PAPER • OPEN ACCESS

Evaluation of optical data gained by ARAMIS-measurement of abdominal wall movements for an anisotropic pattern design of stress-adapted hernia meshes produced by embroidery technology

To cite this article: A Breier *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **254** 062002

IOP Conf. Series: Materials Science and Engineering **254** (2017) 062002 doi:10.1088/1757-899X/254/6/062002

Evaluation of optical data gained by ARAMIS-measurement of abdominal wall movements for an anisotropic pattern design of stress-adapted hernia meshes produced by embroidery technology

A Breier, L Bittrich, J Hahn, and A Spickenheuer
Leibniz-Institut für Polymerforschung Dresden e. V., Institute of Polymer Materials, Department of Composite Materials, Hohe Str. 6, 01069 Dresden, Germany

E-mail: breier@ipfdd.de

Abstract. For the sustainable repair of abdominal wall hernia the application of hernia meshes is required. One reason for the relapse of hernia after surgery is seen in an inadequate adaption of the mechanical properties of the mesh to the movements of the abdominal wall. Differences in the stiffness of the mesh and the abdominal tissue cause tension, friction and stress resulting in a deficient tissue response and subsequently in a recurrence of a hernia, preferentially in the marginal area of the mesh. Embroidery technology enables a targeted influence on the mechanical properties of the generated textile structure by a directed thread deposition. Textile parameters like stitch density, alignment and angle can be changed easily and locally in the embroidery pattern to generate a space-resolved mesh with mechanical properties adapted to the requirement of the surrounding tissue. To determine those requirements the movements of the abdominal wall and the resulting distortions need to be known. This study was conducted to gain optical data of the abdominal wall movements by non-invasive ARAMIS-measurement on 39 test persons to estimate direction and value of the major strains.

1. Introduction

Abdominal wall hernia describes the expulsion of bowels through an opening in the abdominal wall. The margin tissue of the cracked abdominal wall is unable to recover autonomously and untreated hernia can cause complications such as organic dysfunction, intoxication and necrosis of the particular area. Thus, surgical intervention is indispensable. Due to the variety of causes and occurrence abdominal wall hernia surgery is the most frequently operated surgical intervention worldwide [1]. Suture of the fissure causes tension on the margin tissue and often results in relapse [2]. To restore the function of the abdominal wall reinforcing meshes have to be applied [3]. Although the relapse rate can be lowered the application of alloplastic meshes causes infection, migration, dislocation as well as intraabdominal adherence and fistula [2, 3]. Next to influencing factors such as choice of material or surface characteristics a decisive parameter for triggering malfunction is seen in the structural design of the mesh [3, 4]. The structures are distinguished in heavy and light weight meshes, measured in weight per unit area (g/cm^2) and defining a more or less dense porosity. While heavy weight meshes facilitate the generation of scar tissue and imply a higher risk of infection the preferred light weight meshes are often reported on shrinking and wrinkle formation, which can cause pain and discomfort at the implantation site [3, 4]. A further limitation of the commercially available meshes is seen in the mechanical properties not matching the conditions in the abdominal wall [5]. Junge et al. determined elongations of the abdominal wall in a range of 11 % to 32 %, while the probed meshes showed elongations between 4 % to 16 % under the same load [6]. It is assumed, that the motility of the abdominal wall at the implantation site is limited to such an extent, that the relapse occurs on the margin of the mesh at the transition into the natural tissue [6]. Novel designs of commercially available meshes already showed improved re-establishment of the mechanical function [7] and first approaches of simulating the mechanical processes in the abdominal wall by finite element modelling are made [8, 9, 10]. A considerable issue for the simulation of abdominal wall processes is the compilation of reliable data and only few studies introducing numerical values are available [11, 12].

