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Article

Pressure Distribution during Negative Pressure Wound Therapy of Experimental Abdominal Compartment Syndrome in a Porcine Model

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Abstract: 1) Introduction: Negative pressure wound therapy (NPWT) is a frequently applied open abdomen (OA) treatment. There are only a few experimental data supporting this method and describing the optimal settings and pressure distribution in the abdominal cavity during this procedure. The aim of our study was to evaluate pressure values at different points of the abdominal cavity during NPWT in experimental abdominal compartment syndrome (ACS) animal model. 2) Methods: In this study (permission Nr. 13/2014/UDCAR) 27 Hungahib pigs (15.4- 20.2 kg) were operated. ACS was generated by implanting a plastic bag in the abdomen through mini-laparotomy and filled with 2100- 3300 ml saline solution (37 C°) to an intraabdominal pressure (IAP) of 30 mmHg. After 3 hours, NPWT (Vivano Med ® Abdominal Kit, Paul Hartmann AG, Germany) or Bogota bag was applied. NPWT group was divided into -50, -100 and 150 mmHg suction group. Pressure distribution to the abdominal cavity was monitored at 6 different points of the abdomen via a multichannel pressure monitoring system. 3) Results: The absolute pressure levels were significantly higher above than below the layer. The values of the pressure were similar in the midline than laterally. Amongst the bowels the pressure values changed periodically between 0 and -12 mmHg which might be caused by the peristaltic movements. 4) Conclusions: The porcine model of the present study seems to be well applicable for investigating ACS and NPWT. It was possible to provide valuable for clinicians. The pressure was well distributed by the protective layer to the lateral parts of the abdomen and this phenomenon did not change considerably during the therapy.

Keywords: intra-abdominal pressure; abdominal compartment syndrome; pressure sensor; negative pressure wound therapy; open abdomen;

1. Introduction

The intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) are commonly observed in critically ill patients. Although diagnostic and therapeutic guidelines are

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described by the World Society of Abdominal Compartment Syndrome, there are many controversies in the treatment. The treatment of IAH/ACS is basically conservative and semiconservative (minimal invasive intervention). Surgical treatment is necessary if these treatment options fail. The basic surgical approach is the open abdomen (OA) therapy [1,2].

For investigation of the underlying pathophysiologic events a lot of experimental animal models have been developed. Small animal models are useful to investigate pathophysiologic changes. Large animal models are particularly advantageous for evaluating surgical techniques and their effects. The most commonly used large animal model is the porcine model [9].

Negative pressure wound therapy (NPWT) is an increasingly applied method of open abdomen therapy in clinical conditions, although there are only a few experimental data supporting its effectiveness or describing possible complications [3,18,19].

Authors introduce a porcine model for experimental abdominal compartment syndrome and OA therapy, emphasizing NPWT and describing its optimal settings. Abdominal compartment syndrome was created in pigs and pressure distribution within the abdominal cavity was measured during negative pressure wound therapy.

2. Materials and Methods

This study was performed at the Department of Operative Techniques and Surgical Research, Faculty of Medicine, University of Debrecen, Hungary. It was approved by the local institutional committee on animal research (permission No. 13/2014/UDCAV).

26 Hungahib pigs (15.4- 20.2 kg) were kept under standard circumstances (22-23 C °) before the experiment. The operations were performed under general anaesthesia by intramuscular administration of 15 mg/bwkg ketamine and 1 mg/bwkg xylazine. The animals were ventilated through tracheostomy with assisted air and oxygen ventilation. A central venous catheter was placed in the left jugular vein. The left femoral artery was used as arterial access point. A urinary catheter was introduced suprapubically to measure urine output.

After inducing anaesthesia, a plastic bag was implanted in the abdomen through mini-laparotomy (30 mm midline incision) and filled with 2100- 3300 ml pre-heated (37 C°) saline solution until an intra-abdominal pressure (IAP) of 30 mmHg was reached. The abdominal wall was temporarily closed in an airtight manner by two layers of running sutures. The balloon was also used for monitoring the IAP. Body temperature, urinary output, haemodynamic parameters such as heart rate, peripheral oxygen saturation, blood pressure, mean arterial pressure (MAP), central venous pressure (CVP) were monitored throughout the experiment.

