Negative pressure wound therapy using gauze or polyurethane open cell foam: effects on pressure transduction and wound contraction

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Abstract

Negative pressure wound therapy (NPWT), also known as topical negative pressure (TNP), is widely used to manage wounds and accelerate healing. NPWT has thus far been delivered mainly via open cell polyurethane foam, but increasing interest has been directed towards delivering NPWT via gauze. In the present study, a porcine wound model was used to measure pressure transduction and wound contraction in wounds filled with either polyurethane foam or gauze. Negative pressures between -50 and -175 mm Hg were applied in -25 mm Hg increments. Wound bed pressure was measured using a saline filled catheter sutured to the bottom of the wound. The contraction of the wound edges was also determined. For both fillers, wound bed negative pressure increased linearly with delivered vacuum with little deviation from set pressure (correlation coefficient 0.99 in both cases). Similar wound contraction was observed when using foam and gauze. The most prominent contraction was observed in the range 0 to -50 mmHg with greater vacuum only producing minor further movement. In conclusion, gauze and foam are equally effective at delivering negative pressure to the wound. NPWT, via both foam and gauze, results in mechanical deformation of the wound, known to stimulate granulation tissue formation.
INTRODUCTION

Negative pressure wound therapy (NPWT), vacuum assisted closure (VAC®) or topical negative pressure (TNP) are descriptions given to a therapy that has significantly changed the way clinicians manage a wide range of chronic or acute cutaneous and soft tissue wounds.\(^1,2\) Widespread adoption of NPWT over the last 10 years has been driven largely through favourable clinical experience rather than randomised clinical studies or thorough scientific understanding.\(^3\) Described in one form by Chariker\(^4\) but largely popularised through the work of Argenta and Morykwas,\(^5,6\) NPWT typically employs a vacuum which is applied to tissue beneath an adhesive transparent film dressing almost invariably covering a wound-filler material of some description.

One of the fundamental effects of negative pressure delivery at the wound bed is widely believed to be the induction of mechanical deformation of the tissue. Macromechanical effects, such as wound contraction, are typically distinguished from micromechanical effects which are due to the interaction of tissue and dressing at a microscopic level.\(^7\) These actions are thought to result in a further cascade of inter-related biological effects including the promotion of peri-wound blood flow, removal of bacteria, and a stimulation of granulation tissue formation (as originally defined in \(^5,6\) and reviewed in \(^7\)).

Currently, the most commonly used wound-filler material is an open cell polyurethane foam.\(^2\) However, granulation tissue may grow into the cells of polyurethane foam, causing pain at dressing changes and disturbance of the re-epithelialisation process.\(^8-12\) Recently other wound fillers such as medical gauze have become more widely
commercially available\textsuperscript{3,13} and these are believed to avoid the issues of tissue ingrowth, however there have been no reports of comparisons in the transduction of pressure and wound contraction between gauze and foam.

In the present study, an \textit{in vivo} porcine wound model was developed to represent the large surface area, relatively shallow wounds typical of those that might result from traumatic injury or decubitus ulcers which are frequently treated with NPWT. The delivery of negative pressure to the bottom of the wound and the mechanical effect of NPWT on wound-edge tissue contraction was compared over a range of clinically relevant negative pressures when either open cell polyurethane foam or medical gauze were used as wound filler materials.
Materials and Methods

Animal care
Ten domestic Landrace pigs with a mean body weight of 70 kg were fasted overnight with free access to water. The study was approved by the Ethics Committee for Animal Research, Lund University, Sweden, which conforms to the principles outlined in the Declaration of Helsinki. All of the animals received humane care in compliance with the Guide for the Use and Care for Laboratory Animals as promulgated by the council of the American Physiologic society and published by the National Institutes of Health, 1985.

