The paradox of negative pressure wound therapy – in vitro studies

Nicolas Kairinos*, Michael Solomons, Donald A. Hudson

Department of Plastic and Reconstructive Surgery, Groote Schuur Hospital and University of Cape Town, South Africa

Received 9 April 2008; accepted 10 August 2008

SUMMARY

Negative-pressure wound therapy (NPWT) has revolutionised wound care. Yet, it is still not understood how hypobaric tissue pressure accelerates wound healing. There is very little reported on the relevant physics of any substance subjected to suction in this manner. The common assumption is that applying suction to a substance is likely to result in a reduction of pressure in that substance. Although more than 250 research articles have been published on NPWT, there are little data verifying whether suction increases or decreases the pressure of the substance it is applied to. Clarifying this basic question of physics is the first step in understanding the mechanism of action of these dressings.

In this study, pressure changes were recorded in soft plasticene and processed meat, using an intracranial tissue pressure microsensor. Circumferential, non-circumferential and cavity NPWT dressings were applied, and pressure changes within the underlying substance were recorded at different suction pressures. Pressures were also measured at 1 cm, 2 cm and 3 cm from the NPWT placed in a cavity.

In all three types of NPWT dressings, the underlying substance pressure was increased (hyperbaric) as suction pressure increased. Although there was a substantial pressure increase at 1 cm, the rise in pressure at the 2-cm and 3-cm intervals was minimal.

Substance pressure beneath all types of NPWT dressing is hyperbaric in inanimate substances. Higher suction pressures generate greater substance pressures; however, the increased pressure rapidly dissipates as the distance from the dressing is increased. The findings of this study on inanimate objects suggest that we may need to review our current
Negative-pressure wound therapy (NPWT) has been hailed by some as the greatest advance in wound care since antimicrobial therapy. Its uses have expanded dramatically since it was popularised in 1997 by Morykwas and Argenta\textsuperscript{1,2} and encompass many different disciplines. It can be used in chronic wounds of different aetiologies,\textsuperscript{2} as well as acute wounds secondary to trauma\textsuperscript{3} or burns.\textsuperscript{4} It has also been useful in anchoring skin grafts and has been shown to increase graft take.\textsuperscript{5} General surgeons have often used it on open abdomens,\textsuperscript{6} whilst thoracic surgeons have found it useful for sternal sepsis.\textsuperscript{7} It has been found to decrease oedema and bacterial load, increase vascularity and granulation tissue and thereby accelerate wound healing.\textsuperscript{1}

Yet, to date, the mechanism of the action of NPWT remains unknown. Many of the proposed theories are based on work suggesting that on application of an NPWT dressing, tissue pressure is immediately decreased, resulting in dilation of capillaries,\textsuperscript{8,9} removal of oedema, angiogenesis and, ultimately, an accelerated and increased production of granulation tissue.\textsuperscript{2,10} Although it can be conceived that the tissue pressure beneath a pore of the foam may be hypobaric, this does not necessarily mean that the overall tissue pressure generated by the NPWT dressing is hypobaric too. This net tissue pressure is the actual pressure that affects perfusion to the wound. Although work on substance pressures has been done by German researchers,\textsuperscript{11} there is no study in the English literature that has measured substance pressure beneath NPWT dressings to confirm the assumption that NPWT dressings result in decreased underlying tissue pressures. Furthermore, whether substance pressure beneath a circumferential NPWT dressing is different from that beneath a non-circumferential NPWT dressing has never been evaluated. Moreover, an NPWT dressing placed inside a cavity may generate different substance pressures compared to either of the aforementioned two types of dressings. Indeed, it may be possible that, regardless of the type of NPWT dressing used, the net pressure in the underlying substance will always remain equal to atmospheric pressure once the foam has completely collapsed.

The objective of this study was to determine the effects of NPWT dressings on underlying substance pressures. Three foam configurations were tested, namely circumferential, non-circumferential and foam placed inside a cavity (cavity dressing). The effects of different suction pressures were also investigated.

