The etiology of chronic venous ulceration is not fully understood. The pathway from venous insufficiency to ulceration remains a debatable issue. Both the fibrin cuff and the white blood trapping theory have tissue hypoxia in the microcirculation as a common denominator. Hypoxia impedes wound healing by decreasing fibroblast proliferation, collagen synthesis, and angiogenesis. Transcutaneous oximetry (TCOM) is a simple, noninvasive tool to measure tissue oxygenation. This technique avoids the risks of invasive measurement such as tissue disruption around the wound, infection, and exacerbation of nonhealing lesions. TCOM estimates tissue oxygenation and has been used to monitor the effect of wound care interventions.

The Effect of Vacuum-assisted Closure on the Tissue Oxygenation of Venous Ulcers: A Pilot Study

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Abstract: Background. Vacuum-assisted closure (V.A.C.® Therapy, KCI, San Antonio, TX) has been widely used to increase the healing rate of a variety of wounds. It has been hypothesized that one of the actions of VAC is to increase perfusion and subsequent oxygenation of tissue. The aim of the present study was to investigate the effect of VAC therapy on transcutaneous oximetry measurements (TCOM) of skin surrounding chronic venous ulcers. Methods. This was a prospective, experimental pilot study. Patients undergoing compression therapy were recruited from a community wound clinic. All patients had ankle-brachial pressure indices (ABPI) > 0.8. Three TCOM values were taken from around the ulcer and a reference TCOM was taken from the chest. Negative pressure was applied on the ulcer at 125-mmHg continuous subatmospheric pressure and four-layer compression bandaging over the VAC drapes. The duration of the study was 6 days. On day 6, dressings were removed and TCOM was repeated at the same skin sites. Results. Fourteen of the 17 patients completed the trial. The median age was 73 years (range 49–85). No significant difference was found in oxygen partial pressure pre-and post-VAC therapy around the ulcer site (mean 41.5 mmHg versus 40 mmHg [P = 0.67]). There was a significant difference in TCOM between the reference point and the periwound area (mean 60.5 versus 40 [P < 0.0005]). Conclusion. This pilot study suggests that VAC therapy does not change oxygen partial pressure around venous ulcers. TCOM of the skin around ulcers were low despite normal ABPIs.
oxygenation by measuring the diffusion of extracellular oxygen flowing through a heated sensor on the skin. This measurement, which is expressed in millimeters of mercury (mmHg), corresponds to the number of oxygen molecules passing from the superficial skin capillaries through to the epidermis.6

Vacuum-assisted closure (VAC) in the form of topical negative pressure (TNP) has been used for more than a decade to manage open wounds in a variety of clinical settings. Early studies by Morykwas et al7 on swine models revealed that regional blood flow, bacterial clearance, and granulation tissue formation were increased by subatmospheric pressure therapy. Several other studies using animal models have been conducted and confirm those preliminary results.8–10

To date, there have been no reported studies that use TCOM to measure the tissue oxygenation response from topical negative therapy. The aim of this study was to investigate the effect of VAC on transcutaneous oxygen in patients with venous leg ulcers.

Materials and Methods

Participants. This was a prospective, noncomparative pilot study. Patients with chronic venous leg ulcers (CEAP C6) of more than 6 weeks duration undergoing compression therapy for at least 2 weeks in a community specialist wound care clinic were invited to participate in the study. Patients were diagnosed as having superficial venous incompetence with clinical examination and a hand held Doppler (Level 1 investigation).11 The inclusion criterion was venous ulcer size > 1 cm². Exclusion criteria were ankle-brachial pressure index (ABPI) < 0.8, previous VAC therapy, current smokers, lymphedema, severe lipodermatosclerosis (LPS), recurrent ulcers, previous deep vein thrombosis or known deep venous incompetence, body mass index > 35, and presence of infected, malignant, or vasculitic ulcers. Lipodermatosclerosis was defined as “mild” if the skin around the ulcer was involved, and “moderate” if the entire ankle was affected. All subjects were ambulatory and were treated as an outpatient. All participants were provided with trial information sheets and written consent was obtained. Ethical approval was granted by the regional ethics committee.

