Influence on pressure transduction when using different drainage techniques and wound fillers (foam and gauze) for negative pressure wound therapy

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ABSTRACT
Pressure transduction to the wound bed in negative pressure wound therapy (NPWT) is crucial in stimulating the biological effects ultimately resulting in wound healing. In clinical practice, either foam or gauze is used as wound filler. Furthermore, two different drainage techniques are frequently employed. One involves the connection of a non-perforated drainage tube to the top of the dressing, while the other involves the insertion of perforated drains into the dressing. The aim of this study was to examine the efficacy of these two different wound fillers and drainage systems on pressure transduction to the wound bed in a challenging wound (the sternotomy wound).

Six pigs underwent median sternotomy. The wound was sealed for NPWT using different wound fillers (foam or gauze) and drainage techniques (see earlier). Pressures between 0 and −175 mmHg were applied and the pressure in the wound was measured using saline-filled catheters sutured to the bottom of the wound (over the anterior surface of the heart) and to the side of the wound (on the thoracic wall). The negative pressure on the wound bed increased linearly with the negative pressure delivered by the vacuum source. In a dry wound, the pressure transduction was similar when using the different wound fillers (foam and gauze) and drainage techniques. In a wet wound, pressure transduction was better when using a perforated drainage tube inserted into the wound filler than a non-perforated drainage tube connected to the top of the dressing (−116 ± 1 versus −73 ± 4 mmHg in the wound at a delivered pressure of −125 mmHg for foam, P < 0·01), regardless of the type of wound filler. Gauze and foam are equally effective at delivering negative pressure to the wound bed. Perforated drainage tubes inserted into the wound filler are more efficient than a non-perforated drainage tubes connected to the top of the dressing. The choice of drainage technique may be particularly important in wounds with a large volume of exudate.

Key words: Animal model • Experimental surgery • Negative pressure wound therapy • Pressure transduction • Sternotomy wound • Wound fluid drainage • Wound healing

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INTRODUCTION

Negative pressure wound therapy (NPWT) has remarkable effects on the healing of chronic and difficult wounds (1,2). The technique entails the application of negative pressure to a sealed, airtight wound. NPWT promotes a moist wound healing environment (3), increases granulation tissue formation (4), removes edema (5), stimulates cell-mediated immune response (6), decreases the permeability of blood vessels (7) and stimulates angiogenesis and blood flow to the wound margins (8,9). These biological effects depend on the transduction of a negative pressure to the wound bed. Pressure transduction may be affected by the type of wound filler and drainage technique. Commonly used wound fillers during NPWT are open-cell polyurethane foam or gauze. We recently reported that foam and gauze provide similar pressure transduction to the wound bed when examining a small, peripheral wound (10). However, the effects may be different in a more challenging wound with a large wound cavity and large volumes of exudate, such as the sternotomy wound.

In clinical practice, two different drainage techniques are frequently employed. One involves the connection of a non-perforated drainage tube to the top of the dressing, while the other involves the insertion of perforated drains into the dressing. No study has yet been performed to examine the efficiency of these different drainage techniques in NPWT.

The aim of this study was to examine the influence of different wound fillers (foam and gauze) and drainage techniques on pressure transduction to the wound bed during NPWT. This study was performed using a porcine sternotomy wound model, which is a large and challenging wound since it has a high volume. The wound was sealed for NPWT using the wound fillers and drainage techniques described earlier. Wound bed pressure was measured when negative pressures between 0 and −175 mmHg were applied.

MATERIALS AND METHODS

Animals

A porcine sternotomy wound model was used. Six domestic landrace pigs with a mean weight of 70 kg were fasted overnight with free access to water. This study was approved by the Ethics Committee for Animal Research, Lund University, Sweden. The investigation complied with the ‘Guide for the Care and Use of Laboratory Animals’ as recommended by the US National Institutes of Health and published by the National Academies Press (1996). Anesthesia and surgery were performed as described earlier (11).