Meshes for abdominal wall hernia reconstruction are usually fabricated by textile processes, primarily by knitting and warp-knitting but also by weaving or depositing as nonwoven structures [13]. Knitted and warp-knitted structures are generated by loop formation (stitches) and show a feasible porosity, a high elasticity and a predominant anisotropic behavior compared to woven and nonwovens. But knitted meshes tend to unravel when cut and the parameters for influencing the mechanical and anisotropic behavior are limited [13]. A new approach is seen in using embroidery technology for manufacturing meshes with adapted mechanical properties [14]. Embroidery technology can be used for generating dimensionally stable scaffolding structures with defined characteristics for implants and tissue engineering applications [15, 16]. Porosity, mechanical properties or degradability can be adjusted by textile parameters like stitch length, stitch alignment as well as choice of thread size or material [15]. The design of the structures can be performed by the specific punch software EDOpath, primarily developed for light weight construction by Tailored Fiber Placement (TFP) technology, allowing additonally a transfer of finite element method (FEM) data into an embroidery pattern [17].

According to the request for a mesh structure with mechanical behavior adapted to the conditions in the defect area, the idea is to create a structure with reinforcing stiff units in the area of the opening, framed by an elastic unit in the margin area showing a graded transition into the surrounding tissue [14]. The design of the embroidery pattern is to be based on the simulation of the abdominal wall movements. To establish a finite element model for the simulation, data of the human abdominal wall have to be compiled. This study was conducted to gain optical data of the abdominal wall movements by non-invasive ARAMIS-measurement on 39 test persons to estimate direction and value of the major strains.

2. Materials and Methods

The abdominal wall of 35 adult test persons (mean age 33 a ± 10 a), divided into 18 male (mean age 30 a ± 7 a) and 17 female (mean age 36 a ± 11 a), and of 4 children (mean age 10 a ± 4 a) divided into 3 boys (mean age 10 a ± 4 a) and one girl (aged 11 a) were prepared with a speckle pattern comprising the front abdominal area from the costal arch to the pelvic bone. This was obtained by a random dot stamp pattern for a 100 mm x 130 mm stamp area, which was designed with 1.5 mm dot diameter and a black-white contrast of 50% (Fig 1A). The stamp was lined with a 40 mm foam material layer to enable smooth movement of the rubber face on the uneven surface of the abdominal wall (Fig 1B, white arrow). Black body paint (Clean Colors, Fa. Farbstark, Stadthagen) was applied on the face with a foamy painting roller as stamping ink. Four to five imprints were performed on the abdominal skin generating a consistent pattern. Voids were filled up manually with a brush (Fig 1C).

IOP Conf. Series: Materials Science and Engineering **254** (2017) 062002 doi:10.1088/1757-899X/254/6/062002

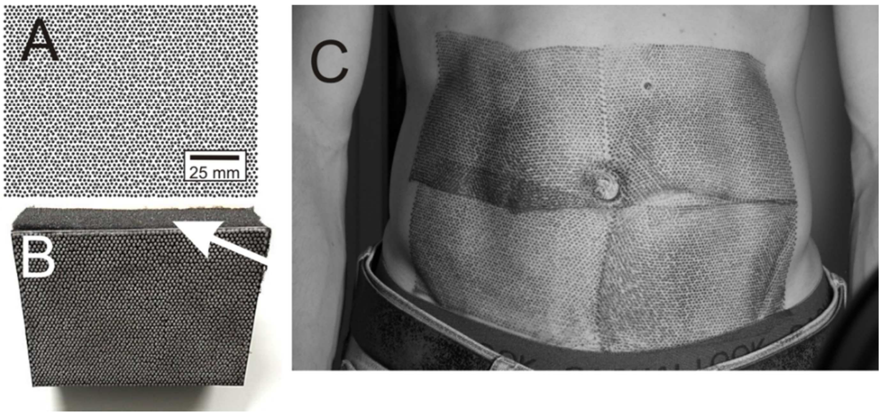

Figure 1. Preparation of the test persons: (A) random dot pattern with 1.5 mm dot diameter and a black white contrast of 50 %, (B) stamp 100 cm x 130 cm with the random dot pattern and lined with a 40 mm foam material layer (white arrow) and (C) abdominal wall of a male test person furnished with a dot pattern.

The prepared test persons were arranged in front of the ARAMIS-measurement system (GOM, Germany) (Fig. 2A) composed of two cameras for a three dimensional image acquisition featuring a resolution of 2400 pixels x 1728 pixels (Fig. 2B). Facets were determined with 15 pixels x 12 pixels. Deformations of the facets were measured during six abdominal movements (relaxed (Fig. 3 A, D), semi protruded, protruded (Fig. 3 B, E), semi contracted, contracted (Fig. 3 C, F) and strained). A qualitative evaluation of the major strain was performed using the ARAMIS software (Fig. 3 A, B, C). For further analysis with finite element (FE)-software tools the three dimensional position data of each facet was exported and fitted to a cubic B-spline surface for each deformation step (Fig. 3 D, E, F). A hernia mesh can be connected to the surface for mechanical simulation of stress and strain behavior during dynamic loads by interpolating the deformation states.