After 3 hours, the bag was deflated and removed through a total midline laparotomy and the open abdomen therapy was initiated. The abdomen was temporarily closed by Bogota bag, a urinary catheter was inserted with sutures to the wound edges in six animals (untreated pigs from historic data). In case of the other 20 pigs NPWT (Vivano Med ® Abdominal Kit, PAUL HARTMANN AG, Germany) was applied. A micro-structured organ protection layer was placed on the small intestines under the parietal peritoneum, which was covered by a foam dressing and a self-adhesive layer on the top. The set was then connected to a special device (VivanoTec® Unit, PAUL HARTMANN AG, Germany) to create reduced pressure within the abdominal cavity.

The NPWT group was divided into 3 further subgroups. In case of 7 animals -50 mmHg suction was applied, another 7 pigs were included in the -100 mmHg, and 6 in the -150 mmHg group.

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Pressure distribution to the abdominal cavity was monitored via a microcontroller based multichannel pressure sensor system (MBMPSS) at six different points of the abdomen. The systems' pressure measurement were referenced to atmospheric pressure. Two sensors were positioned laterally (8 cm from the lateral side of the wound edge), another two in the midline above and under the protection layer. Two further sensors were placed amongst the small bowels. (Figure 1.) The device measured pressures every 10 seconds throughout the negative pressure treatment interval of 120-minutes (720 data/each sensor).

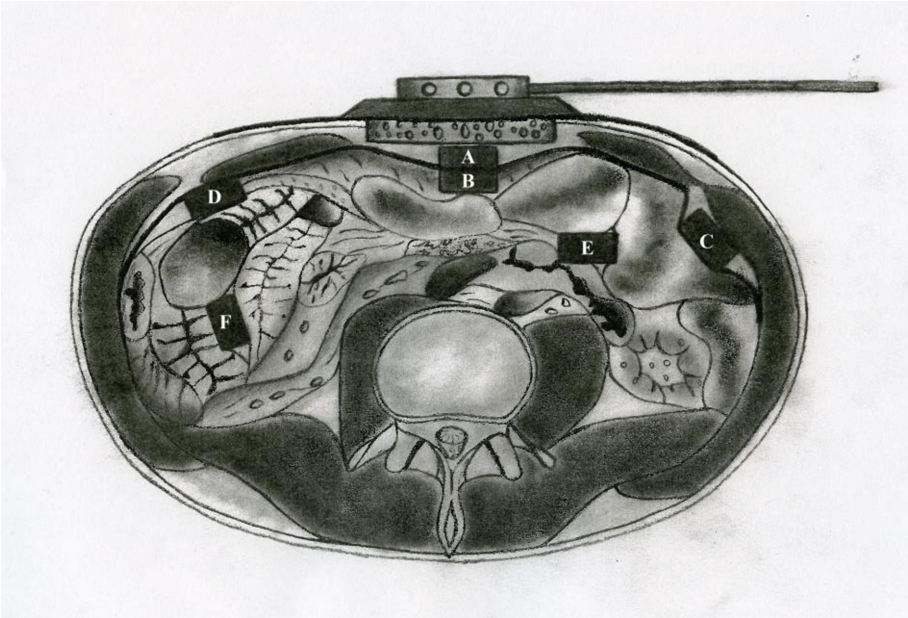

Figure 1. The positions of the pressure sensors. A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels

Results are expressed as mean ± SD. Each measurement time points in the presented tables and diagrams represents the sum of 10 measured values in every 5 minutes of each animal from the beginning (0 point) of NPWT. The relation between the summary of the measured sensors (50 measured data of each sensor at each pressure level) were analysed using the correlation analysis method. The assessment of the correlation analysis is summarized in Table 1.

Table 1. Correlation coefficient (Guilford, 1950)

Correlation coefficient	Level of correlation
0	no linear relationship
0-0.2 (-0.2-0)	negligible correlation with irrelevant relationship
0.2-0.4 (-0.4- -0.2)	low correlation, definite but small relationship
0.4-0.7 (-0.7- -0.4)	moderate correlation with significant relationship
0.7-0.9 (-0.7- -0.9)	high correlation with strong relationship
0.9-1 (-1- -0.9)	very high correlation with strong dependable relationship

3. Results

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The correlation between measurement points of 50, 100 and 150 mmHg NPWT are represented in Figure 2-4.