Experimental setup

A midline sternotomy wound was created. Saline-filled pressure catheters were sutured to the wound filler, which was then placed on the bottom of the wound (over the anterior surface of the heart) and to the side of the wound (on the thoracic wall) (Figure 1). The pressure catheters were connected to a calibrated custom-built pressure gauge. The wound was filled with saline-soaked AMD gauze (RENASYS-G, Smith & Nephew, St. Petersberg, FL) or one of two kinds of foam: VAC foam size 18 × 12.5 × 3.3 cm (VAC®Black GranuFoam®, KCI, San Antonio, TX) or RENASYS-F foam, 20 × 12.5 × 3 cm (RENASYS-F, Smith & Nephew, St. Petersberg, FL). One layer of foam or two rolls of gauze were placed between the sternal edges. A second layer of foam or two rolls of gauze were placed over the first layer, between the soft tissue wound edges, and secured to the surrounding skin.

Drainage was applied using two different techniques. The first involved connecting a non-perforated drainage tube (T.R.A.C. pad®, KCI, San Antonio, TX) to the top of the dressing and adhesive drape (see later). The second involved the insertion of two perforated drains (round 19 French silicone drain when using foam and flat Jackson-Pratt drain when using gauze) into the wound filler. One drain was placed between two layers of wound filler (foam or gauze) and the other was placed at the top of the wound filler. The two drains were joined with a Y-connector. Neither the perforated drains nor the T.R.A.C. pad® had working air bleeds to clear fluid from the lines. The wound was sealed with a transparent adhesive drape and connected to a custom-built vacuum source. The vacuum source was set to deliver negative pressures of 0, −50, −75, −100, −125, −150 and −175 mmHg. The wounds were either ‘dry’ where normal, small levels of exudate and blood were removed from the wound or ‘wet’ where the wound was filled by injecting with 100 ml saline using a syringe.

Key Points

- negative pressure wound therapy (NPWT) has remarkable effects on the healing of chronic and difficult wounds
- we recently reported that foam and gauze provide similar pressure transduction to the wound bed when examining a small, peripheral wound
- however, the effects may be different in a more challenging wound with a large wound cavity and large volumes of exudate, such as the sternotomy wound
- in clinical practice, two different drainage techniques are frequently employed
- one involves the connection of a non-perforated drainage tube to the top of the dressing, while the other involves the insertion of perforated drains into the dressing
- no study has yet been performed to examine the efficiency of these different drainage techniques in NPWT
- the aim of this study was to examine the influence of different wound fillers (foam and gauze) and drainage techniques on pressure transduction to the wound bed during NPWT
- a porcine sternotomy wound model was used
to simulate highly exuding wounds. Both kinds of wound fillers and drainage techniques were applied to both dry and wet wounds.

Taken together, the wound was filled with either saline-soaked AMD gauze or one of two kinds of foam: VAC foam or RENASYS-F foam. Drainage was applied using two different techniques. The first involved connecting a non-perforated drainage tube to the top of the dressing and adhesive drape. The second involved the insertion of two perforated drains into the wound filler. For each dressing application, the vacuum source was set to deliver negative pressures of 0, −50, −75, −100, −125, −150 and −175 mmHg. The order in which the different dressings and negative pressures were applied was varied in a randomised way.

Calculations and statistics

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 ± SEM.

