wyniku pracy sformułowano pewne wnioski ważne dla chirurgów oraz dla dalszych bardziej zaawansowanych badań z zastosowaniem modeli dwuwymiarowych układu powięź-siatka.

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