In the 50 mmHg NPWT group between A-F sensors the correlation was moderate with significant relationship, between A-B, B-F sensors the correlation was high with strong relationship and between A-C, A-E, B-D, B-E sensors the correlation was slight, almost negligible. Between A-D sensors there was no linear relationship (Figure 2.).

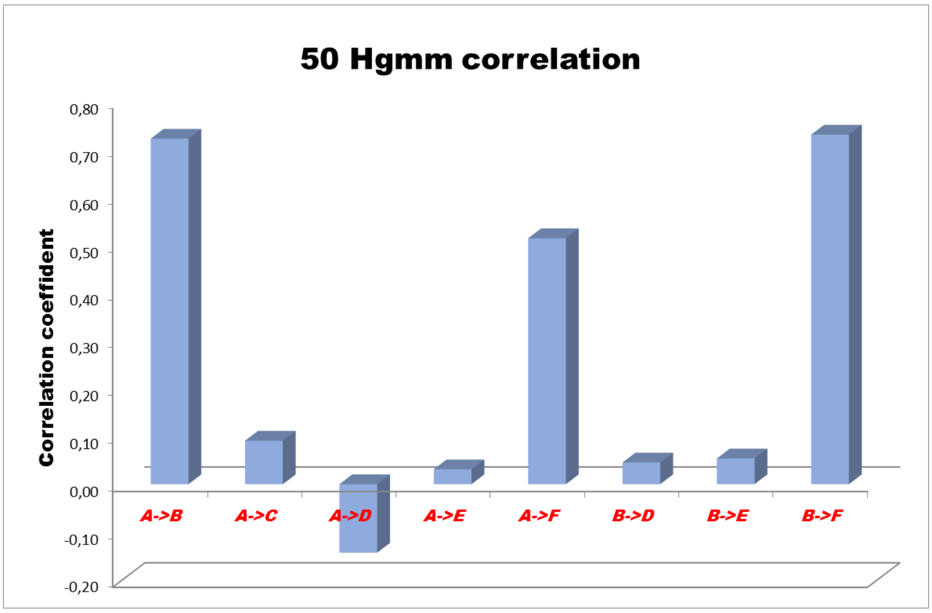

Figure 2. Relation analysis between the sensors during -50 mmHg NPWT

A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels

In the 100 mmHg NPWT group between B-E sensors the correlation was slight with irrelevant relationship, between A-B, A-C, A-D, A-F and B-F sensors the correlation was high with strong relationship and between B-D sensors the correlation was very high with strong dependable relationship. There was no linear relationship between A-E sensors (Figure 3.)

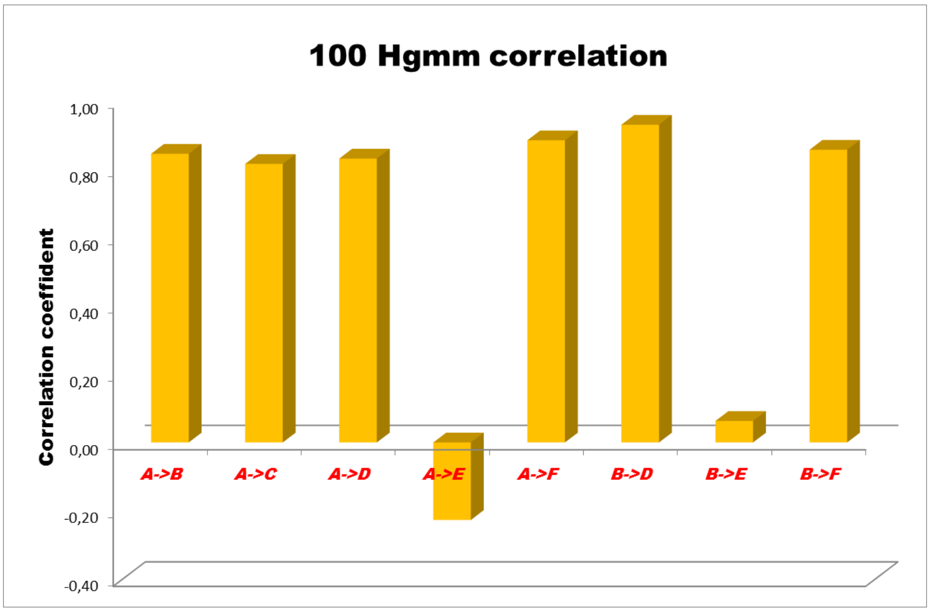

Figure 3. Relation analysis between the sensors during -100 mmHg NPWT

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A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels