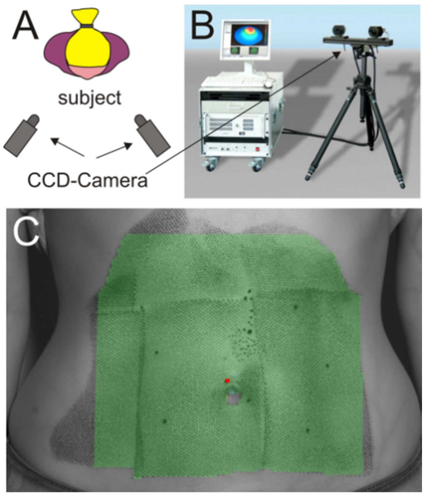

Figure 2. ARAMIS measurement system (GOM, Germany: (A) positioning of the test person, (B) measurment equipment with comuputer (left) and camera unit (right) and (C) determined measuring zone (green) on the abdominal wall.

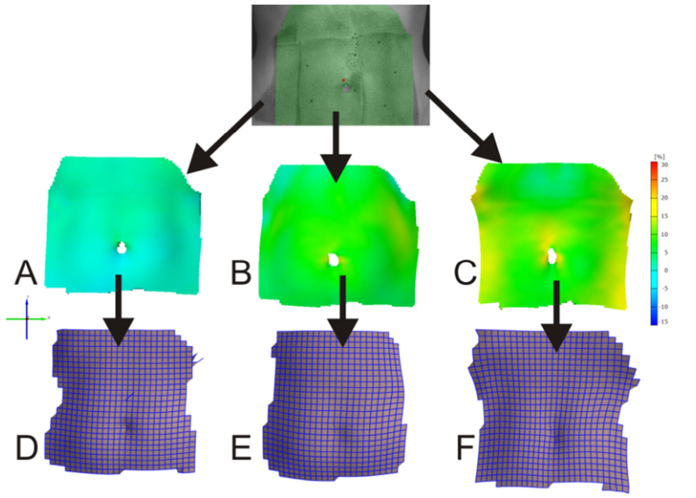

Figure 3. Evaluation of the abdominal wall movements by the ARAMIS software (A, B, C) and exported three dimensional position data fitted to a cubic B-spline (D, E, F) for relaxed (A, D), protruded (B, E) and contracted (C, F) state.

3. Results

An optimal dot pattern design and a reproducible application method were specified for optical measurements of human abdominal walls. Talcum was identified as an important additive in the body paint to achieve accurately rimmed dots and thus a distinguishable contrast. The dot pattern had to be

IOP Conf. Series: Materials Science and Engineering **254** (2017) 062002 doi:10.1088/1757-899X/254/6/062002

supplemented with some individual spots applied manually with a brush which were used by the ARAMIS software to identify the measuring unit and its movements.

The major strain of each test person’s abdominal wall was qualitatively evaluated. Section planes were cut longitudinal across the abdominal wall and the major strains along these axes could be depicted in diagrams and determined to a percental value for all motion states (Fig. 4). An anisotropic mechanical behavior of the abdominal wall could be demonstrated. A strong variation of the major strain values was observed comparing different test persons of the same sex in one motion state. The minimum value of the major strain was -15 % for male and female test persons, whereas the maximum value was 60 % for male and 50 % for female test persons.