Anaesthesia and Surgery
An intramuscular injection of ketamine (Ketaminol vet™ 100mg/ml; Farmaceutici Gellini S.p.A, Aprilia, Italy) 15mg/kg body weight, in combination with midazolam (Dormicum, 1 mg/ml, Roche, Stockholm, Sweden) at a dosage of 0.1 mg/kg and xylazine (Rompun vet.™ 20mg/ml; Bayer AG, Leverkusen, Germany) 2mg/kg, was used for premedication. Anaesthesia was induced by continuous intravenous infusion of propofol (Diprivan™ 20 mg/ml; Astra Zeneca, Sweden) at a dosage of 0.1 to 0.2 mg/kg/min in combination with intermittent fentanyl (Leptanal™; Lilly, France) and atracurium besylate (Tracrium™; Glaxo, Täby, Sweden) at doses of 0.02 µg/kg and 0.2 to 0.5 mg/kg, respectively. A ventilator (Servo-Ventilator 900, Elema-Schönander, Sweden) was used for mechanical ventilation. The same settings were used for all animals: volume-controlled, pressure-regulated ventilation, 8.5 L/min, 15 breaths /min, and an inhaled oxygen fraction of 35%. A continuous Ringers acetate infusion was maintained throughout the experiment and a supra-pubic catheter was
inserted into the urinary bladder. Animals were laid on the side and a single circular full thickness wound of 5 cm diameter was created on the para-vertebral area of the back, penetrating into the muscle. Data from foam or gauze filled wounds were collected from the same wounds but the order of measurement was varied. Wounds were kept moist between measurements by means of saline soaked gauze. Temperature was monitored and maintained at 37°C. Animals were kept fully anaesthetised for 12 to 14 hours and subsequently euthanized with a lethal dose of potassium injected into the heart.

**Measurement system**

To measure negative pressure at the wound bed, the tip of a saline filled pressure catheter was sutured to the centre of the bottom of the wound (Figure 1A). The pressure catheter was then connected to a custom built pressure gauge on which the pressure at the bottom of the wound could be monitored. The pressure gauge was calibrated prior to use (Uniflow, model 59-UCAL, Baxter Healthcare Corporation, Edward Critical-Care Division, Irvine, CA, USA).

Negative pressure was delivered by a specially designed Test rig (Figure 1B). Each rig comprised linear drive vacuum pumps and associated flow meters, vacuum sensors, solenoid and proportional control valves and a general purpose microprocessor board connected to the sensors, valves and pumps through a bespoke input/output board. System operation, adjustment/calibration and data-logging were managed by a pair of laptop computers connected to the general purpose microprocessor board via RS232C and terminal emulators. The apparatus was configurable to control and measure from a variety of source locations, at data-log
rates from 0.25 to 60 seconds, and at pressure/vacuum levels between +50 and -200 mmHg. Data was logged in text files and imported into Microsoft Excel for tabulation and graphing. Sensors were calibrated before and after each series of tests.

**Application of negative pressure**

Wound filler (polyurethane foam or gauze) was placed in the wound cavities over the pressure catheter. Polyurethane foam (VAC® black GranuFoam®, KCI, San Antonio, USA) was applied by cutting the foam to the correct shape according to the manufacturer’s clinical protocol. Drainage tubes were connected to the foam dressing by means of a TRAC®-pad (KCI, San Antonio, USA). Gauze (Kerlix, Tyco, Gosport, UK) was moistened with saline and placed in the bottom of the wound. A Jackson-Pratt wound drain was placed within the wound cavity along with the moistened gauze. This method of NPWT application is also known as the Chariker-Jeter method.  

An investigation was also carried out into the effect of placing an impregnated gauze non-adherent dressing (Cuticerin, Smith & Nephew, Hull, UK) as a wound contact layer between the wound filler and the wound bed containing the pressure measurement catheter. Wound contact layers are commonly applied in clinical practice to prevent adhesion of the wound tissue to the wound filler. Wound contact layer was applied prior to application of both wound fillers. Additional evaluations were undertaken to assess whether placement of the drain affected the transmission of negative pressure to the wound bed. The wound drain was applied within the gauze (as shown in Figure 2), beneath the gauze and on top of the gauze.
In all cases drainage tubes were connected to the wound filler material and the wound was then sealed with transparent adhesive drape (OpSite Flexigridd™ Smith & Nephew, Hull, UK). The drainage tubes were connected to the same Test rig vacuum source as described above, which was set to deliver negative pressures of -50, -75, -100, -125, -150, and -175 mmHg.

**Measurement of wound contraction**

To quantify the degree of tissue contraction, eight ink marks were tattooed around the margins of each wound (see Figure 2) with the aid of a template to position the marks at a defined distance from the wound edge. To calculate the area of the wound the distance across the open wound between opposite marks was recorded and the area calculated in mm². Measurements were taken immediately following dressing application and after the application of negative pressure in -25 mm Hg increments.