In the 150 mmHg NPWT group, between A-D sensors the correlation was slight with irrelevant relationship, between A-E and A-F sensors the correlation was moderate with significant relationship, between A-C the correlation was very high with strong dependable relationship. Low correlation, small but definite relationship has been proved between A-B, B-E, B-F sensors. Between B-D there was no linear relationship (Figure 4.)

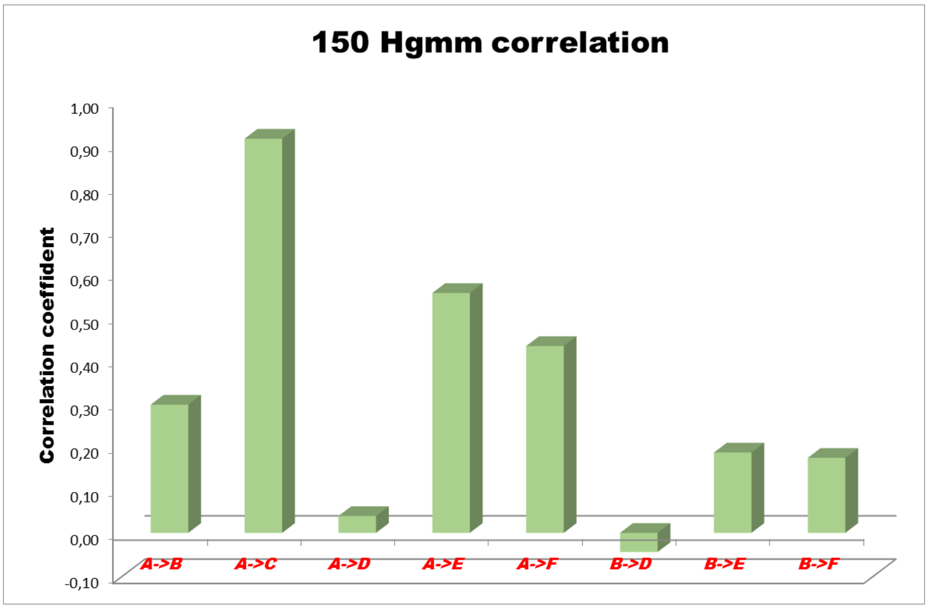
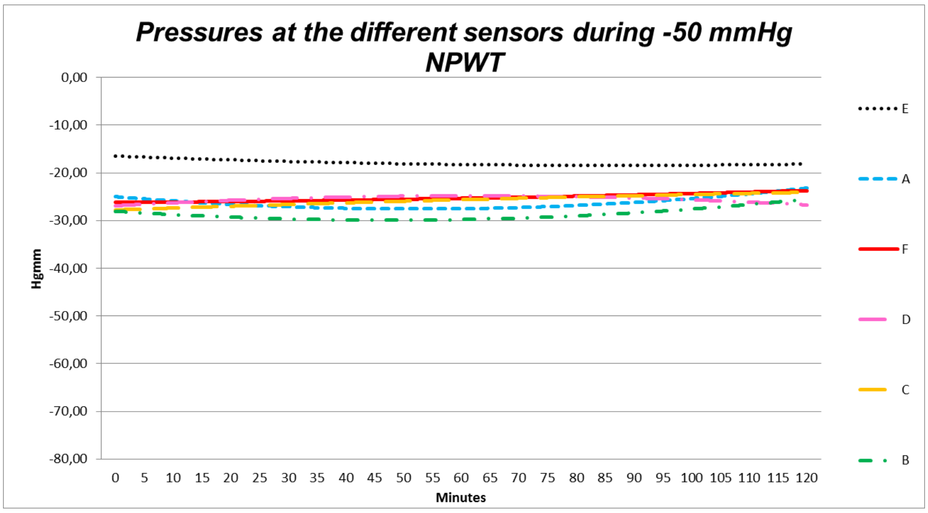