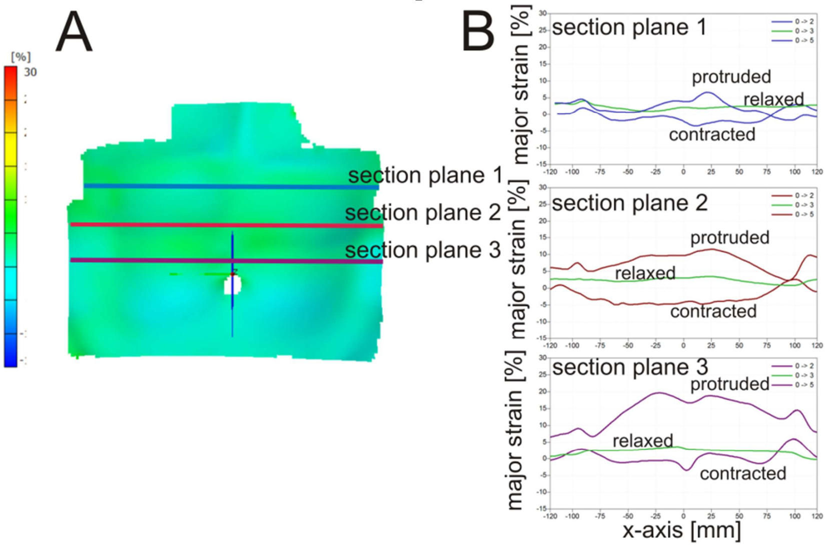

Figure 4. Section planes longitudinal to the abdominal wall (A) and the major strains along these x-axes.

Furthermore, the experimental data were transferred to a FE model. A parametrizable surface was defined to enable individual meshing and simulating the spatial distortion of the abdominal wall. However, the material parameters of the abdominal wall tissues are unknown. So the strain behavior between each deformation state was modelled with the FE software ANSYS by applying arbitrary isotropic material parameters and using the experimentally fitted displacement data at each node. Fig. 5 shows the first principal strain of an analysis with this data.

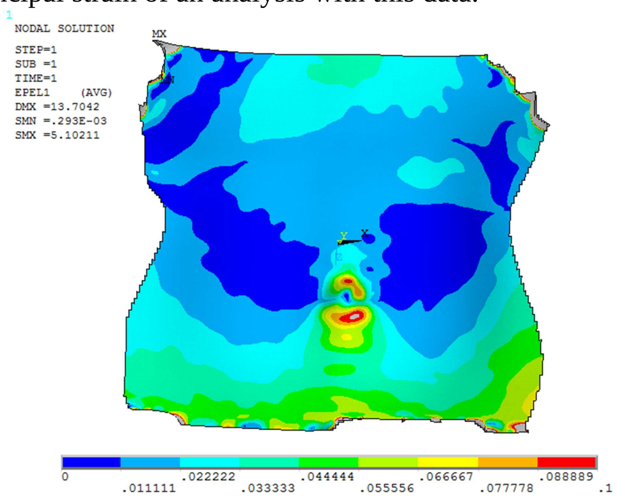

Figure 5. Contour plot of the first principal strain of the semi contracted state obtained by finite element analysis.

4. Discussion

Commonly used hernia meshes display isotropic mechanical and physical properties, while the abdominal wall musculature exhibits an anisotropic mechanical behavior. To prevent hernia mesh failure an adapted structure is required. Embroidery technology enables the manufacturing of anisotropic mesh structures by stress-adapted pattern design. However, the design of stress-adapted patterns requires a comprehensive knowledge of the stress-strain conditions in the abdominal wall and simulating the abdominal wall movements by FEM seems feasible. In this study optical data, gained from abdominal movements of test persons, were applied to determine direction and value of the major strains. But the corresponding stresses are meaningless as long as no realistic material parameters are found.

An approach to fit the anisotropy parameters of the material was made by relaxing the boundary conditions of the model in extended regions within the centre of the model, here by removing the displacement constraints at the corresponding nodes and replacing it by a constant hydrostatic pressure. Comparing the strain distribution of this new simulation to the first simulation result, the fitting parameters can be defined to the anisotropy parameters of the material in the relaxed zone and the magnitude of the hydrostatic pressure. Thus an iterative fitting method will lead to a qualitative material model, which allows at least qualitatively meaningful stress results. These derived FE-models can be used to simulate defects and patching with hernia mesh structures.

5. Conclusion

A non-invasive measurement method was established to gain optical data of the abdominal wall during different movements. Therewith, an FE model was developed to design embroidery patterns for mesh structures with an anisotropic mechanical behavior. The compiled data and the derived FE model not only enable the determination of the major stresses, they also comprise the potential to an iterative fitting method resulting in a qualitative material model. Future works will focus on the transfer of these models into embroidery pattern designs and thus to individualized hernia mesh structures.

