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Elevated Vacuum Suspension Systems for Adults with Amputation: A Review of Clinical Effectiveness, Cost-Effectiveness, and Guidelines

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Authors: Calvin Young, Hannah Loshak

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Abbreviations

AGREE	Appraisal of Guidelines for Research & Evaluation
AMSTAR	A MeaSurement Tool to Assess systematic Reviews
BBS	Berg Balance Scale
CAREN	Computer-Assisted Rehabilitation Environment
CRD	Centre for Reviews and Dissemination
GRADE	Grading of Recommendations Assessment, Development and Evaluation
IPAQ-SF	International Physical Activity Questionnaire Short Form
LCI	Locomotor Capabilities Index
MeSH	Medical Subject Headings
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SAT-PRO	Satisfaction with Prosthesis
SF-36	Short Form 36
VA/DoD	The Department of Veterans Affairs and the Department of Defense
VASS	vacuum-assisted suspension system

Context and Policy Issues

A prosthesis is an artificial device that functionally and cosmetically replaces a missing limb or body part. In the United States, the number of individuals living with limb loss exceeds two million.[1] This number is projected to nearly double by the year 2050, up to 3.6 million people.[2] A majority of amputations affect the lower limbs;[3,4] however, amputation can also occur on the upper extremities or other body parts (e.g., breasts, genitals). Limb loss may be a result of trauma, peripheral vascular disease, cancer, infection, or congenital anomalies.[5] For example, amputation may be used as a last resort when severe infection of a limb has led to irreversible tissue necrosis.[6]

A typical prosthesis used for limb replacement has three main components: a pylon, a socket, and a suspension system. The pylon is the internal skeleton that forms the bulk of the device. Traditionally made of metal alloys or carbon-fiber composites, pylons are built to withstand the kinetic forces required during prosthetic use.[7] The socket is located at the proximal end of the device and acts as a receiver for the residual limb. The connection between the residual limb and the prosthetic socket is facilitated by the suspension system. There are many types of suspension systems available, including pin-lock systems, suction suspension, supracondylar suspension cuffs, total elastic suspension, or elevated vacuum suspension systems.[8,9] Prosthetic socket design and suspension systems have been described as important factors that may significantly impact the satisfaction of the end user.[9,10] Thus, it is important to ensure appropriate systems are selected for individuals with varying needs. However, it is unclear whether more novel mechanisms of prosthetic suspension, such as elevated vacuum suspension systems,[11] provide benefit over other methods of suspension.

The objective of the current report is to evaluate the clinical effectiveness and cost-effectiveness of prosthetics with elevated vacuum suspension systems versus standard prosthetic systems for adults with amputation. Additionally, evidence-based guidelines regarding the use of elevated vacuum suspension systems will be reviewed.

Research Questions

1. What is the clinical effectiveness of elevated vacuum suspension systems versus standard prosthetic systems for adults with amputation?

2. What is the cost-effectiveness of elevated vacuum suspension systems versus standard prosthetic systems for adults with amputation?
3. What are the evidence-based guidelines regarding the use of elevated vacuum suspension systems?

Key Findings

Three relevant systematic reviews, five randomized controlled trials, and five non-randomized studies were identified regarding the clinical effectiveness of elevated vacuum suspension systems for adults (≥18 years of age) with amputation.

Evidence of limited quality suggested that elevated vacuum suspension systems may improve balance, physical capability, prosthetic pistoning, fear and risk of falling, residual limb volume, and skin health compared to non-vacuum suspension systems in adults with amputation; however, there was inconsistency in these results (i.e., in several instances there were no statistically significant differences between vacuum suspension systems and standard prosthetic systems).

Two evidence-based guidelines regarding the use of elevated vacuum suspension systems were identified. One guideline suggests that vacuum assisted suspension sockets permit the least amount of pistoning, followed by suction suspension and pin-lock suspension systems. The guideline also recommends that vacuum suspension systems may decrease daily limb volume fluctuations and facilitate favourable pressure distribution during gait compared to other suspension systems. Despite these positive recommendations, the authors of the guideline noted that vacuum assisted suspension sockets are not universally indicated and that awareness and compliance are required from the user of the device. The strength of these recommendations was not assessed. The second guideline stated that there was insufficient evidence to recommend for or against any particular prosthetic suspension system for adults with lower limb amputation (weak recommendation).

