Elevated vacuum systems and residual limb skin health

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Background and Aim

A lower-limb prosthesis is an artificial device designed to replace a lower limb, restoring mobility and cosmetic appearance. Modern lower-limb prostheses typically consist of 3 components: a pylon, a socket, and a suspension system. The socket is directly in-contact with the residual limb, while the suspension system secures the limb within the socket (1). Despite advances in prosthetic design, maintaining skin integrity remains a significant clinical challenge. Mechanical forces during walking can contribute to pain, ulceration and delayed wound healing. Poor socket fit and changes in residual limb volume further exacerbate these issues and may lead to abandonment of the prosthesis (2). Prosthetists and prosthetic technicians aim to minimise these complications through socket design and suspension selection. In our centre, elevated vacuum systems have recently been tried for two patients with persistent residual limb ulceration. We therefore wanted to understand whether there is any evidence to support the use of EVS instead of other suspension systems.

Methods

Databases: Medline, Embase, CINAHIL, Scopus

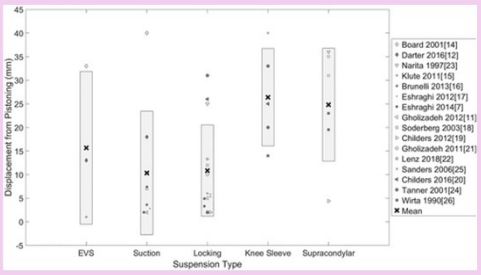
Keywords: Elevated, dynamic, active, vacuum, negative, pressure, socket, prosthetic, prosthesis, prosthesis design, joint prosthesis, suspension, artificial limb, tissue, tissue survival, scar, wound, skin, heal, health, damage, circulate, blood flow, volume, proprioception, pain, outcome, effectiveness.

Number of Papers: 44 papers were identified.

Analysis: In the initial screening, titles and abstracts were reviewed, and all potentially relevant papers were included. Findings were then organised into three overarching themes: residual limb displacement, gait and skin physiology. During full-text review, additional relevant case studies and experiments were identified through reference list screening.

Exclusion criteria: Duplicates, published before the year 2000.

Results



GRAPH 1: Pistoning by suspension type. X is the mean. Grey boxes are 1 SD above and below the mean (1).

Displacement

Pistoning is the vertical movement of the residual limb within the socket and is the most assessed measure of displacement. Excessive pistoning increases shear forces, friction and distal tissue irritation. Reduced displacement is hypothesised to improve distal wound tolerance, reduce pain and skin irritation, enhance limb stability during prolonged walking. Across 16 studies (see Graph 1), EVS did not constantly demonstrates reduced pistoning compared with other systems. Although high-level empirical evidence directly linking EVS to wound healing remains limited, multiple case studies report improved healing of distal wounds following transition to EVS (3,4), particularly in diabetic transtibial amputees.

The relationship between gait, displacement and EVS is widely studied. Those studies conclude that optimising gait and displacement theoretically improves residual skin health, based on Boyle's Law. However, there is no direct empirical evidence to support the relationship between those factors.

Gait: Level walking

There are mixed results when comparing EVS to pin or suction systems. During level walking, most studies report no significant differences in temporal-spatial gait.

Gait: Incline walking

EVS demonstrates improved gait symmetry, particularly during uphill ambulation. Two studies (N=10 and N=12) reported improved step length symmetry with EVS, although most other gait variables remained statistically similar (5, 6). Improved step symmetry is due to improved limb-socket coupling. This, in turn, improves proprioception. This is particularly relevant for individuals with diabetic peripheral neuropathy or Charcot arthropathy, where reduced sensory feedback leads to instability and compensatory gait patterns. Consistent, equal loading patterns on prosthetic and natural legs are thought to support tissue tolerance and may create an environment more conducive to wound healing and long-term skin health (1-4).

Gait and volume stability

Volume stability helps maintain socket fit, thereby reducing shear forces and irritation of distal tissues. Findings are mixed (2,8): EVS has been linked to increased limb volume during walking in some studies, reduced fluctuations compared to suction in others, and some suggest no significant difference compared to pin suspension. The increase in limb volume during walking may be caused by physiological changes (such as increased arterial pressure and vasodilatation), rather than vacuum alone.

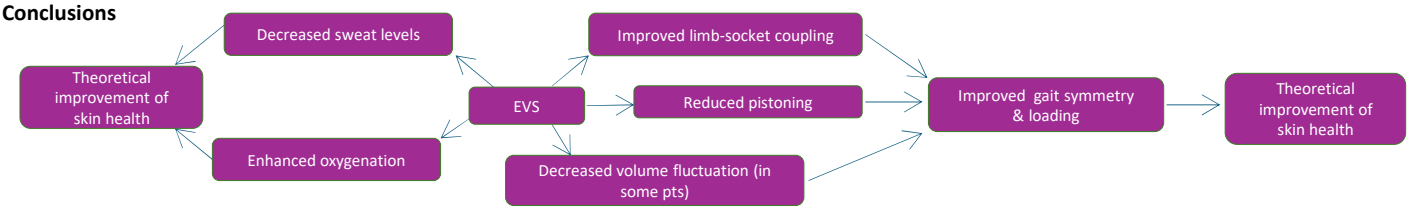
Skin physiology

TABLE 1 (9): Skin physiology changes following 16 weeks of EVS in 10 participants.

TCOM - transcutaneous oxygen measure
LSF - laser speckle flowmetry
TEWL - trans-epidermal water loss.

Factor measured	Baseline (EVS)	16 weeks (EVS)	Non-vacuum system	Interpretation for EVS
TCOM	Reduced during activity (in socket)	Normalised compared to out-of-socket	Remained reduced	Stable environment, allowing adaptive vascular change
LSF	Decreased 50% in-socket	Decreased 50% in-socket	Decreased 50% in-socket	Perfusion decreased due to socket compression effect
TEWL	N/A	Decreased by 19.5%, especially in high stress	Increased	Skin barrier function improved Sweat level decreased
Reactive Hypereamia	Present	Reduced	Higher	Less ischaemic stress

Conclusions



EVS may influence residual limb skin health through a number of biomechanical and physiological mechanisms, summarised in the figure above. However, current evidence remains limited by small sample sizes and population-specific outcomes. Confidence in these results should be strengthened by larger, longitudinal studies in the future that consider past medical history, smoking status, and an adequate acclimation period. Additionally, mechanical and electrical EVS should be studied separately to determine whether they yield different outcomes. An interesting question is how much negative pressure is needed to achieve adequate oxygenation and skin barrier function.

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