6. Acknowledgments

The authors acknowledge the financial support of the Federal Ministry of Education and Research (AiF-IGF-Project “LoVarMed”, financial support number: 320050).

References

[1] Kalaba S, Gerhard E, Winder J S, Pauli E M, Haluck R S and Yang J 2016 Design Strategies and Applications of Biomaterials and Devices for Hernia Repair *Bioact. Mat*. **1**(1) p 2 - 17.

[2] Friedrich M 2008 Wechselwirkung zwischen leichtgewichtigen Herniennetzen aus Polypropylen verschiedener Hersteller und ausgewählten humanen Zellen, *Dissertation* Lübeck, Univ. Klinik für Chirurgie.

[3] Schumpelick V, Klosterhalfen B, Müller M et al. 1999 Minimierte Polypropylen-Netze zur präperitonealen Netzplastik (PNP) der Narbenhernie - Eine prospektive randomisierte klinische Studie. *Chirurg* **70**, p 422-30.

[4] Zogbi L, Trindade EN and Trindade M 2013 Comparative study of shrinkage, inflammatory response and fibroplasia in heavyweight and lightweight meshes. *Hernia* **17**(6), p 765-72.

[5] Dietz U 2013 Medizinische Herausforderungen für textile Implantate *Fachtagung Polymere Biomaterialien - vom Material zum Gewebe* Würzburg.

[6] Junge K, Klinge U, Prescher A et al. 2001 Elasticity of the anterior abdominal wall and impact for reparation of incisional hernias using mesh implants. *Hernia* **5**(3), p 113-8.

[7] Podwojewski F, Otténio M, Beillas P et al. 2013 Mechanical response of animal abdominal walls in vitro: Evaluation of the influence of a hernia defect and a repair with a mesh implanted intraperitoneally *Journal of Biomechanics* **46** (3), p 561-6.

[8] Tomaszewska A, Lubowiecka I, Szymczak C et al. 2013 Physical and mathematical modelling of implant-fascia system in order to improve laparoscopic repair of ventral hernia *Clinical*

Biomechanics **28** (7), p 743-51.

[9] Justinger C. Shklyar I, Klein P and Schilling M 2011 Developing new strategies in abdominal wall closure using a virtual mechanical model. *The World Journal of Hernia and Abdominal Wall Surgery* **15,** p 855.

[10] Hernández-Gascóna B, Peñaa E, Melerod H et al. 2011 Mechanical behaviour of synthetic surgical meshes: Finite element simulation of the herniated abdominal wall. *Acta Biomaterialia* **7**(11), p 3905-13.

[11] Cobb WS, Burns JM, Kercher KW, Matthews B, Northon HJ and Heniford T 2005 Normal intraabdominal pressure in healthy adults *J Surgical Research* **129**, 231-5.

[12] Pott PP, Schwarz MLR, Gundling R, Nowak K, Hohenberger P, et al. 2012 Mechanical properties of mesh materials used for hernia repair and soft tissue augmentation. *PLoS ONE* **7**(10), e46978.

[13] Zhu LM, Schuster P, Klinge U 2015 Mesh Implants: An overview of crucial mesh parameters. *World Journal of Gastrointestinal Surgery* **7** (10), p 226 – 36.

[14] Hahn J, Bittrich L, Breier A, Spickenheuer A 2017 Stress adapted embroidered meshes with a graded pattern design for abdominal wall hernia repair *AUTEX Conference* (Korfu)

[15] Breier A 2015 Embroidery technology for hard tissue scaffolds. *Biomedical Textiles for Orthopaedic and Surgical Applications: Fundamentals, Applications and Tissue Engineering* ed Blair T (Woodhead Publishing) p 23–43.

[16] Hahner J, Hinüber C, Breier A, Siebert T, Brünig H and Heinrich G 2015 Adjusting the mechanical behavior of embroidered scaffolds to lapin anterior cruciate ligaments by varying the thread materials *Text. Res. J.* **85**

[17] Spickenheuer A, Schulz M, Gliesche K et al 2008 Using tailored fibre placement technology for stress adapted design of composite structures. *Plastics, Rubber and Composites* **37**(5-6), p 227-32.