No evidence regarding the cost-effectiveness of elevated vacuum suspension systems versus standard prosthetic systems for adults with amputation was identified. The limitations of the included studies (e.g., high risk of performance bias due to a lack of blinding, lack of long-term follow-up data) should be considered when interpreting the findings of this report.

Methods

Literature Search Methods

A limited literature search was conducted by an information specialist on key resources including Medline via OVID, the Cochrane Library, the University of York Centre for Reviews and Dissemination (CRD) databases, the websites of Canadian and major international health technology agencies, as well as a focused Internet search. The search strategy was comprised of both controlled vocabulary, such as the National Library of Medicine's MeSH (Medical Subject Headings), and keywords. The main search concepts were artificial limbs and vacuum suspension. No filters were applied to limit the retrieval by study type. Where possible, retrieval was limited to the human population. The search was also limited to English language documents published between January 1, 2009 and December 3, 2019.

Selection Criteria and Methods

One reviewer screened citations and selected studies. In the first level of screening, titles and abstracts were reviewed and potentially relevant articles were retrieved and assessed for inclusion. The final selection of full-text articles was based on the inclusion criteria presented in Table 1.

Table 1: Selection Criteria

Population	Adults (≥18 years of age) with amputation
Intervention	Elevated vacuum suspension systems (a system containing small automatic pump motor), also known as sleeveless vacuum systems, vacuum assisted suspension, or sub-atomic atmospheric suspension
Comparator	Q1-Q2: Standard or traditional prosthetics or systems (e.g., lock-in or shuttle lock suspension, suction suspension, definitive fit of sock, traditional paddings, fiber glass socket padding/adjustments) Q3: Not applicable
Outcomes	Q1: Clinical effectiveness (e.g., quality of life, pain, comfort, gait, proprioception, wound healing) Q2: Cost-effectiveness (e.g., cost per net benefit) Q3: Evidence-based guidelines
Study Designs	Health technology assessments, systematic reviews, randomized controlled trials, non-randomized studies, economic evaluations, and evidence-based guidelines

Exclusion Criteria

Articles were excluded if they did not meet the selection criteria outlined in Table 1, they were duplicate publications, or were published prior to 2009. Primary studies retrieved by the search were excluded if they were captured in one or more included systematic reviews. Systematic reviews that had relevant included studies fully captured in other, more recent or more comprehensive (i.e., outcome data from relevant primary studies was more completely summarized) systematic reviews were excluded. Finally, guidelines with unclear methodology were excluded.

Critical Appraisal of Individual Studies

The included systematic reviews were critically appraised by one reviewer using A MeaSurement Tool to Assess systematic Reviews (AMSTAR) II,[12] the clinical studies were critically appraised using the Downs and Black checklist,[13] and evidence-based guidelines were assessed using Appraisal of Guidelines for Research & Evaluation (AGREE) II.[14] Summary scores were not calculated for the included studies; rather, the strengths and limitations of each included study were described narratively.

Summary of Evidence

Quantity of Research Available

A total of 180 citations were identified in the literature search. Following screening of titles and abstracts, 149 citations were excluded and 31 potentially relevant reports from the electronic search were retrieved for full-text review. In addition, six potentially relevant publications were retrieved from the grey literature search for full-text review. Of these 37 potentially relevant articles, 22 publications were excluded for various reasons, while 15 publications met the inclusion criteria and were included in this report. These comprised three systematic reviews,[4,15,16] five randomized controlled trials,[11,17-20] five non-randomized

studies,[21-25] and two evidence-based guidelines.[1,9] Appendix 1 presents the PRISMA[26] flowchart of the study selection. Additional references of potential interest are provided in Appendix 6.

Summary of Study Characteristics

Three relevant systematic reviews,[4,15,16] five randomized controlled trials,[11,17-20] five non-randomized studies,[21-25] and two evidence-based guidelines[1,9] were identified for inclusion in this review. No relevant health technology assessments or economic evaluations were identified. Detailed study characteristics are available in Appendix 2, Table 2, Table 3, and Table 4.