**Statistical Evaluation**

To assess the correlation between set pressures and delivered pressures, correlation coefficient values were calculated. To assess whether application of negative pressure caused a reduction in wound size when treated with either foam or gauze, a Wilcoxon Signed Rank test was used and the Hodges-Lehman estimates of median differences and corresponding 95% confidence intervals were calculated. A linear regression model was used to compare the reduction in wound size with incremental changes in negative pressure.
Results

Pressure transduction

The transmission of negative pressure to the bottom of the wound through the two
different wound filling materials (gauze and polyurethane foam) was assessed. Figure
2 shows the appearance of wounds filled with either foam or gauze and subjected to -
50 mmHg of negative pressure. Figure 3 shows the relationship between the pressure
set on the Test rig vacuum device and the pressure measured at the bottom of the
wound. In both polyurethane foam and gauze filled wounds, the set pressure and
detected pressure increased in a linear fashion. Deviation of the measured wound
pressure from the set pressure was minimal (correlation coefficient = 0.99 for both
materials), indicating effective pressure transmission by both foam and gauze.

There was no difference in the relationship between set pressure and the pressure
measured on the bottom of the wound when the Jackson-Pratt drain was applied
within the gauze, beneath the gauze or on top of the gauze (data not shown).

Finally, there was no diminution of wound bed pressure for gauze or foam filled
wounds when an impregnated non adherent gauze wound contact layer (Cuticerin)
was placed underneath the wound filler, on the bottom of the wound (Table 1).

Wound contraction

The wounds, filled with either gauze or foam, changed in appearance when a negative
pressure of –50 mm Hg was applied (Figure 2). In both cases the wound filler
hardened under negative pressure. A significant decrease in wound size was observed
upon application of negative pressure (both for gauze and foam-filled wounds $p<0.05$). Upon application of $-125$ mm Hg, the foam-filled wounds contracted to 92% and gauze-filled wounds contracted to 95% of the original size (non-significant $p>0.05$). The relationship between applied negative pressure and the decrease in wound area is shown in Figure 4. For both materials, the greatest relative contraction was observed between 0 and -50 mm Hg with only minor further contractions at higher negative pressures.
Discussion

Negative pressure wound therapy has remarkable effects on wound healing.}\(^2,^{14}\) A number of studies have examined the mechanisms involved in NPWT and have shown evidence for reduced bacterial counts, increased wound edge microvascular blood flow and granulation tissue formation as components of NPWT.\(^6,^{15-17}\)

It is believed that the beneficial effects of NPWT on wound healing rely on pressure transmission to the wound and the mechanical deformation of the wound edge tissue that the suction force creates. We have examined these parameters and compared the performance of two different wound filling materials; open cell polyurethane foam, which is a well documented wound filler frequently employed in the clinic,\(^5\) and medical gauze, which is an alternative wound filler used earlier in the development of NPWT\(^4\) but which has only recently become commercially available for the application of NPWT in clinical practice.\(^3,^{13}\)

The results from the present study show that pressure transduction to the bottom of the wound is indistinguishable when using polyurethane foam or gauze. Previous publications have reported on the transmission of negative pressure to the wound bed.\(^18-20\) It has been shown in the thoracic cavity that pressure transmission is dependent on direct communication with the vacuum source.\(^19\) The wound model used in the current study is a superficial wound in which the entire wound bed has contact with the wound filling material, which is crucial in order to achieve an even distribution of pressure to the wound bed.
The effect of different wound contact dressings on the negative pressure transmission was examined by Jones et al.\textsuperscript{18} and Petzina et al.\textsuperscript{20} Pressure drops with the interposition of wound contact layers with different degrees of occlusion. In the present study, paraffin impregnated wide meshed gauze (Cuticerin), was used. The wound bed pressure did not diminish in the presence of this wound contact layer with either foam or gauze. This may be because this dressing is a relatively ‘open’ wound contact material. For the optimal performance of NPWT therapy, it may be important to use a wound contact layer that has similar physical properties and does not hinder the transduction of negative pressure to the wound bed.

The wound filling materials tested in the current study show adequate pressure transduction to the bottom of the wound, which is crucial in order to assure drainage of excess wound fluid and debris and also to cause deformation of the wound edge tissue. In the present study we also investigated to what extent NPWT caused wound edge tissue deformation, namely the macro-mechanical effects. NPWT via foam was compared to that via gauze. The results show that both foam and gauze elicited similar levels of wound contraction.