Figure 4. Relation analysis between the sensors during -150 mmHg NPWT

A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels

In each group, there was good correlation between the sensors in the middle and the lateral positions, in contrast to the superficially and deeply positioned sensors, where pour correlation was experienced. From other point of view the absolute pressure in all three groups amongst the bowels were significantly lower than below or before the protective layer. In the lateral and medial positions the pressure levels were nearly the same. (Figure 5-7.)



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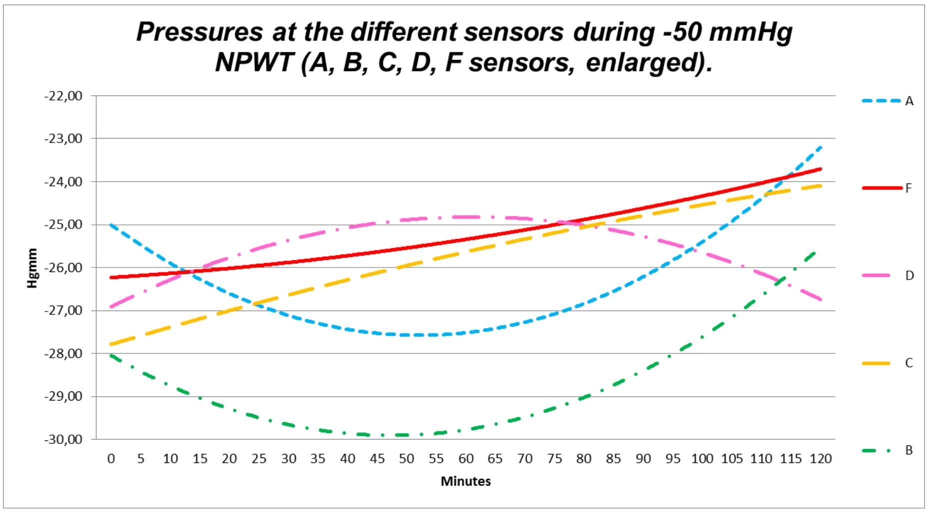
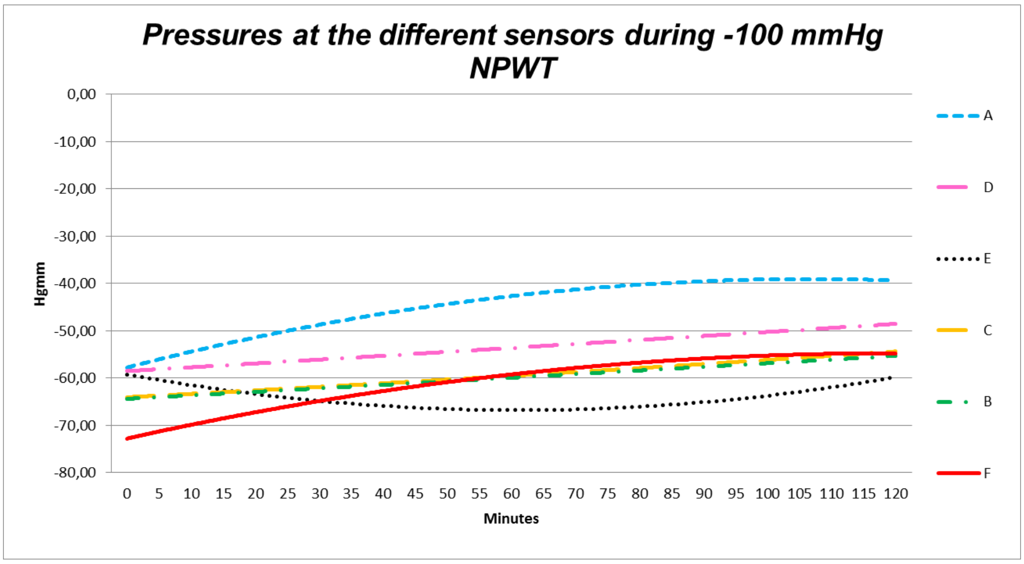


