Effects of foam or gauze on sternum wound contraction, distension and heart and lung damage during negative-pressure wound therapy of porcine sternotomy wounds

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Abstract

The study was performed to compare the effects of negative-pressure wound therapy (NPWT) using gauze and foam on wound edge movement and the macroscopic appearance of the heart and lungs after NPWT. Sternotomy wounds were created in 6 × 70 kg pigs. Negative pressures of −40, −70, −120 and −160 mmHg were applied and the following were evaluated: wound contraction, distension and the macroscopic appearance of the heart and lungs after NPWT. Wound contraction was greater when using foam than gauze (3.5 ± 0.3 cm and 1.3 ± 0.2 cm, respectively, P < 0.01). The application of traction to the lateral edges of the sternotomy resulted in greater wound distention with foam than with gauze (5.3 ± 0.3 cm and 3.6 ± 0.2 cm, respectively, P < 0.001). After using foam, the surface of the heart was red and mottled, and lung emphysema and sometimes, lung rupture were observed. After using gauze, the organ surface had no markings. The study shows that foam allows greater wound contraction and distension than gauze. This movement of the wound edges may cause damage to the underlying organs. There is less damage to the heart and lungs when using gauze than foam.

Keywords: Animal model; Wound contraction; Experimental surgery; Heart rupture; Negative-pressure wound therapy; Sternotomy wound

1. Introduction

Negative-pressure wound therapy (NPWT) is a closed drainage system in which controlled suction is applied to a wound bed by a vacuum pump. Suction draws the wound edges together and contracts the wound.

In a sternotomy wound it is important that the sternum wound edges must be adequately contracted by a durable NPWT to maintain the sternum wound closed when the patient moves, coughs and breathes [1]. Furthermore, heart, lungs and bypass grafts are at risk of impaired function or organ rupture during NPWT. Recent publications have reported right ventricular rupture during NPWT in cardiac surgery [2, 3], which may be the result of the heart being drawn against the sharp edges of the sternum bone by the suction [4].

No study has yet been performed on the effects of different wound fillers in NPWT on sternum wound contraction and distention, or on the macroscopic effects on the heart and lungs after NPWT. Foam is presently the material of choice for the negative pressure treatment of poststernotomy mediastinitis. However, interest in delivering NPWT via gauze has increased [5]. Paglinawan et al. demonstrated that the use of either gauze or foam result in increased granulation tissue formation [6]. In a case series, the rate of wound healing under NPWT using gauze was similar to that for foam [5]. The advantages with gauze includes conformability and ease of application to large and irregular wounds [7]. Furthermore, gauze for NPWT has been shown to tamponade superficial bleeding [8]. Most importantly, there are no reported problems with ingrowth of granulation tissue into gauze in NPWT [9], minimizing the problems of wound bed disruption and mechanical tissue damage as foam is torn from the wound bed during dressing changes also pieces of foam may become stuck in the wound bed and if left in the wound could act as foreign bodies that may hinder wound healing.

The aim of the present study was to examine the effect of NPWT on sternum wound contraction, distention and the thoracic organs. A porcine sternotomy wound was used and the two different wound fillers (foam and gauze) were examined. NPWT was applied and the wound contraction, sternum wound distention and the macroscopic appearance of the heart and lungs was determined.
2. Materials and methods

2.1. Wound preparation

The study was approved by the Ethics Committee for Animal Research, Lund University, Sweden. Anesthesia and surgery were performed as described previously [10]. Sternotomy wounds were created in six 70 kg pigs. Two 6-0 steel wires for use in sternal closure were secured around the ribs on each side of the sternum and attached to a custom-made traction device. The traction device is connected to a force transducer and a recorder. Negative pressures of 0, –40, –70, –120 and –160 mmHg were applied. The wound width was measured at traction forces between 0 and 320 N, applied to the lateral edges of the sternotomy.

