The paradox of negative pressure wound therapy - in vitro studies

N Kairinos, M Solomons, D A Hudson
Department of Plastic and Reconstructive Surgery, Groote Schuur Hospital and University of Cape Town, South Africa
Correspondence to: nickykairinos@gmail.com, nickykairinos@hotmail.com

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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 perception of the physics underlying NPWT dressings. Further research of this type on living tissues is warranted.

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Introduction

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[1,2] and encompasses many different disciplines. It can be used in chronic wounds of different aetiologies,[2] as well as acute wounds secondary to trauma[3] or burns.[4] It has also been useful in anchoring skin grafts and has been shown to increase graft take.[5] General surgeons have often used it on open abdomens,[6] whilst thoracic surgeons have found it useful for sternal sepsis.[7] It has been found to decrease oedema and bacterial load, increase vascularity and granulation tissue and thereby accelerate wound healing.[1]

Yet, to date, the mechanism of action of NPWT remains unknown. Many of the proposed theories are based on work suggesting that on application of a NPWT dressing, tissue pressure is immediately decreased, resulting in dilation of capillaries,[8,9] removal of oedema, angioneogenesis and, ultimately, an accelerated and increased production of granulation tissue.[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,[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 to that beneath a non-circumferential NPWT dressing has never been evaluated. Moreover, a NPWT dressing placed inside a cavity may generate different substance pressures 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.

This study's objective 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.

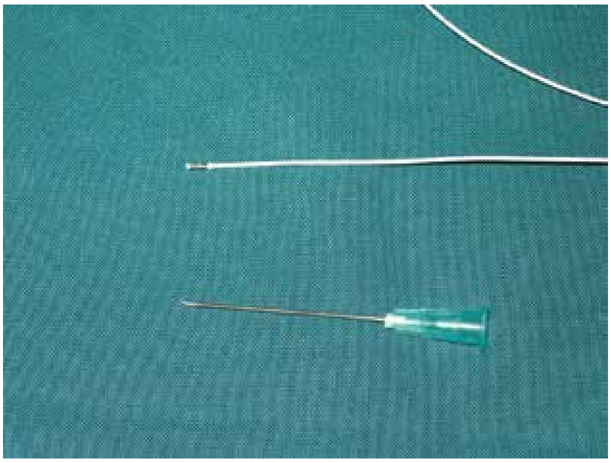

Figure 1. Intracranial Pressure Microsensor with standard 21-gauge needle for size comparison.

Figure 2. Sausage skewered onto disposable pen to represent limb/finger with underlying bone. Pressure transducer inserted to a depth of about five centimetres into substance of sausage.

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, liquids or any compliant substances, e.g. 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 five 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 five centimetres 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 part of the sausage to be excluded from the NPWT dressing, i.e. 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 mmHg to –500 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

Figure 3. Sausage within sandwich-type circumferential NPWT dressing. Portion of sausage is left in continuity with atmospheric pressure.

Figure 4. Two slabs of soft plasticene with pressure transducer in between and NPWT dressing over one slab.

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 mmHg to –500 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 substance allows for the homogenous transfer of pressure. A round cavity (three centimetre diameter, two centimetre 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.

Figure 5. Processed meat with NPWT dressing inside cavity. Pressure transducer introduced from opposite side and lodged about one centimetre deep to base of cavity.

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, a similar experiment to the aforementioned one was undertaken, except this time three transducers were used simultaneously and placed in the wall of the cavity, at a distance of one-, two- and three-centimetres away from the cavity (Figure 6). The transducers were zeroed and suction pressures ranging from –100 to –500 mmHg were applied, and the substance pressures at the respective distances from the cavity were recorded.

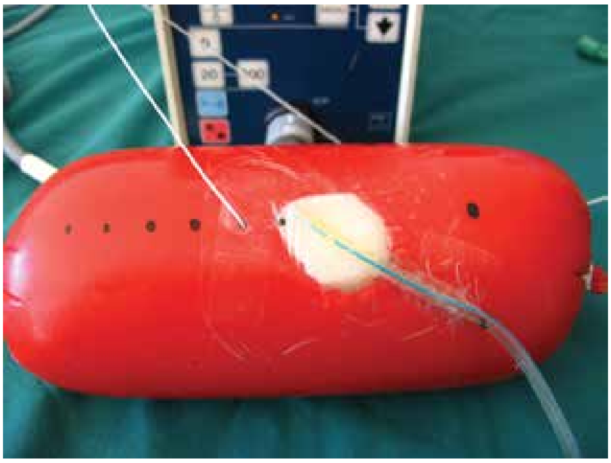

Figure 6. Markings at one-centimetre intervals away from cavity, at which point three pressure transducers are to be placed at a depth of one centimetre.

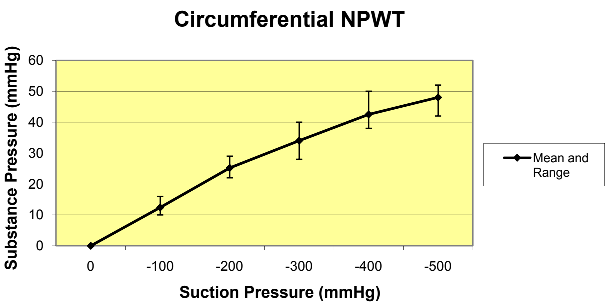

Figure 7. Pressure change (mean and range when experiment repeated five times) in sausage substance in relation to increasing suction pressure (circumferential NPWT).