Methods

Substance pressures were measured using an intracranial tissue pressure microsensor (Codman/Johnson and Johnson Professional Inc., USA), which makes use of a strain gauge transducer (Figure 1). It measures both positive and negative pressures in gas and liquids or any compliant substances, for example, soft tissue. Negative pressure was created using a portable suction pump with an accurate pressure gauge (Schuco, USA). In a pilot study, it was found that conventional foam resulted in similar substance pressure effects to the commercially available, reticulated, open-cell foam (Kinetic Concepts Inc., USA), and therefore this foam was used in this study. All experiments were repeated 5 times, and the means of these values were calculated.

Circumferential NPWT dressings

In order to simulate a limb, a large sausage was skewered onto a pen (which would represent the underlying bone). Using the supplied placement cannula, the pressure transducer was carefully placed in the substance of the sausage (Figure 2). The transducer was placed about 5 cm from the puncture site (at one end of the sausage) and care was taken not to allow the transducer to be in continuity with the cavity created by the pen or the outer atmosphere. This would allow for true measurement of substance pressure alone. Rather than wrap the foam slab around the sausage, the sausage was loosely sandwiched between two separate slabs of foam. This was to create a circumferential NPWT dressing that would not constrict the sausage and thereby create a mechanical increase in substance pressure, which is unrelated to the changes due to the differential pressures. A portion of the sausage was left protruding from the foam, and the adherent occlusive dressing was stuck directly onto this portion of the sausage, allowing a part of the sausage to be excluded from the NPWT dressing, that is, exposed to normal atmospheric pressure (Figure 3) in the same way that a limb would not be entirely covered by a circumferential NPWT dressing. The transducer was
zeroed in order to record the change in pressure that might occur. Different suction pressures were applied, ranging from $-100 \text{ mmHg}$ to $-500 \text{ mmHg}$, and the resultant substance pressures within the sausage were recorded.

**Non-circumferential (flat) NPWT dressings**

In order to determine whether non-circumferential NPWT dressings increase or decrease pressures within underlying substances, the transducer had to be placed within the substance of a compliant material. For this purpose, two slabs of soft plasticene were used. The pressure transducer was placed in between the two slabs, which were gently stuck together. A non-circumferential NPWT dressing was applied to the side of one slab (Figure 4). If the NPWT dressing would create a suction/pulling force on this slab, this would decrease the pressure on the transducer and vice versa if the dressing generated a pushing force, which would increase substance pressures. The transducer was zeroed and suction pressures ranging from $-100 \text{ mmHg}$ to $-500 \text{ mmHg}$ were applied to the dressing, with the resultant pressures within the plasticene being recorded.

**NPWT dressings that are in a cavity**

The material considered most suitable for this experiment was processed meat. As with the sausage experiment, this type of substance allows for the homogeneous transfer of pressure. A round cavity (3 cm diameter, 2 cm depth) was excised from the meat with the rest of the outer plastic covering still intact. Because adhesive occlusive dressing does not stick to processed meat, this covering not only represented the surrounding skin of a wound, but also provided a surface for the adhesive occlusive dressing to stick to. From the opposite side of the processed meat, the pressure transducer was placed, with the help of the supplied placement cannula, about 1 cm deep to the base of the cavity. A cylindrical piece of foam was then inserted snugly into the cavity, with its outer surface flush with the...
surface of the processed meat. The rest of the NPWT dressing was completed with adhesive occlusive dressing and appropriately sized suction tubing (Figure 5). The transducer was zeroed and suction pressures ranging from –100 to –500 mmHg were applied, and the substance pressure in the base of the cavity was recorded.

This experiment raised the question of whether the pressures in the walls of the cavity were similar to the pressure in the base of the cavity, and whether this pressure dissipated as the distance from the cavity increased. To answer this question, an experiment similar to the aforementioned one was undertaken, except that this time three transducers were used simultaneously and placed in the wall of the cavity, at a distance of 1, 2 and 3 cm away from the cavity (Figure 6). The transducers were zeroed, and the suction pressures ranging from –100 to –500 mmHg were applied and the substance pressures at the respective distances from the cavity were recorded.