It is believed that the beneficial effects of NPWT on healing may depend on these macromechanical effects and the shearing forces at the dressing-wound interface. Mechanical stress is known to promote the expression of growth factors (e.g. vascular endothelial growth factor and fibroblast growth factor-2) and to stimulate granulation tissue formation and angiogenesis\textsuperscript{21-23}. In a computerized model of vacuum-induced wound bed micro-deformation, most elements were stretched five to twenty percent
by negative pressure, which is similar to in vitro strain levels shown to promote cellular proliferation.\textsuperscript{24}

In the present study, the greatest change in wound area was observed between 0 and -50 mmHg, with higher levels of negative pressure only resulting in slight incremental decrease in wound size. Similar findings were shown in a study by Isago et al\textsuperscript{25} carried out in rat wounds and using polyurethane foam. Negative pressures of -50, -75 and -125 mm Hg caused similar reduction in wound area. Furthermore, in a pig sternotomy wound model\textsuperscript{26}, the wound contraction upon NPWT application was similar in wounds treated with low (-50 to -100 mmHg) and high (-150 to -200 mmHg) negative pressures. Interestingly, we showed that at low negative pressures the wound filler (in this case foam) was more dynamic and adapted better to the shape of the wound. Taken together, low levels of negative pressure are sufficient to induce macromechanical deformation during NPWT therapy.

Still, the level of negative pressure for optimal wound healing is not known. Morykwas et al.,\textsuperscript{17} suggest that the stimulation of granulation tissue is related to the level of negative pressure, although only the extremes: -25 mm Hg and -500 mmHg, used in addition to -125 mmHg were reported. When measuring wound edge microvascular blood flow, the NPWT effects are dependent on the wound edge tissue composition.\textsuperscript{16, 27} Higher levels of negative pressure (approximately -100 mmHg) are needed in stiff wound tissue, e.g. muscle, while lower levels of negative pressure (approximately -75 mmHg) may be more favourable in soft tissue wounds, e.g. subcutaneous fat. Further studies are needed in order to elucidate in detail which
negative pressure level is optimal in order to achieve maximal granulation tissue formation in different types of wound.

We show here similar macro-mechanical wound properties when using foam and gauze. Foam is a frequently employed wound filler material in clinical practice. It has had excellent clinical outcomes and has an open pore structure for optimal pressure transduction. It also has a large capacity to remove fluid. On the other hand, growth of granulation tissue into the pores of the foam, is a recognised clinical problem and many clinicians use a wound contact layer to prevent tissue growth into foam which causes tissue disruption on removal. Gauze may be advantageous in that it is capable of transducing negative pressure to the wound bed and aiding fluid removal and it is reported not to be susceptible to tissue in growth. Gauze may have a second utility over foam in that foam needs to be cut to the size of the wound, whereas you do not need to cut gauze as precisely making it easier to apply the filler.

In conclusion, this study shows that pressure transduction to the wound, during NPWT, is performed equally effectively using foam or gauze as the wound filler material. NPWT causes a suction force that result in wound edge tissue deformation. It is believed that the beneficial effects of NPWT therapy on healing may depend in part on these mechanical effects and the shearing forces at the filler-wound interface. Similar wound edge contraction was observed at low (-50 mmHg) and high (-175 mmHg) levels of negative pressure. Further studies are needed in order to elucidate in detail which negative pressure level is optimal in order to achieve maximal new tissue formation in different types of wounds.
REFERENCES


Acknowledgments

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### Tables

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**Table 1. Effect of using wound contact layer on transmission of Negative pressure to the wound bed.** The relationship between set pressure and actual pressure delivered to the wound bed was assessed as described in Materials and Methods. Wound contact layer (WCL) was applied prior to application of the wound filler (gauze or foam) and delivered pressure measured (n=3 ±SD).
Figure 1. Measurement of wound bed negative pressure. (A) Full thickness acute wounds were created as described in Materials and Methods and a saline filled catheter sutured into the wound bed (inset enlarged view of catheter). (B) Custom designed vacuum test rig device described in Materials and Methods.

Figure 2. NPWT delivery through open cell polyurethane foam or gauze
Identical wounds were filled with either open cell polyurethane foam or saline moistened gauze. Negative pressure was applied through a generic vacuum device as described in Materials and Methods. Images were taken before (0 mmHg) and after negative pressure was applied (here -50 mmHg). The numbered circumferential markings were used to quantify the extent of tissue contraction.

Figure 3. Negative pressure transmission to the wound bed through either gauze or polyurethane foam. The relationship between set pressure and actual pressure delivered to the wound bed was assessed as described in Materials and Methods. Delivery pressure transmitted through gauze (closed points) or polyurethane foam (open points) to the wound bed is shown (n≥10 except 25 mmHg where n≥5 ±SD).

Figure 4. Tissue contraction on application of NPWT using either polyurethane foam or gauze.
Wounds were filled as described with either gauze (closed points) or polyurethane foam (open points) and negative pressure applied from -50 -175 mm Hg at -25 mm Hg increments as described in Materials and Methods. Wound area was calculated (in mm$^2$) at each pressure setting (n=7 ± SD)).
Figure 2.
Figure 3.
Figure 4.