Study Design

The three included systematic reviews[4,15,16] had objectives and inclusion criteria that were broader than the current report (i.e., wider in scope). The review by Highsmith et al.,[4] published in 2016, searched for systematic reviews and primary studies published between January 1st 1997 and January 1st 2013 with a series of literature searches conducted in March, 2013. A total of three primary studies[27-29] relevant to the current report were included in this review. The other two systematic reviews were published in 2015 by Safari and Meier.[15,16] These complimentary systematic reviews, which made use of the same literature searches, included randomized and non-randomized studies published between January 1998 and July 2013. The first review[15] included primary studies with qualitative outcomes (three studies[28,30,31] relevant to the current report), while the second review[16] included primary studies that reported on quantitative outcomes (five studies[27,28,32-34] relevant to the current report). In total, the systematic reviews[4,15,16] included eight unique relevant clinical studies.[27-34] The relevant primary study overlap between these systematic reviews is summarized in Appendix 5, Table 11.

Ten primary studies[11,17-25] regarding the clinical effectiveness of elevated vacuum suspension systems for adults with amputation were identified. These included five randomized controlled trials[11,17-20] and five non-randomized studies.[21-25] Randomized study designs included three single single-centre, single-blinded (participants were blinded), randomized crossover trials[11,17,18] and two single-centre, open-label, randomized crossover trials.[19,20] The five non-randomized studies[21-25] utilized various methodologies, including: two cross-sectional observational studies,[21,24] one prospective, longitudinal cohort study,[22] one non-randomized crossover trial,[23] and one quasi-experimental before-and-after intervention study.[25]

Two evidence-based guidelines[1,9] were identified regarding the use of elevated vacuum suspension systems in adults with amputation. The guideline by Stevens et al.[9] (published in 2019) provides several recommendations regarding prosthetic socket design, interface, and suspension of definitive transtibial prostheses. The recommendations were informed by secondary knowledge sources (i.e., systematic reviews, meta-analyses, and scoping reviews) identified through literature searches were conducted in May 2017. The second guideline,[1] published in 2017 by the United States' Department of Veterans Affairs and the Department of Defense (VA/DoD), is an update to their 2007 "Clinical Practice Guideline for the Rehabilitation of Lower Limb Amputation". A series of extensive literature searches were conducted to identify relevant literature published between January 2007 and July 2016. Face-to-face meetings were convened with various members of the clinical guideline work group to draft recommendations following a review of the identified literature. The

Grading of Recommendations Assessment, Development and Evaluation (GRADE) tool was used classify recommendations as “strong” or “weak”.

Country of Origin

The included systematic reviews were by authors in Iran[15,16] and the United States.[4] Relevant primary studies included in the systematic reviews were conducted in Italy[29] and the United States[27,28,30-34] and published between 2001 and 2012.

The randomized controlled trials were conducted Canada[11,17,18] and the Untied States.[19] Non-randomized studies were conducted in Spain,[25] Turkey,[21] and the United States.[22-24]

The evidence-based guidelines were developed by researchers in the United States.[1,9]

Patient Population

One systematic review[4] included studies that enrolled adult patients with transtibial amputation who were living in a developed country. The characteristics of participants in the included studies (e.g., number of participants, mean age, sex) were not reported. The two systematic reviews by Safari and Meier[15,16] included primary studies that recruited individuals with unilateral or bilateral transtibial amputations for any reason who had at least six months of prosthesis experience (i.e., those with a mature residual limb). The first review[15] included 790 adults with an average age of 50.7 years. The proportion of female participants in studies that reported sex was 20.3% and a majority of amputations were a result of trauma. The second Safari and Meier[16] review included 302 adult participants (mean age of 42.64 years). Similar to the first review,[15] the proportion of female participants in studies that reported sex was 18.6% and a majority of amputations were a result of trauma. The characteristics of participants from primary studies[27-29,32-34] relevant to the current report were not reported separately.

Three included randomized controlled trials[11,17,18] enrolled the same group of participants from the Ottawa Hospital Rehabilitation Centre, Prosthetics and Orthotics Services. These 12 individuals (11 males, one female) had unilateral transtibial amputation, could walk without walking aids (i.e., were K3 or K4 according to Medicare Functional Classification Levels), and used their prosthesis daily. Their mean age was 57.2 years. The study by Rosenblatt et al.[19] recruited 36 individuals with a lower limb amputation (transtibial or transfemoral) who had their amputation ≥1 year ago. Participants’ mean age was 50.7 years (sex was not reported). The Rink et al.[20] study included 10 participants (nine males, one female) who had a mean age of 47.1 years with unilateral lower-limb amputation.

