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Mechanical response of human abdominal wall based on digital image correlation and artificial neural network analysis

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ABSTRACT: The motivation of the undertaken studies are recurrences of the ventral hernia operated with the use of synthetic implants. The main objective is to identify areas of human abdominal wall that reveal similar mechanical behaviour under intraabdominal pressure. Such an information is important for the proper design of surgical meshes used for ventral hernia repair. The presented research is based on experiment and data analysis. Full-field measurement of abdominal wall displacement during loading is performed using Digital Image Correlation system (DIC). A specific type of artificial neural networks (ANN) called Self-Organising Maps (SOM) is applied in the study to find regions of abdominal wall with similar mechanical performance during the experiment. Although the results do not show significant differences among the regions, the identified areas are distributed in stripes aligned with the mediolateral axis of the human body. During the experiment the principal strain values evolve with load and principal strain directions change within breathing and when the pressure load increases. The presented study can be a step forward to better understanding of living human abdominal wall mechanics and also better fitting of existing surgical meshes used in repairs of ventral hernia as well as to the design of new implants.

KEYWORDS: mechanics of abdominal wall, digital image correlation, full-field measurements, self-organizing maps, strain field

1. Introduction

The motivation of the undertaken studies are recurrences of the ventral hernia operated with the use of synthetic implants. Hernia is a discontinuity of the abdominal wall that can be reconstructed by implants. Even if since many years this type of surgery is a common medical procedure, the recurrences still affect nearly 30% of patients [1].

Human abdominal wall is a complex structure [1]. Although there are studies investigating the mechanical behaviour of abdominal shells (see e.g., [2-4], it is not really known how the implants match its mechanical properties and if their design should be specific to the place of hernia (see e.g., [1], [5]). However, as indicated in [6-7] the mechanical compatibility of implant and abdominal tissue is important to prevent the disconnection of implant and the recurrence of the hernia.

The main objective of the study is to find regions of human abdominal wall whose mechanical performance would be similar under intraabdominal pressure load. The identified regions may also have similar mechanical properties. If this were true it would provide an important information for the design of surgical meshes manufactured for repairs of ventral hernias.

The presented research is based on experiment and data analysis. Digital Image Correlation system (DIC) was used to record the motion of the abdominal wall during the application of a pressure load. DIC is an optically-based technique used to measure the evolving full-field 2D or 3D coordinates on the surface of a test piece throughout a mechanical test. Here the experimentally achieved data was used to calculate displacements and strains of the tested surface that was later used into the analysis of deformation of abdominal wall using artificial neural networks (ANN). A specific type of ANN called Self-Organising Maps (SOM) [8] was applied in the study to identify regions of abdominal wall with similar mechanical performance during the experiment.

2. Experiment and data analysis

The experiment was performed on human subjects in hospital during peritoneal dialysis procedure when a dialysis fluid was introduced into the abdominal cavity of the patient. Under the hydrostatic pressure change during filling, the abdominal wall deformed. The evoluition of the deformation was recorded by a four camera DIC system Dantec Q-400. The abdomen was covered by a special pattern (Fig. 1) since the DIC correlate images following the printed speckles.

The displacements, strains and principal strains directions on the external surface of the abdominal wall were calculated.

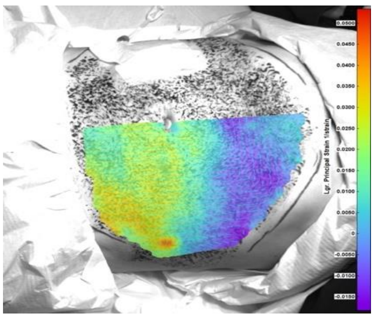

Fig. 1. Human abdominal wall covered by speckle pattern for DIC tests; calculated strain field

Four states of the abdomen were considered in total, inhalation and exhalation (Fig. 2), both with drained abdominal cavity and with filling of the dialysis fluid. Maximal and minimal principal strains and directions in each of four states during the whole test were calculated. Thus 8 sets of data were acquired and used in the analysis.

