The Biomechanical Implications of Elevated Vacuum Suspension for Persons with a Transtibial Amputation

Nicholas G. Gomez, PhD, CPO; The University of Utah; nggomez60@gmail.com

Creation Date: December 2022; Re-assessment Date: December 2027

Clinical Question: Does elevated-vacuum suspension (EVS) improve gait parameters and reduce joint loadings of persons with a transtibial amputation (TTA) compared to prosthetic socket suspension that does not utilize elevated vacuum?

Background: Primary interest in EVS has revolved around its ability to potentially better manage residual limb volume compared to other types of suspension[1]. Proper volume management reduces residual-limb movement within the socket, which reduces skin breakdown, areas of excessive pressure, and discomfort[2]. Stability of the socket over time from an EVS can even improve skin health in the long term[3]. Reduced movement within the socket has the potential to increase confidence in a prosthesis, which could change how a person with an amputation chooses to walk. While there is substantial literature[4] investigating how choice of prosthetic feet can impact gait symmetry, metabolic efficiency, and stability, it is not clear whether the addition of EVS also has an objective impact on gait parameters and how the joints of the lower extremities are loaded, which has implications for the development of conditions such as osteoarthritis. To investigate this matter, a review of the literature was performed to examine how the addition of EVS impacts gait symmetry and loading of the joints in the lower extremities.

Search Strategy:
Databases Searched: Pubmed, CINAHL, Scopus
Search Terms: (vacuum OR elevated vacuum OR vacuum suspension OR elevated vacuum suspension) AND (gait OR joint loading OR joint contact forces OR contact force) AND (transtibial OR trans tibial OR trans-tibial OR below-knee OR below knee)
Inclusion/Exclusion Criteria: English, peer-reviewed, original research, not case series, not erratum, not reply to, not review, not comments regarding, not gray literature, not volume management

Synthesis of Results: Four representative articles[5-8] were selected for review that investigated how elevated-vacuum suspension impacted the gait and/or joint loads in persons with a TTA. All of the studies compared vacuum suspension to a non-vacuum suspension[5-8], and in two cases[4,7], to a control population without an amputation as well. Temporal-spatial parameters, gait kinematics, and gait kinetics were evaluated using three-dimensional motion capture systems and force plates[5-7]. Conclusions about joint loadings were made using results from the gait kinetics[7] and from direct evaluation of the knee joint using an ultrasonographic linear probe[8]. Key findings were that vacuum suspension resulted in more symmetrical gait[4-6] and increased cartilage in the knee joint of the amputated side[8]. The definition of gait symmetry varied, and could refer to improved Gait Profile Scores[5], more equal step lengths[6], an improved symmetry index[6], or more equal joint kinetics[7]. These studies were limited by small sample sizes and poor control of confounding variables. An example of this was evaluating elevated vacuum suspension with and without a knee sleeve. Conclusions were generalized to vacuum suspension but differences in gait metrics resulting from restricted knee range of motion caused by external knee sleeves were not controlled. Consequently, specific gait differences between studies were inconsistent.
Clinical Message: The results evaluated indicated that the vacuum suspension has biomechanical benefits in the form of increased gait symmetry and reduced cartilage degradation in the amputated limb. These changes have the potential to reduce the development of degenerative conditions such as osteoarthritis. Future studies should focus on larger sample sizes and long-term follow up of participants to evaluate potential benefits that cannot be captured in a single data collection session performed in the laboratory setting.

References:

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Evidence Table

	Ferreira, 2015[4]	*Gholizadeh, 2020[5]*	*Xu, 2017[6]*	*Onat, 2010[7]*
Population	17 unilateral transtibial amputees, 12 using Kondylen Bettung Münster (KBM) fitting, 5 using elevated vacuum socket; Data from 88 able-bodied control participants.	12 unilateral transtibial amputees. K3-K4 mobility level.	9 unilateral transtibial amputees; 9 able-bodied control participants. All male, K3-K4 mobility level.	38 below-knee amputees, 12 using active-vacuum suspension, 1 using passive-vacuum suspension, 25 using pin suspension.
Study Design	Comparative Analysis.	Experimental.	Between-subjects and within-subjects.	Cross-sectional.
Intervention	Socket with elevated-vacuum suspension.	Össur elevated-vacuum suspension system (Unity) at -16 to -20 in Hg.	Elevated-vacuum suspension at 0, -5, -10, -15, -20 in Hg increments.	Active and passive vacuum suspension.
Comparison	Socket made using Kondylen Bettung Münster fitting.	Seal-in V liner with suction suspension.	compared between health groups and within participants with an amputation at each vacuum level.	Silicone liner pin system suspension.
Methodology	Temporal-spatial parameters and gait kinematics during self-selected, level walking on a 10m walkway assessed using three-dimensional gait analysis and a Helen Hayes marker system. At least 6 trials were collected for each subject.	Temporal-spatial parameters, gait kinematics, and gait kinetics measured at self-selected walking speed on a variety of simulated terrains using a CAREN Extended System (instrumented treadmill and 3D motion analysis) Order of vacuum ON and OFF was randomized.	Temporal-spatial parameters, gait kinematics, and gait kinematics assessed during, level walking at 1.2-1.4m/s using 3D motion capture and force plates. Vacuum level was randomized. 5 trials with clean force plate strikes were taken at each vacuum level.	Ultrasonographic linear probe used to evaluate cartilage thickness of both knees of each participant with them lying supine with knees in maximum flexion. Muscle thickness evaluated with knees in extended position.
Outcomes	Gait Profile Score (GPS) and Movement Analysis Profile (MAP).	All temporal-spatial parameters, gait kinematics, and gait kinetics were compared between vacuum and no-vacuum conditions. Additionally, a symmetry index between sound limb and amputated limb for step length, step time, and stance time was evaluated.	Temporal-spatial parameters, gait kinematics, and gait kinetics for intact leg and leg with an amputation at 5 different vacuum levels. TAPES and Socket Comfort Score self-report outcomes were also used.	Cartilage thickness of the knee joint at the medial femoral condyle, lateral femoral condyle, and inter-condylar area. Muscle thickness of the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius muscles.

	Ferreira, 2015[4]	*Gholizadeh, 2020*[5]	*Xu, 2017*[6]	*Onat, 2010*[7]
Key Findings	Vacuum suspension group had better overall GPS scores compared to KBM group. Symmetry between lower limbs was higher in the vacuum group compared to the KBM group.	Vacuum suspension resulted in more symmetrical step length. Participants exerted less power at the ankle of their sound limb under the vacuum condition but the authors noted it may not achieve the level of clinical significance.	At all vacuum levels, stance phase of amputated side was shorter than sound side. Knee adduction moment balance between limbs improved with increased vacuum. Increased vacuum corresponded with increased braking and propulsive ground reaction forces on the amputated side, indicating increased reliance on prosthesis at higher vacuum levels.	Muscle and cartilage thickness of amputated limb lower than sound limb regardless of suspension type. Medial femoral condylar and lateral femoral condylarcartilage thickness was lower for silicon liner pin system compared to vacuum suspension.
Study Limitations	Small sample size, particularly in the vacuum group. Placement of knee marker on knee sleeve of vacuum sockets may have introduced erroneous results. No clear reporting of vacuum level nor pre/post vacuum level comparison. Primarily traumatic etiology. High male to female ratio (15:2).	No acclimation period given for no-vacuum condition. No pre/post vacuum level comparison. Participants were a high-functioning group, making generalizations to lower-functioning groups difficult. High male to female ratio (11:1).	Transtibial amputation group older than control group. The mass and inertial properties of the amputated limb+prosthesis were not well-approximated. Results for mechanical pumps may not be comparable to other vacuum methods. Vacuum levels post-trials were not evaluated.	Small sample size, cross-sectional design, lack of healthy control group or functional assessment. Mobility classification not reported. No reporting of vacuum level or pre/post vacuum level comparison. High male to female ratio (31:7). Did not consider the effect of previous suspension systems.