Figure 5. Pressures at the different sensors during -50 mmHg NPWT

A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels



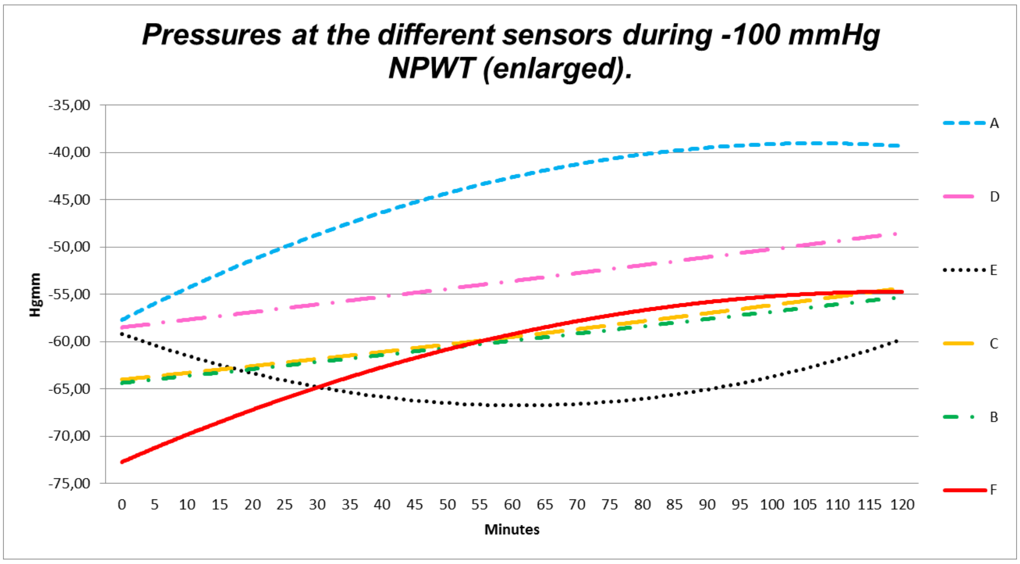


Figure 6. Pressures at the different sensors during -100 mmHg NPWT

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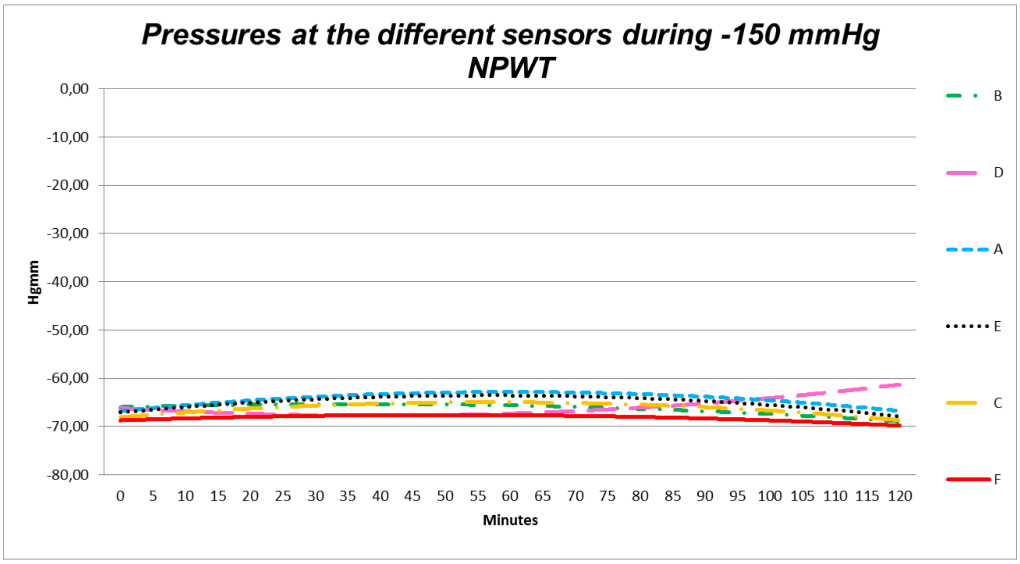
A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels



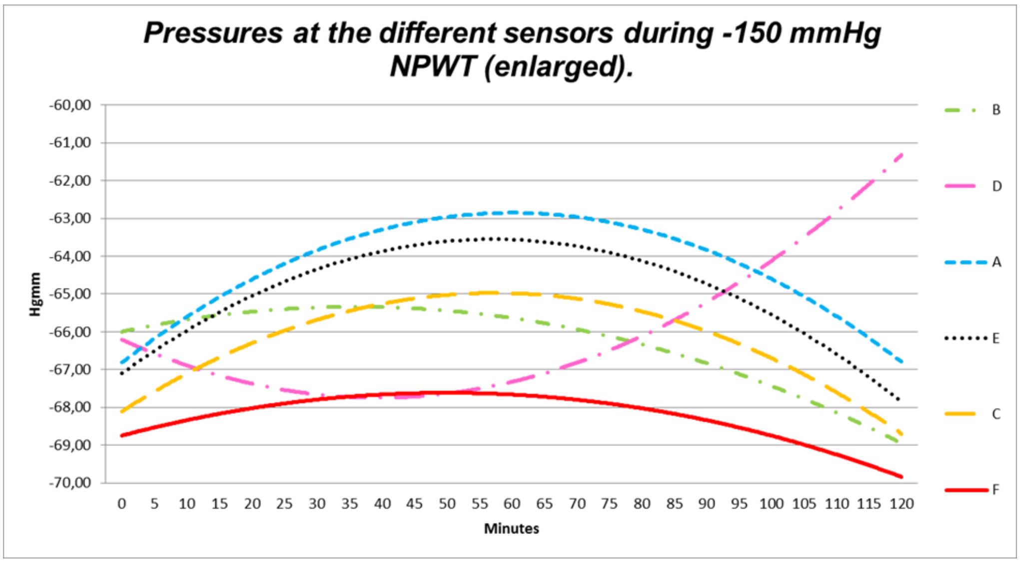


Figure 7. Pressures at the different sensors during -150 mmHg NPWT

A: midline above the layer, B: midline under the layer, C: laterally above the layer, D: laterally under the layer, E: midline amongst bowels, F: laterally amongst bowels

During NPWT the measured pressure levels showed no significant changes with time. (Figure 3.)

At -50 mmHg pressure level, A and B are convex, D is a concave curve, C and F are linear functions, E is a monotonically decreasing curve. Monotonity of functions A, B, D changes after 50-60 minutes from the 0 point of the experiment.

At -100 mmHg , monotonity of curve A is unchanged during experiment. A and F are concave. Function E changes into a concave curve. B is a linear, D is an apparently linear function.

At -150 mmHg pressure level, A, C, E, F, are convex and they change in monotonity after 60 minutes. B is a concave, D is a convex curve.

Monotonity of the curves are the most equalized at -100 mmHg.

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4. Discussion

According to the World Society of Abdominal Compartment Syndrome (WSACS) the definition of ACS is a sustained elevation of IAP above 20 mmHg (with or without abdominal perfusion pressure (APP) < 60 mmHg) that is associated with a new organ dysfunction/failure [1]. ACS is a life-threatening condition, leaving it untreated leads to multi-organ failure and death. When IAP is permanently over 20 mmHg despite conservative treatment, and organ dysfunction is present, surgical intervention is necessary. The aim of the damage control surgery is to control bleeding and contamination of the abdominal cavity and to decompress. In order to provide possibility for planned re-laparotomy, open abdomen therapy is required.

There are many temporary abdominal closure (TAC) techniques like skin only sutures, the application of absorbable meshes, Bogota bag, zipper systems, Wittmann Patch and the different NPWT methods. OA complications are well-known, these are the enteroatmospheric fistula formation, fluid and protein loss, catabolism, fixation of the abdominal organs, fascial retraction etc. [1-5]. According to the guidelines created by the WSACS, NPWT is recommended in treatment of ACS, because it gives superior results to simple packing techniques [1]. NPWT is increasingly accepted in clinical conditions, although there are only a few experimental data regarding its effects and complications. There is a lack of evidence-based recommendations related to the most favorable settings.