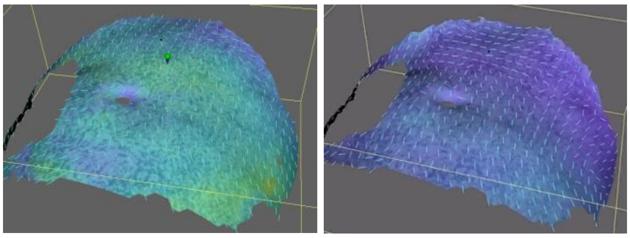

Fig. 2. Principal strain directions on external surface of abdominal wall during inhalation and exhalation in case of drained abdominal cavity

Principal strains in all 4 states were selected as the data representing the mechanical behaviour of the surface of abdominal wall and used in the analysis by Self-organising maps. Therefore the 8 data sets collected from the entire abdominal wall in 4 time points built the ANN input vector. This way the complex data representing the abdominal wall behaviour including drained and filled cavity and exhalation and inhalation states can be analysed simultaneously.

Consequently, the SOM reduced the 8-dimensional data space to two-dimensional result space by grouping the data points and showing on a 2D map represented by U-matrix (Fig. 3).

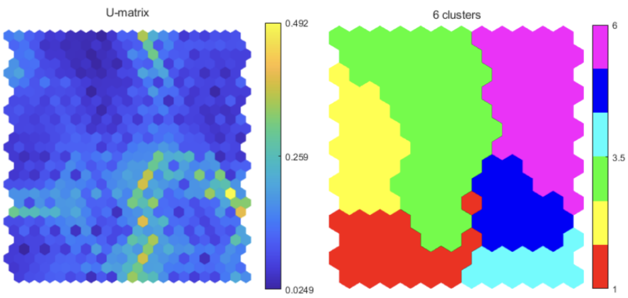

Fig. 3. U-matrix with clusters of data points indicated by colours (bright colours separate groups of data marked by darker colour) – left; map of clusters – right

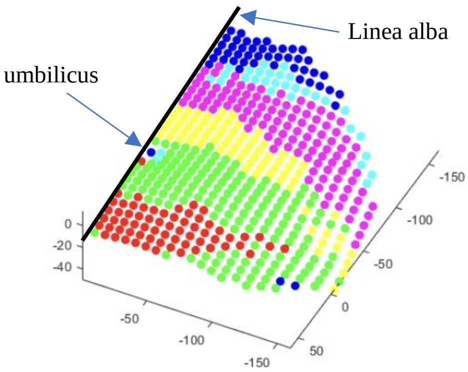

Fig. 4. Clusters of data points mapped to a half of the abdominal wall. The geometry of abdomen presented in [mm]

The clusters are composed of data points on the abdominal wall that reveal similar mechanical behaviour under pressure.

After grouping, the input data points were mapped to the abdominal wall (Fig. 4) showing regions with similar strains under pressure referring to its similar mechanical behaviour. Although the boundaries of the clusters are not intense, so maybe the behavior does not change significantly, you may notice some regions (color coded in Fig. 4) arranged in stripes aligned with the mediolateral axis of the body.

Only half of the abdomen studied was included in the data analysis after taking into account the symmetry and the fact that on the other side a catheter was inserted. The catheter covered part of the area being examined, making the data acquisition difficult.

All participants of the experiment submitted a consent to participate in the study under a protocol approved by the local Ethics Committee (NKBBN 314/2018).

3. Conclusions

The presented study is based on *in vivo* tests on human subjects what is hardly seen in literature. According to the Authors knowledge, identifying regions with similar mechanical behaviour of human abdominal wall based on *in vivo* tests and full-field measurement incorporating strains at different loading states at a time has not been reported yet.

Within the analysis one can notice that not only principal strains values evolve with the load, but also principal strain directions change. The mechanical behaviour of the abdominal wall in terms of strains changes along the sagittal axis of the human body.

The study can be a step forward to better understanding of living human abdominal wall mechanics. This can lead to better fitting of existing surgical meshes used in repairs of ventral hernia and to the design of new implants. Moreover, the regions of similar mechanical behaviour under pressure may possibly also indicate similar mechanical properties but this hypothesis should be verified by further research.

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