The non-randomized study by Çalışkan Uçkun et al.[21] recruited 51 individuals (45 males, six females; mean age of 47.6 years) with transtibial amputation who were Medicare Functional Classification Level K3 or higher and wore their prosthesis for at least eight hours per day. Rosenblatt and Ehrhardt[22] enrolled 27 users of lower limb prostheses with unilateral amputation. Participants’ mean age was 51.2 years and the proportion of female participants was 37.0%. The study by Darter et al.[23] included 10 adult men (mean age 31 years) with transtibial amputation. Şahin Onat et al.[24] enrolled 38 individuals (31 males, 7 females) with transtibial amputation who had been using a below-knee prosthesis for at least six months. Their mean age was 41.0 years. Finally, Samitier et al.[25] recruited 16 individuals (14 males, 2 females; mean age of 65.12 years) with unilateral transtibial amputation. Overall, a total of 200 participants were included in the relevant primary clinical studies. The participant populations were predominantly males with transtibial amputation.

The guideline by Stevens et al.[9] provides information relating to the treatment of individuals with transtibial amputation as a result of traumatic event, poor vascular status, or other etiologies. The intended users of this guideline are prosthetists, surgeons, therapists, physicians, case managers, and policy makers. The VA/DoD[1] guideline covers a wide-range of topics regarding the rehabilitation of individuals with lower limb amputation and is intended for use by clinicians who provide care to patients in rehabilitation for lower limb amputation.

Interventions and Comparators

The three included systematic reviews[4,15,16] investigated a variety of interventions and comparators regarding the prosthetic management of adults with transtibial amputation. Relevant to the current report, all three systematic reviews[4,15,16] included studies that compared elevated vacuum suspension systems to total surface bearing sockets with pin-locking suspension systems. The second systematic review by Safari and Meier[16] also included two primary studies[32,33] that compared elevated vacuum suspension systems versus prosthetics with sleeve suspension or suction suspension.

The interventions in the included clinical studies[11,17-25] (both randomized and non-randomized studies) were various prosthetics equipped with elevated vacuum suspension systems. Although the authors of five studies[19,21-24] did not restrict their study population to a specific prosthetic device, all participants in the randomized trial by Rink et al.[20] were using the LimbLogic vacuum system, three studies[11,17,18] (conducted with the same participants) used the Iceross Seal-In V liner and Pro-flex XC foot with Unity pump, and participants in the Samitier et al.[25] were provided Ottobock Harmony P2 & HD devices. Comparators from the relevant clinical studies included: suction suspension systems,[11,17-19,23] sleeve suspension systems,[19] pin-lock systems,[21,24] or non-vacuum assisted devices (which could have included a number of suspension systems).[20,22,25]

The Stevens et al.[9] and VA/DoD[1] guidelines considered a wide variety of interventions that may be considered for use in adults with lower limb amputation. These included prosthetics with vacuum assisted, suction, pin-lock, or cuff and sleeve suspension systems.

Outcomes

The three systematic reviews[4,15,16] included studies that evaluated outcomes relating to clinical effectiveness. Highsmith et al.[4] did not appear to restrict their systematic review to specific outcomes. Relevant primary studies[27-29] reported on socket pressure parameters, limb pistoning (i.e., the undesirable movement of the residual limb out of the socket and back into the socket when body weight is taken off or applied to the prosthetic, respectively), patient preference, activity levels, and timeliness of prosthetic fitting. The Safari and Meier reviews separately reported on qualitative[15] and quantitative[16] outcomes. Qualitative outcomes from relevant primary studies[28,30,31] reported in their first review[15] included functional capability, balance task performances, pain, activity level, fear of falling, frustration with the socket, and residual limb health. Relevant studies[27,28,32-34] in the quantitative review[16] reported on gait symmetry, limb pistoning, various socket pressure parameters, and residual limb volume.

The ten primary studies[11,17-25] examined a wide range of clinical outcomes. Three randomized controlled trials,[11,17,18] reported on several temporal-spatial gait parameters (e.g., velocity, stride length, step width) and kinematic and kinetic parameters (e.g., peak plantar flexion, ankle range of motion, hip range of motion) collected using the Computer-Assisted Rehabilitation Environment (CAREN) Extended System. The Rosenblatt et al.[19]