RESULTS

Negative pressures between −50 and −175 mmHg was applied to a sternotomy wound, which is a large and challenging wound since it has a high volume. The pressure was measured at both the bottom and the side of the wound. The pressure in the wound increased linearly with the negative pressure supplied by the vacuum source at both locations (Figure 2). The pressure in the wound was only slightly lower than the negative pressure supplied by the vacuum source (e.g. the wound bed pressure was $−122 ± 1$ mmHg in a dry wound when a pressure of $−125$ mmHg was applied, using foam and perforated drains inserted into the wound filler; Figure 3). Evidently, negative pressure transduction from the vacuum source to both deep and superficial parts of the wound is effective even in large volume wounds.
Figure 2. Type of wound filler. Comparison of pressure transduction to the wound bed during NPWT when using different wound fillers (VAC foam, RENASYS-F foam and gauze). NPWT was applied using a drain connected to the top of the dressing (T.R.A.C. pad®). The vacuum source was set to deliver negative pressures between 0 and −175 mmHg and the wound bed pressure was measured on the side of the wound (upper panels) and at the bottom of the wound (lower panels). The left panels show the results for a dry wound and the right panels show the results for a wet wound, simulated with 100 ml saline. Values are given as means ± SEM from six experiments. It can be seen that pressure transduction to the wound bed is similar for foam and gauze, regardless of whether the wound is wet or dry. Similar results are obtained when using a drain connected to the top of the dressing or perforated drains inserted into the wound filler (not shown).

Wound filler
The effect of the type of wound fillers (foam or gauze) on pressure transduction is shown in Figure 2. Foam and gauze offered similar pressure transduction from the vacuum source to the wound (e.g. −122 ± 1 for foam and −118 ± 1 mmHg for gauze, in a dry wound treated with NPWT at −125 mmHg, \( P = \text{n.s.}, n = 6 \)). Furthermore, the two different types of foam (VAC® black GranuFoam® and RENASYS-F foam) gave similar wound bed pressures (\( P = \text{n.s.}, n = 6 \)).

Drainage technique
The effect of the type of drainage techniques on pressure transduction is shown in Figure 3. Pressure transduction in wet wounds was better when using perforated drains inserted into the wound filler, than when using a non-perforated drain connected to the top of the dressing (e.g. −116 ± 1 versus −73 ± 4 mmHg in the wound at an applied pressure of −125 mmHg for foam, \( P < 0.01, n = 6 \)). Pressure transduction in dry wounds was similar when using the two different drainage techniques (\( P = \text{n.s.}, n = 6 \)). The effects of the alternative drainage techniques were the same when either foam or gauze was used as the wound filler.

DISCUSSION
Pressure transduction to the wound bed during NPWT is crucial to ensure the biological effects in the wound edge tissue leading to enhanced granulation tissue formation and healing. The type of drainage system and wound filler could affect pressure transduction to the wound bed. In this study, a porcine sternotomy wound model was used since this is a large and challenging wound that has a high volume. We examined the pressure transduction from the vacuum source to the wound bed through clinically commonly applied wound fillers (foam or gauze) and drainage techniques (a non-perforated drain connected to the top of the dressing or perforated drains inserted into the dressing).

The sternotomy wound
The results show that NPWT is effective at delivering negative pressure to the sternotomy wound edges. The pressure on the wound bed
Figure 3. Type of drainage technique. Comparison of pressure transduction to the wound bed during NPWT when using different drainage techniques: perforated drains inserted into the wound filler and a non-perforated drain connected to the top of the dressing (T.R.A.C. pad®). The vacuum source is set to deliver negative pressures between 0 and $-175$ mmHg and the wound bed pressure is measured on the bottom of the wound and on the side of the wound. The panels on the left show the results for a dry wound and those on the right the results for a wet wound (100 ml saline). Values are given as means ± SEM from six experiments. It can be seen that in a wet wound (right panels), the pressure transduction is better when using perforated drains inserted into the wound filler (drain) than a non-perforated drainage tube connected to the top of the dressing (T.R.A.C. pad®).

increased linearly with the negative pressure delivered by the vacuum source. Similar results have been shown earlier by others (11,12). The pressure on the wound bed is slightly lower than the negative pressure applied. The pressure drop may be greater in a large-volume cavity wound with high levels of wound fluid, such as a sternotomy or abdominal wound, than in a small, dry wound. The sternotomy wound in a 70 kg pig model was therefore chosen for this study to mimic a challenging wound.