2.2. Experimental procedure

A sternotomy wound naturally gapes approximately 5–10 cm. The wound width was measured before and after suction was applied (wound contraction). Lateral traction (0 and 320 N) was applied to draw the wound edges apart and the wound width was measured. The macroscopic appearance of the heart and lungs were observed after the first course of experiments in each animal, which typically lasted for approximately two hours.

2.3. Calculations and statistics

Six pigs were used for the study. In each pig, a wound was either filled with RENASYS foam, VAC foam or gauze in a randomized order. For each of these three fillers, four different negative pressures and nine different force levels were applied. The reason for testing all these different parameters in the same animal was to get a well-controlled study. Calculations and statistical analysis were performed using GraphPad 5.0 software (San Diego, CA, USA). Statistical analysis was performed using the Kruskal-Wallis test with Dunn’s test for multiple comparisons. Significance was defined as $P<0.05$. Values are presented as means ± S.E.M.

3. Results

3.1. Wound contraction

Foam resulted in greater wound contraction than gauze (e.g. $3.5 ± 0.3$ cm for foam and $1.3 ± 0.2$ cm for gauze, $n=6$ and $P<0.01$ at –70 mmHg, Fig. 2). The two different types of foam (VAC® black GranuFoam® and RENASYS-F foam) resulted in similar wound contraction ($n=6$, $P=\text{n.s.}$, Fig. 3). The degree of wound contraction was similar for all the negative pressures studied (–40, –70, –120 and –160 mmHg, $n=6$, and $P=\text{n.s.}$, Fig. 2).

3.2. Wound distension

The foam filled wound opened up to a greater extent than the gauze filled wounds (e.g. $5.3 ± 0.3$ cm for foam and $3.6 ± 0.2$ cm for gauze, $n=6$ and $P<0.001$ at –70 mmHg, Fig. 3). The force vs. wound distension curves show that before lateral traction has been applied, foam filled wounds are more contracted than gauze filled wounds. When high levels of lateral force have been applied both foam and gauze filled wounds have opened up to a similar width. Taken together, gauze contracts the wound less, but resists sideways distortion more effectively than foam. In contrast, foam contracts the wound more, but is then susceptible to easier sideways distortion. The two different types of foam (VAC® black GranuFoam® and RENASYS-F foam) had similar effects ($n=6$, $P=\text{n.s.}$, Fig. 3). Different levels of negative pressure (–40, –70, –120 and –160 mmHg) allowed similar sideways distortion of the sternum wound edges ($n=6$ and $P=\text{n.s.}$, Fig. 3).

3.3. Macroscopic appearance of the thoracic organs

The heart and lungs were inspected after the first course of experiments in each animal. After NPWT using foam, the surface of the right ventricle of the heart was red and mottled, and lung contusion and emphysema were seen in all cases (Fig. 4). Lung ruptures were observed in two of the six animals. After NPWT using gauze, the organ surfaces...
had no markings, and the lungs were macroscopically unaffected.

4. Discussion

4.1. Wound contraction

The results show that the sternum wound contracts when NPWT is applied. Wound contraction by suction has been shown before in numerous studies on peripheral wounds [11, 12]. Mechanical effects on the wound edge resulting from NPWT are believed to be one of the fundamental mechanisms by which NPWT promotes healing. Wound contraction creates deformational forces at the wound-foam interface [13], which is thought to initiate a series of interrelated biological effects including the promotion of wound edge microvascular blood flow, the removal of bacteria and the stimulation of granulation tissue formation [13].

The results obtained in the present study are the first to show that foam results in greater wound contraction than gauze. This is probably because foam, which is an open cell structure material, allows greater compression and volume reduction than gauze, which is a woven and denser material. Gauze will thus resist contraction to a greater extent than foam. We found similar wound contraction using foam and gauze in a previous study on peripheral wounds [12]. It is likely that the reason for the discrepancy between the results in this study and the previous one is that the peripheral wound was a small, 5 cm diameter circular wound, where there was less compliance in the surrounding tissues whereas as the dimensions and ability for contraction of the sternotomy wound are substantially greater. In the smaller wound the difference in contraction between foam and gauze was less apparent. We know that transduction of negative pressure through foam or gauze is equivalent when studied in both small peripheral wounds [7] and in large volume sternotomy wounds and differences in pressure transduction does therefore not provide a plausible explanation for the difference in wound contraction by foam and gauze. Interestingly, most of the contraction seems to be observed at relatively low levels of pressure –40 to –80 mmHg and additional negative pressure does not increase contraction further.