study monitored several gait parameters, locomotor abilities, function related to prosthetic wear and use, and prosthesis-related quality of life in their study population. The fifth randomized controlled trial[20] assessed outcomes relating to skin health, including skin barrier function, residual-limb perfusion, transcutaneous oxygen measurement, and reactive hyperemia. Çalışkan Uçkun et al.[21] measured level of physical activity and quality of life as their outcomes of interest with the International Physical Activity Questionnaire Short Form (IPAQ-SF) and the Short Form 36 (SF-36), respectively. The IPAQ-SF is a validated seven-item questionnaire that categorizes subjects as having a high, moderate, or low level of activity.[35] The SF-36 is a multipurpose survey consisting of 36 questions that is used to evaluate mental and physical functioning and overall health-related quality of life. Responses are weighted between 0 (lowest level of health) and 100 (highest level of health) and combined to yield a physical health composite score and a mental health composite score.[36] The non-randomized study by Rosenblatt and Ehrhardt[22] examined risk of falling and stumbling. Darter et al.[23] measured socket fit and displacements while applying body weight within their study population using digital video fluoroscopy recording. The outcomes of interest in the Şahin Onat et al.[24] study were femoral cartilage and quadriceps muscle thicknesses, which were measured using musculoskeletal ultrasound. The Samitier et al.[25] study report on participants' overall mobility, balance, physical and locomotor capability, satisfaction with their prosthesis, and use of prosthesis. Balance was measured using the Berg Balance Scale (BBS), a 14-item validated scale that assigns subjects with a score between 0 and 56 (higher scores indicate greater ability to balance).[37] The Locomotor Capabilities Index (LCI), which is a 14 item self-administered questionnaire (scored between 0 and 42 points; higher score implying greater mobility), was used to quantify locomotor ability.[25] Patient satisfaction was measured with the Satisfaction with Prosthesis (SAT-PRO) questionnaire. This self-administered questionnaire is comprised of 15 categories, with lower scores indicating higher satisfaction.[38] Prosthetic use was quantified using the Houghton Scale, which is a four-item instrument scored between 0 and 12, with higher scores indicating greater performance and greater comfort.[39]

The recommendations made by Stevens et al.[9] addressed three key considerations: 1) comparative clinical effectiveness, 2) benefits of treatments (e.g., timeliness of prosthetic fitting, enhanced activity levels, patient satisfaction, reduced movement of the residual limb within the socket, mitigation of forces within the socket, stabilization of limb volume, improved comfort, and better gait symmetry), and 3) harms of treatment (e.g., injury to the residual limb secondary to socket forces, discomfort, heat and perspiration, donning difficulties, and system maintenance requirements). The VA/DoD[1] guidelines considered several outcomes within their evidence review, including changes in functional status, walking ability, quality of life, patient satisfaction, strength, pain, morbidity, safety (e.g., falls), and complications.

Summary of Critical Appraisal

Additional details regarding the strengths and limitations of the included publications are provided in Appendix 3, Table 5, Table 6, and Table 7.

Systematic Reviews

The three included systematic reviews[4,15,16] were generally well-conducted according to AMSTAR II criteria.[12] All three reviews[4,15,16] had clearly defined research questions, objectives, and eligibility criteria. The authors stated their choice of included study designs and provided justification for their decision. The review methods for two of the systematic reviews[15,16] were prospectively registered in a published protocol, decreasing the risk for

selective reporting. Key search terms and search strategies were provided in all three reviews,[4,15,16] increasing their reproducibility, and literature searches were performed in multiple databases. The methods for article selection, data extraction, and quality assessment were well-documented and were conducted in duplicate (with the exception of quality assessment in two reviews,[15,16] where it was unclear if it was conducted by a single author or in duplicate), decreasing the likelihood for inconsistency in these processes. The reviews[4,15,16] included flow charts illustrating study selection and provided reasons for study exclusion. Risk of bias and limitations of primary study designs were assessed using appropriate tools and were considered when discussing the results of the reviews.[4,15,16] Finally, the authors of all thee systematic reviews[4,15,16] disclosed their sources of funding (which were considered unlikely to have influenced the findings of the reviews) and stated that they had no related conflicts of interest.

As for the limitations of the reviews, the literature search strategies of all three reviews[4,15,16] did not include grey literature searches, increasing the risk for missing relevant, non-indexed studies, and although reasons for exclusion were provided, the reviews[4,15,16] did not include a list of the excluded studies. Additionally, several key study characteristics from the primary studies were missing from all three of the systematic reviews,[4,15,16] including number of trial participants, study designs, and detailed descriptions of study results. Finally, there was no discussion of publication bias and the countries in which relevant primary studies were conducted were not described[4] or were conducted outside of Canada;[15,16] therefore the generalizability of the findings to the Canadian setting is unclear.