Materials. All VAC equipment was provided by Intermed-Kinetic Concepts, Inc (Auckland, New Zealand). VAC therapy consisted of polyurethane foam (black foam) dressing with a pore size of 400 µm–600 µm, adhesive draping, and an evacuation tube connected to the VAC® Freedom® or MiniVAC® system. Once the black foam dressing had been applied, therapy was commenced at 125-mmHg subatmospheric pressure continuously. Four-layer compression bandaging using the Charing Cross method (orthopedic wool, support crepe bandage, class 3a bandage plus cohesive bandage) providing 40 mmHg at the ankle graduating to 17 mmHg below the knee, was applied over the sealing drapes.12,13 Negative pressure therapy was commenced for 6 days with a dressing change on day 3.

Measurements. All TCOM were performed while participants were in a relaxed supine position breathing room air. The skin site was prepped and light desquamation was achieved using a 70% isopropyl alcohol swab. Nurses trained in the technique placed three sensors heated to 44˚C around the ulcer in the recommended manner (ie, not over prominent bones or major vessels). The reference point measurement was taken from the second intercostal space. Resting transcutaneous oxygen pressure (TcPO2) was estimated using a transcutaneous oxygen monitor (Tina TCM 4, Radiometer, Copenhagen, Denmark) and data were recorded after the readings had been stabilized for 10 to 15 minutes. Recordings were taken on days 1 and 6 in the same environment and location for each patient. Tracings on picture diagrams and markings on the limbs were drawn to ensure accuracy in subsequently placing the sensors on the same location at the second visit.

Participants had a 24-hour phone line to call if assistance with the VAC device was needed. The VAC system was checked at each visit to ensure that the seal had been maintained at -125 mmHg throughout the study period.

Statistical Analysis

The mean of the three TCOM around the ulcer for each patient was calculated. The data were entered into a Microsoft Excel database and statistically analyzed using R software (R Foundation for Statistical Computing, Vienna, Austria.) Differences in means were compared with the paired Student’s t-test; significance was determined at P < 0.05.

Results

Seventeen participants (5 men and 9 women) were recruited, of whom three did not complete the trial and were excluded from the data analysis. Two of the patients did not cope with the VAC equipment (pump and the tubing) and the other participant withdrew on the sec-
ond day due to significant pain from the ulcer. The median age was 73 years (range 49–85). Sixteen participants were nonsmokers and one was an ex-smoker. One patient had undergone previous hyperbaric oxygen therapy (HBOT) for their ulcer. Five patients had moderate LDS. There were no complications encountered with the TCOM. One patient developed contact dermatitis from the sealing drape on day 6.

Individual TcPO2 measurements and clinical details are outlined in Table 1. Figure 1 shows the mean ± standard deviation of TcPO2 at the reference point and peri-wound area on day 1 and day 6. There was no significant difference in mean TcPO2 within the periulcer region (41.5 mmHg ± 14.6 and 40.0 ± 15.9 mmHg, respectively \( P = 0.67 \)). There was a significant difference in TcPO2 between the reference site and the periulcer area \( P < 0.001 \). The TCOM peri-ulcer values on day 1 and 6 were on average, less than the reference TCOM by 18.3 mmHg \( P < 0.005 \) and 20.6 mmHg \( P < 0.0005 \), respectively. The mean of the TCOM reference point on day 1 and 6 were 59.8 ± 12.4 and 60.6 ± 12.9.

**Discussion**

This prospective pilot study suggests that TcPO2 is lower around chronic venous ulcers than in normal tissues and that VAC applied over a 6-day period does not increase tissue oxygenation.

The 6-day study period was chosen for two reasons: a prospective trial on patients with venous ulcers used this regimen and showed that most ulcers formed granulation tissue within this period; and because animal models revealed maximum increase in capillary density on the sixth day.

We strictly adhered to the application of TCOM in the recommended manner as described by Sheffield to reduce the limitations of this tool. However, one limitation with the device might be that TCOM estimates oxygen around the wound not the wound base and a 6-day period might not be sufficient to stimulate neoangiogenesis. In addition, the adjacent tissue is likely to have a higher PO2 than the wound itself.