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 one centimetre from the wall of the cavity

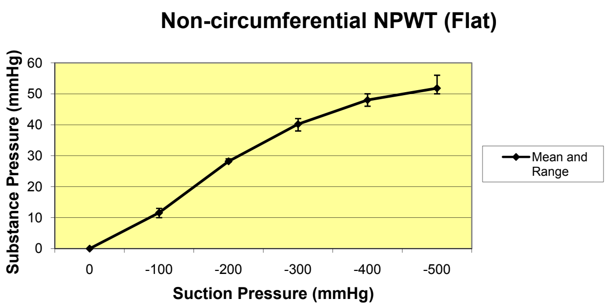

Figure 8. Pressure change in plasticene (mean and range when experiment repeated five times) in relation to increasing suction pressure (non-circumferential NPWT).

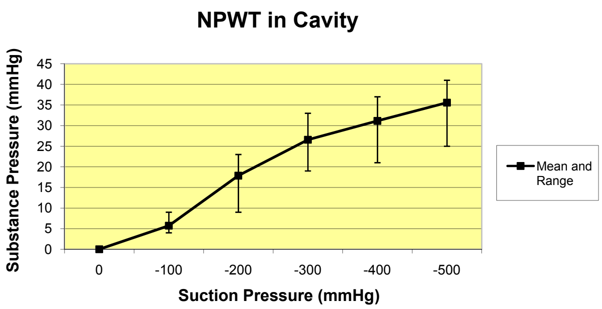

Figure 9. Pressure change (mean and range when experiment repeated five times) in base of cavity of processed meat in relation to increasing suction pressure (NPWT foam placed in cavity).

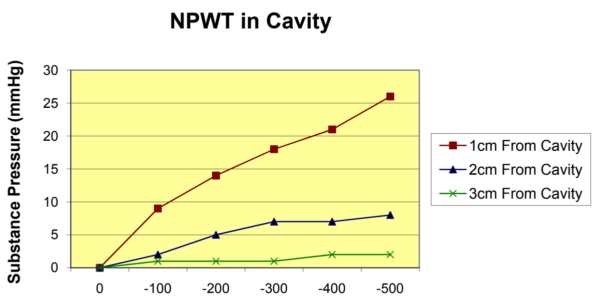

Figure 10. Pressure changes in processed meat at varying distances from cavity, in relation to suction pressure (NPWT in cavity).

demonstrated an increase in pressure too, although the rise in pressure was not as acute as in the base (Figure 10). At both the two and the three centimetre intervals the pressure rise was minimal and increasing suction did very little to generate higher pressures, indicating 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 what the particular substance is. 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 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,[12] although the authors did not elaborate on the cause of this ischaemia or how it affects 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 raises 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 may also 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.[10] 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 has also demonstrated the abovementioned finding.

Conclusion

NPWT generates hyperbaric pressures in inanimate substances, regardless of 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 cause for concern regarding the role of NPWT in tissue with borderline perfusion and further studies on living tissues are warranted.

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References:

1. Morykwas MJ, Argenta LC, SheltonBrown EI, et al. Vacuum-assisted closure: A new method for wound control and treatment: Animal studies and basic foundation. Ann Plas Surg. 1997;38:553-62.
2. Argenta LC, Morykwas MJ. Vacuum-assisted closure: A new method of wound control and treatment: Clinical experience. Ann Plas Surg. 1997;38:563-76.
3. DeFranzo AJ, Argenta LC, Marks MW, et al. The use of vacuum-assisted closure therapy for the treatment of lower-extremity wounds with exposed bone. Plas Reconstr Surg. 2001;108:1184-91.
4. Kamolz LP, Andel H, Haslik W, et al. Use of subatmospheric pressure therapy to prevent burn wound progression in human: first experiences. Burns. 2004;30(3):253-8.
5. Scherer LA, Shiver S, Chang M, et al. The vacuum-assisted closure device: A method of securing skin grafts and improving graft survival. Arch Surg. 2002;137:930-3.
6. Stone PA, Hass SM, Flaherty SK, et al. Vacuum-assisted fascial closure for patients with abdominal trauma. J Trauma Injury Infection Critical Care. 2004;57:1082-6.
7. Song DH, Wu LC, Lohman RF, et al. Vacuum assisted closure for the treatment of sternal wounds: The bridge between debridement and definitive closure. Plast Reconstr Surg. 2003;111:92-7.
8. Petzina R, Gustafsson L, Mokhtari A, et al. Effect of vacuum-assisted closure on blood flow in the peristernal thoracic wall after internal mammary artery harvesting. Eur J Cardiothorac Surg. 2006;30:85-9.
9. Chen S, Li J, Li X, et al. Effects of vacuum-assisted closure on wound microcirculation: An experimental study. Asian J Surg. 2005;28(3):211-7.
10. Mendonca DA, Papini R, Price PE. Negative-pressure wound therapy: a snapshot of the evidence. Int Wound J. 2006;3:261-71.
11. Willy C, von Thun-Hohenstein H, von Lübken, et al. Experimental principles of the V.A.C.®- therapy – pressure values in superficial soft tissue and the applied foam. Zentralbl Chir. 2006;131:S50-61.
12. Wackenfors A, Gustafsson R, Sjogren J, et al. Blood Flow Responses in the Peristernal Thoracic Wall During Vacuum-Assisted Closure Therapy. Ann Thorac Surg. 2005;79:1724-31.