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Negative Pressure Wound Therapy and the Perfusion Paradox: Reconciling Clinical Success with Foundational Principles of Tissue Healing

Opinion

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Abstract

Negative pressure wound therapy (NPWT) has become a cornerstone of modern wound management because it often reduces wound burden while accelerating closure. Despite this success, a persistent physiologic paradox remains. Negative pressure applied at the wound interface generates compressive forces against the wound bed, impairing tissue perfusion at commonly used therapeutic pressure settings. Traditional foam-based wound fillers require high negative pressure settings (-125mmHg) to achieve effective exudate clearance, narrowing the therapeutic window between exudate management and perfusion preservation. High quality clinical trials across multiple wound types have failed to demonstrate consistent superiority of NPWT over conventional dressings, particularly in high-risk wounds (i.e. dysvascular, pressure-related, infected), where perfusion may be a more significant factor. These conflicting clinical and physiological findings suggest that the limitations of current systems may relate less to the generic concept of NPWT and more to long standing dependence on high-resistance ROCF interfaces. This paradox begs the question, as to whether an optimal wound interface that possesses high outflow efficiency enabling lower therapeutic negative pressure settings could resolve this paradox and improve clinical outcomes, especially in high-risk wounds.

Discussion

Negative pressure wound therapy (NPWT) is commonly described as the application of sub-atmospheric pressure to tissue. In practice, NPWT improves exudate control, reduces dressing change burden, and accelerates wound healing, in many cases, which has driven widespread adoption [1] However, according to Newton's 3rd law of motion, application of negative pressure to a sealed NPWT wound dressing must transmit an opposing force against the wound bed, resulting in compression of the wound surface [2,3].

Low magnitude compression (20-30mmHg) may be beneficial by reducing interstitial edema, improving lymphatic drainage and improving local perfusion.4 However, compression has dose-dependent effect on tissue healing, and increasing compressive forces, especially when continuously applied for days at a time, will eventually impair microvascular perfusion, particularly in dysvascular tissue or wounds over hard prominences [2]. Perfusion studies demonstrate progressive reductions in blood flow beneath negative pressure dressings as suction magnitude increases, challenging the assumption that negative pressure inherently improves perfusion [2-4].

Despite these physiological findings, NPWT systems have relied almost exclusively on reticulated open cell foam (ROCF) as the wound filler of choice. This material, characterized by pore sizes of approximately 400 to 600 microns, exhibits increasing resistance to flow under compression [2,3]. As resistance increases, higher negative pressure settings are required to achieve effective fluid evacuation. Experimental work demonstrates that maximal exudate removal with foam-based interfaces occur around -125mmHg, even though maximal wound contraction occurs at lower pressures [4]. This material-specific requirement for high negative pressure settings creates a narrow therapeutic window for ROCF in which clinicians must balance fluid management with perfusion preservation.

The mechanisms underlying the therapeutic effect of NPWT remain incompletely defined despite decades of use. Proposed therapeutic effects include macrodeformation, microdeformation, and altered cellu-

lar signaling [5]. The paradox between commonly observed favorable clinical outcomes with less dressing maintenance requirements when using NPWT with ROCF compared to the adverse effect this particular approach has on wound bed perfusion has been known for quite some time, but under-appreciated, possibly due to the lack of an effective alternative NPWT interface. This has fostered confirmation bias, whereby favorable clinician experiences overshadow contradictory physiologic data and inconsistent clinical trials [6].

High quality clinical trials demonstrate a lack of consistent patient centered benefits despite widespread clinical adoption of NPWT with ROCF. Randomized studies in open fractures, incisional wounds after major extremity trauma, and surgical wounds healing by secondary intention have failed to demonstrate meaningful improvements in patient centered outcomes compared with standard dressings [7-9]. Systematic reviews similarly fail to consistently find superior healing with NPWT, especially in high-risk wound categories [6,10]. The SAWHI trial in subcutaneous abdominal wound healing impairment showed no improvement in healing with NPWT and reported higher wound-related adverse events compared with conventional care [11]. Across multiple wound categories, higher level evidence shows inconsistent benefit of NPWT and some even signal potential harm in select populations [10,12,13]. Optimizing the wound filler to permit effective therapy at lower pressures may better align clinical performance with basic principles of tissue perfusion and wound healing. It is rare that the first generation of any medical device or key component of a medical device is optimal (Figure 1). However, despite substantial efforts to improve the pumps and adhesive drapes over the last 30+ years, as well as the addition of instillation, the basic material of NPWT remains ROCF. Maybe it's time to consider a change?

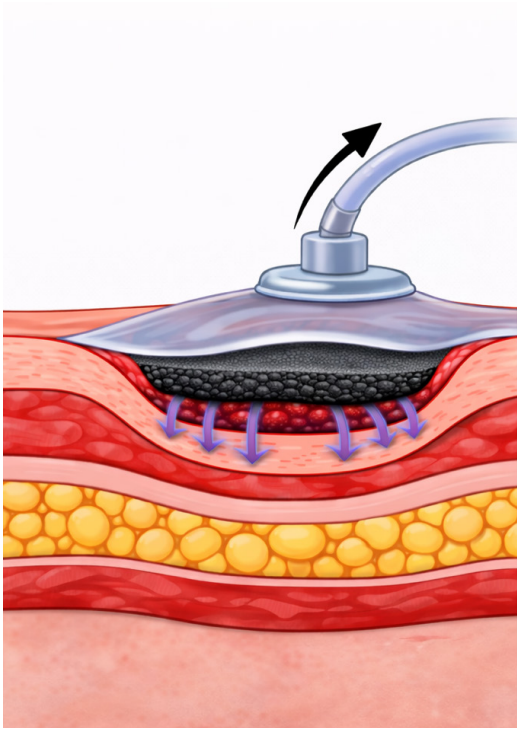

Figure 1: AI-generated illustration demonstrating the paradox of NPWT with ROCF. High negative pressure (-125mmHg) is needed to evacuate exudate (black arrow) through ROCF, which is felt to be beneficial to wound healing, but this results in reciprocal positive pressure against the wound (purple arrows) sufficient to cause hypoperfusion of the wound bed.

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