Results

Circumferential NPWT dressings

Pressure inside the substance of the sausage increased proportionately with increasing suction pressure (Figure 7). The high sensitivity of the transducer demonstrated that this increase occurred even at very low suction pressures, and at no time was a negative pressure recorded.

Non-circumferential NPWT dressings

In the plasticene, the transducer recorded a proportionate increase in pressure as the suction pressure was increased (Figure 8). At no time was a negative pressure recorded.

NPWT dressing in a cavity

The transducer in the base of the cavity recorded a proportional increase in pressure as the suction pressure was increased (Figure 9). The pressure recorded 1 cm from the wall of the cavity demonstrated an increase in pressure too, although the rise in pressure was not as acute as in the base (Figure 10). At both the 2- and the 3-cm intervals the pressure rise was minimal and increasing suction did very little to generate higher pressures, indicating that the pressure appears to dissipate very rapidly in this particular substance. There was no decrease in pressure, however, at any of the placement distances.

Discussion

The results of this study demonstrate that all types of NPWT dressings generate an increase in pressure within the underlying substance, regardless of the type of substance. The increase in pressure is directly proportional to the amount of suction pressure used. The increase in substance pressure dissipates as the distance from the NPWT dressing is increased.

These findings, however, conflict with other studies suggesting that NPWT creates a hypobaric tissue pressure.1,2,11 This questions the proposal that the resultant hypobaric tissue pressure results in vasodilatation and increased perfusion.8,9 As substance pressures have been demonstrated to be hyperbaric, the cause for increased pressure inside the tissue should be reexamined.12
perfusion seems unlikely to be directly due to NPWT. The sequelae of this increased tissue pressure may, however, indirectly result in increased perfusion at a later stage. Hyperbaric tissue pressure and the potential for ischaemia, with release of vasodilatory mediators, may explain the hyperaemia that is observed when the foam is removed. This potential for ischaemia has already been demonstrated by Wackenfors et al., although the authors did not elaborate on the cause of this ischaemia or its effects on wound healing. The tissue ischaemia may further act as a stimulus for the increased angiogenesis observed. Additionally, it can be postulated that the increased pressure dissipates oedema fluid away from the wound. Should this fluid be dissipated to the wound surface, the NPWT dressing is then in a position to remove it from the wound. The decrease in wound oedema may be one mechanism accounting for the increased perfusion observed after the application of NPWT over a period of time.

The increased substance pressure generated by NPWT and the potential for ischaemia raise concern about the safety of NPWT when applied to tissues with compromised perfusion. This has clinical relevance when applied over an avulsed flap of skin or any other traumatised tissue with borderline perfusion, particularly when used circumferentially.

A limitation of this study is that all substances tested are inanimate. Unlike living tissues, inanimate substances do not have various fluid compartments and also may not have the same visco-elastic properties that human tissues have. Therefore, the specific pressures observed in this study are not necessarily indicative of pressures that may be generated in human tissue. However, although the specific pressures may be different, the trend observed, namely increasing substance pressure for increasing suction pressure, is likely to occur in living tissues too. Indeed, the study by Willy et al. demonstrated increased tissue pressures on human tibialis anterior muscle after application of NPWT. Preliminary, unpublished data from our unit involving a large study on live human tissues have also demonstrated the above-mentioned finding.

NPWT generates hyperbaric pressures in inanimate substances, regardless of the method of application (circumferential, non-circumferential or in cavities). This increase in pressure is directly proportional to the amount of suction applied. The increased pressure dissipates rapidly as distance from the wound edge is increased.

These findings suggest that it may be necessary to reconsider our current understanding of the physics relating to NPWT. Furthermore, the hyperbaric tissue pressure generated by NPWT may be a cause for concern regarding the role of NPWT in tissue with borderline perfusion, and therefore further studies on living tissues are warranted.

Acknowledgements

Johnson & Johnson provided the Codman’s intracranial tissue pressure microsensors and monitors. This study was funded partly by research funding from the Hand Unit, Dept of Orthopaedic Surgery, University of Cape Town, South Africa.

None of the authors has a financial interest in any of the products or devices mentioned in this article.

References