Besides clinical results, small and large animal models are available for investigating IAH, ACS and the different TAC techniques, including NPWT experimentally. Especially large animals like pigs are suitable for investigating ACS effect on hemodynamics, organ function, circulation, and evaluate conservative and surgical treatment options, because of the relative close anatomy and pathophysiology to humans [8,10,11,14-16]. ACS definition in an animal model can be stated if an artificially increased IAP leads to circulatory, renal, respiratory insufficiency [9]. In our pig model 3 hours of IAH (30 mmHg) was enough for the above mentioned consequences of ACS to appear.

Every former animal ACS model showed that well-timed decompression reduces mortality, has favorable effect on the ACS induced changes on hemodynamics and organ function [12,13]. NPWT was found superior to other TAC methods by authors investigating the different TAC techniques [3,6]. However, Benninger et al. advised to use bag or zipper system firstly and to use NPWT only a few days later in order to prevent reoccurrence of IAH/ACS [17].

According to the available clinical and experimental data, NPWT increases tissue perfusion, collagen production, granulation and angiogenesis, which helps wound healing. It provides medial traction preventing lateralization of the abdominal wall or dehiscence. The fascial closure rates are estimated around 35-92%. It ensures effective drainage in order to prevent abscess formation [5-7,18,19]. Vivano Med Abdominal Kit consists of three layers: 1. A perforated polyethylene sheet (interface layer) for covering the abdominal organs, which reduces adhesions, protects the bowels, and lowers fistula rate. 2. A polyurethane foam to be placed within the wound edges, in order to provide medial traction and help fluid drainage. 3. An adhesive film closes the wound airtight on the surface, it prevents fluid and heat loss and external contamination. The system is connected to vacuum source using special tubing set. However, the complication rate is lower and there is hardly available experimental data on optimal settings, the ideal advisable pressure level is still remains unknown.

It is hypothesized that the negative pressure conducted to the small bowels may elevate the risk of fistula formation, decreases tissue microcirculation and causes ischemia [3,21,23]. Clinical data show that the risk of fistula formation is around 0-15% [4,5]. The effect of NPWT on bowel surface has hardly been investigated. According to the few literature data NPWT may reduce small bowel wall blood flow, especially close to the visceral protective layer [20,21,23]. This complication might be more severe with the negative pressure applied [20,23]. Bjarnason et al. investigated the pressure distribution of NPWT in the abdomen has provided data, that the foam conducts 75% of applied pressure to the abdomen [19]. The negative pressure is significantly reduced on the bowel surface, but lowering the applied pressure does not further reduce pressure to bowels [3,19]. In our model, irrespectively of the suction applied (-50, -100, -150 mmHg) significantly lower values of negative pressure could be measured between the small bowels deep than near the protective sheet. Under the protective sheet the negative pressure values are significantly lower than above that.
Bjarnason et al. has found that outside the inner layer negative pressure diminishes [19]. It is similar to our data. Pressures are similar in the middle and in the lateral regions of the abdomen, supporting the theory that the visceral layer provides excellent pressure distribution.

The negative pressure is conducted well to the area underneath the protective sheet in the midline and to the superficial lateral region of the abdominal cavity. The pressure distributed with good efficacy to the inter-intestinal space in the midline and laterally also. These findings were most pronunced with application of 100 mmHg negative pressure.

5. Conclusions

Pressure distribution at different points of the abdomen could be evaluated during NPWT, which helps clinicians to choose the optimal settings. The organ protection layer provides excellent pressure distribution in the abdominal cavity. The extensive cover of the abdominal organs with this layer is highly advised. The favorable effect of Vivano Med Abdominal Kit has been proved in this animal model.

6. Patents

Author Contributions: "A.CS., K.P., N.N. and ZS.SZ. conceived and designed the experiments; A.CS., K.B., K.P., Á.D., M.B. and ZS.SZ. performed the experiments; Z.A.G., GY.J., A.CS. and ZS.SZ. analyzed the data; A.CS., ZS.SZ. and ZS.B. wrote the paper."

Conflicts of Interest:

"The authors declare no conflict of interest."

"The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results".

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