Type of wound filler
The efficiency of pressure transduction to the tissue from the vacuum source depends on the structure or nature of the wound filler. Previous publications have reported on the transmission of negative pressure to the wound bed (12–14,10). It has been shown that interface dressings influence the delivery of negative pressure to the tissue (12–14). We recently reported that foam and gauze provided similar pressure transduction to the wound bed when examining a small, peripheral wound in a porcine model (10). This study is the first to compare pressure transduction through different wound fillers in a large, deep, and high-output wound. The results confirm that the choice of wound filler (foam or gauze) does not affect the pressure transduction to the wound bed.
Drainage technique
Pressure transduction to the wound bed depends on the type of drainage. This study shows that when a non-perforated drain is connected to the top of the dressing in a wet wound, pressure transduction is not as efficient as when perforated drains are inserted into the wound filler. There may be several reasons for this. Firstly, when drains are inserted inside the wound filler, the wound fluid can be drained from all directions surrounding the end of the tube, while fluid can only be drawn in one direction when the tube is connected to the top of the dressing. Secondly, a perforated tube has many holes through which wound fluid can enter, while a non-perforated tube has only one. Thirdly, when the drainage tube is inserted inside the wound filler, the wound fluid does not need to be drawn through the entire thickness of the wound filler, but when the drain tube is connected to the top of the dressing, fluid has to travel a longer distance to reach the end of the tube.

Amount of wound fluid
The choice of drainage technique is most important in wounds with large amounts of exudate. Wound fluid prevents suction through the wound filler. This study was performed using saline to simulate wound fluid and the wounds were studied for periods of up to 2 hours rather than 2 days. In the clinical setting, wound fluid also contains blood and debris, which have a higher density than saline. The clinical situation may therefore be more complicated, as coagulated blood and other debris may clog the drainage tubes or the wound filler. Nevertheless, for high-output wounds it may be advantageous to have a perforated drain with numerous drainage holes. On the other hand, one advantage of the drainage tube being connected to the top of the dressing is that it is easy and quick to apply in the clinical setting.

Clinical implications
This study shows that perforated drains that are inserted into the wound filler provides better pressure transduction than when a non-perforated drain is connected to the top of the dressing. This is preclinical data and the efficacy of different drainage techniques have, to our knowledge, not yet been assessed clinically. Based on the findings from this study, the choice of drainage technique may be especially important in large wounds with high wound fluid output volumes, such as sternotomy wounds and abdominal wounds. For smaller wounds and dry wounds, the drainage technique probably does not play a major role. Clinically, we usually apply two drains in sternotomy wounds to obtain maximal wound fluid removal and eliminate the risk of blood coagulates and debris obstructing the tubes. One drain is usually placed between the two layers of wound filler, at the transition between the sternum bone and soft tissue. This drain will remove most of the secreted wound fluid. The upper part of the wound filler then remains reasonably dry. The other drain is located on the top of the wound filler. This drain will deliver negative pressure, resulting in contraction and stabilisation of the wound edges.

CONCLUSIONS
Pressure transduction to the wound bed during NPWT depends on the drainage technique while the type of wound filler, foam or gauze, has no effect. Perforated drains inserted into the wound filler is more efficient than a non-perforated drainage tube connected to the top of the dressing. This effect is most evident in a wet wound, and the choice of drainage technique may be particularly important in high-output wounds. Pressure transduction to the wound bed is crucial to assure drainage of excess wound fluid and debris, and stimulates biological effects in the wound edge tissue ultimately resulting in healing.

ACKNOWLEDGEMENTS
This study was funded by the Åke-Wieberg Foundation, the Magn Bergvall Foundation, the Swedish Medical Association, the Royal Physiographic Society in Lund, the Crafoord Foundation, the Swedish Heart–Lung Foundation, the Swedish Hypertension Society and Smith & Nephew Wound Management. We thank Robin Martin (Smith & Nephew) for review of the manuscript.

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