Therefore, the values measured might be overestimating the TcPO2 levels. TCOM has some limitations in venous ulcer measurements, as there are several skin changes present on the limbs. Jünger et al showed that the greater the severity of trophic skin changes, the lower the TcPO2 and the number of nutritive capillaries observed.

A limitation of this experiment was its small number

![Figure 1](image)

**Figure 1.** Mean transcutaneous oxygen measurements in mmHg (± 95% CI) at the reference point (chest) and at the peri-ulcer area.
of participants. If TCOM were taken from the unaffected limb, an interesting dimension would have been added to this study, as this might reveal if the microcirculation was affected bilaterally. Cina et al\textsuperscript{17} showed TcPO\textsubscript{2} in healthy subjects decreased with an increase in age. Both foot and calf TcPO\textsubscript{2} values of healthy controls were more than 60 mmHg. Patients with peripheral arterial occlusive disease had TcPO\textsubscript{2} values more than 50 mmHg in the asymptomatic lower limb.

Several other studies have shown that TcPO\textsubscript{2} is low in patients with venous skin changes and ulcers when compared to normal controls, which provides support for the theory that hypoxia is a contributing factor.\textsuperscript{18,19} Moosa et al\textsuperscript{20} showed that perivenous ulcers had a mean TcPO\textsubscript{2} of 10 mmHg, which was similar to the mean value of 5.6 mmHg reported by Nemeth et al.\textsuperscript{21} Older models of TCOM devices only had 2 sensors (reference and perulcer) and studies reported a single perulcer figure rather than a circumferential representation of the skin, as was the case in the present study. This might explain why our perulcer values were higher than published studies.

We improved the seal of the electrode and the semipermeable patch by stripping excess scale and any remains of topical moisturizing products applied before compression bandaging. In some instances, the patch did not have an adequate seal and the skin had to be prepped several times before an adequate seal was achieved. Initial sensor positions were marked with a surgical marker and remarked on day 3 (during dressing change) to ensure that measurements were obtained from the same skin areas.

Due to financial constraints in the public system, a Duplex ultrasound scan of the venous system to identify reflux in the deep or perforator veins was not performed. However, as we measured the response of tissue oxygenation with VAC therapy, the presence of reflux in the deep system would probably not affect the results of this study.

TCOM is used to assess patients being considered for HBOT, to monitor the response to HBOT, and to predict the healing patterns of lower limb amputation levels.\textsuperscript{17,22–24} Studies have revealed that in order for wounds to heal successfully, TcPO\textsubscript{2} must remain > 40 mmHg.\textsuperscript{25} However, a similar study suggests that TCOM does not significantly predict venous ulcer recurrence in patients with healed venous ulcers.\textsuperscript{25}

A study of negative pressure therapy in induced wounds in a rabbit model showed the negative pressure increased blood flow by increasing capillary density and the caliber diameter.\textsuperscript{5} These acquired experimental wounds might differ significantly from chronic venous ulceration in humans and this may partially explain the lack of observed change in TCOM in this study. Christenson\textsuperscript{26} showed that patients with venous ulcers had elevated subcutaneous and intramuscular pressures and reduced TcPO\textsubscript{2}. Patients who had subcutaneous fasciotomy following superficial reflux elimination surgery had significantly improved wound healing rates and improved TcPO\textsubscript{2} compared to the group who had surgery alone.\textsuperscript{26} This possibly explains why TcPO\textsubscript{2} following negative pressure therapy did not improve during our observed period.

Intermittent compression treatment has been shown to improve skin perfusion and tissue oxygenation of venous ulcers when applied over a 60-minute period.\textsuperscript{17} Future experiments using quantitative techniques such as capillary microscopy, laser Doppler flowmeter and TCOM in patients with venous ulcers can be used to examine the skin blood flow response while TNP is applied \textit{in situ} and post therapy. In addition, longer study duration might reveal a more established change in the microcirculation.

**Conclusion**

Negative pressure therapy applied over a 6-day period did not change oxygen partial pressure of the skin close to chronic venous ulcers. However, the study demonstrated moderate tissue hypoxia despite normal ABPIs.

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