Different amounts of wound contraction, offered by different types of wound fillers, may be desirable for different types of wounds. The advantage of greater wound contraction, such as that achieved with foam, may be massive stimulation of granulation tissue and, thus, faster healing. Large wound contraction may also be preferable in wounds dependent on reverse tissue expansion for secondary wound
Fig. 3. Wound distension upon the application of lateral force to draw apart the sternum wound edges. The wound was sealed for NPWT using gauze, RENASYS-F foam, or VAC foam. Negative pressures of 0, –40, –70, –120 and –160 mmHg were applied. The lateral wound edges were then drawn apart using the traction device and the wound width was measured. Results are presented as mean values ± S.E.M. It can be seen that foam allowed greater wound distension than gauze. NPWT, negative-pressure wound therapy.

3.2. Wound distension

The sternum wound edges move when the patient moves, coughs and breaths. NPWT is an effective treatment for poststernotomy mediastinitis, partly because it stabilizes the sternum, which allows early mobilization of the patient, and reduces the need for mechanical ventilation [14]. One crucial property of the therapy is therefore the resistance to external forces. The present study is the first to compare the effects of NPWT on sternum stability when using foam and gauze. When a lateral mechanical force is applied to the sternum edges so as to open the wound, the degree of distension is greater when using foam than when using gauze. The reason for the greater distension by foam is probably that this is a spongy open cell structure material that will spring out to a large volume as the wound edges are pulled apart. Gauze on the other hand is a woven material that does not have these spongy properties.

4.2. Wound distension

The sternum wound edges move when the patient moves, coughs and breaths. NPWT is an effective treatment for poststernotomy mediastinitis, partly because it stabilizes the sternum, which allows early mobilization of the patient, and reduces the closure, e.g. for upper and lower limb compartment syndrome. However, when NPWT is applied to a wound that cannot be closed (e.g. due to an enlarged heart) a lower degree of wound contraction, such as that obtained with gauze, may be preferable. Also, a lower degree of wound contraction may result in a lower risk of the underlying organs becoming wedged between the sternal edges: this may reduce the risk of damage to the heart and lungs. Furthermore, patient pain may be reduced by minimizing the mechanical effects on the wound edge.

4.3. Effects on heart and lungs

After NPWT using foam, the surface of the right ventricle of the heart was red and mottled, and lung contusion and emphysema were observed in all cases. Lung rupture was
the wound edges as the suction is applied and the foam is compressed, exposing them to the sharp edges of the sternum. The present results showing damage to heart and lungs during NPWT is in line with previous clinical evidence. Approximately 4% of the patients treated with NPWT for poststernotomy mediastinitis die from heart rupture [13]. In November 2009, the Food and Drug Administration (FDA) filed an alert [15] and the importance of protecting the heart and other exposed organs is emphasized in international scientific literature [13].

5. Conclusions

The study shows that foam allows greater wound contraction and distension than gauze. It is probable that the application of NPWT will be tailored to different wound types in the future. Foam has the advantage of considerable wound contraction, and may be effective in the stimulation of granulation tissue formation, thus accelerating healing. Gauze has the advantage of causing minimal damage to the underlying organs, e.g. lung rupture and epicardial bleeding. Also, since gauze causes less contraction of the wound than foam, gauze may be preferable when the underlying organs are too large to enable primary closure (e.g. enlarged heart). Further clinical evaluation would be required to establish whether foam or gauze is the best clinical option for the negative pressure treatment of open sternotomy wounds.

References