Randomized Controlled Trials

The authors of the five randomized controlled trials[11,17-20] provided a clear description of their objectives, interventions, controls, methods for patient recruitment, outcomes, and main findings. Details on baseline participant characteristics (e.g., age, sex, weight, years since amputation, cause of amputation) were provided and were constant across intervention and comparator groups due to the nature of the studies (i.e., randomized crossover trials). The order in which participants received the interventions and comparators was randomized and compliance was reliable in all five studies.[11,17-20] Actual probability values (*P*-values) and estimates of random variability (e.g., standard deviations, confidence internals) were reported and the major findings were presented clearly in all five randomized controlled trials,[11,17-20] increasing the strength of reporting. Study participants, care providers, and health care settings appeared to be representative of the population and care settings of interest, increasing the external validity of the studies. Three of these studies studies[11,17,18] were conducted in Ottawa, Ontario, and should therefore have relatively high generalizability to Canadian settings. The authors of all five studies[11,17-20] declared that they had no potential conflicts of interest and disclosed their sources of financial support or funding.

As for methodological limitations, the included randomized controlled trials[11,17-20] recruited a limited number of participants, which may have decreased the ability for studies to detect significant differences between interventions. Total study populations ranged between 10[20] and 32[19] individuals. This issue is particularly noteworthy considering none of the studies[11,17-20] conducted a power calculation prior to recruiting participants. Although three studies[11,17,18] stated participants were blinded to the order of intervention assignment, clinicians and study conductors appeared to be unblinded at the time of outcome assessment in all studies,[11,17-20] creating a risk for bias in either direction depending on the perceptions and expectations of those involved. In addition, four studies[11,17-19] did not

provide an appropriate acclimation period between intervention and comparator assessments; participants may have had increased performance on the suspension system they were more familiar with. Finally, the authors of three of the included studies[11,17,20] either received financial support from or were an employee of orthopaedics manufacturers.

Non-Randomized Studies

There were several strengths common to all five non-randomized studies,[21-25] including: 1) clearly described objectives, interventions, controls, main outcomes, and participant characteristics (e.g., age sex, type of amputation, years since amputation), 2) reliable compliance with the intervention (i.e., the socket systems), 3) reported estimates of random variability (e.g., standard deviations, confidence intervals) and actual probability values (*P*-values), 4) clearly described major findings, and 5) all study authors declared that they had no potential conflicts of interest and sources of funding were disclosed and were unlikely to have influenced the findings of the studies. Two studies[21,25] provided a detailed outline of the methodology used to recruit participants; however, these methods were unclear in three studies.[22-24] Two studies[23,25] were conducted using a crossover or before-and-after design, decreasing the risk for bias due to uncontrolled confounding as participants were tested with both interventions of interest. Finally, study participants, care providers, and health care settings appeared to be representative of the population and care settings of interest, increasing the external validity of the studies.[21-25]

The included non-randomized studies[21-25] also had several limitations. For example, all five studies[21-25] were open-label, increasing the risk for bias in either direction depending on the perceptions and expectations of participants and outcome assessors. Additionally, intervention assignment was not done at random (creating a risk for bias due to uncontrolled factors) and adverse events that may have been related to type of prosthetic suspension system were poorly reported. The Samitier et al.[25] study was at risk for several biases due to its before-and-after design. For example, participants may have performed better on physical tests (e.g., the Four Square Step Test, the Timed Up and Go Test, or the 6-Minute Walk Test) with the vacuum-assisted prosthesis because they were familiar with the testing procedure. Two studies[23,25] recruited a limited number of participants ($N \leq 16$), and four of the included non-randomized studies[22-25] did not perform a power calculation prior to participant recruitment; studies may not have been powered to detect statistically significant between-group differences. The generalizability of the findings from the five non-randomized studies to Canadian settings is unclear given they were conducted in Turkey,[21,24] Spain,[25] and the United States.[22,23]

Evidence-Based Guidelines

Both guidelines[1,9] provided a clear description of their scope and purpose, including objectives, health questions, intended users, and target population. The recommendations were well presented and unambiguous and the views of the funding bodies did not appear to have influenced the content of the guidelines.[1,9] There were explicit links between the supporting evidence (which was identified using systematic approaches) and the final recommendations. However, the guideline by Stevens et al.[9] did not conduct their literatures searches in multiple electronic databases and only included literature from secondary knowledge sources (i.e., systematic reviews, meta-analyses, and scoping reviews). The decision to exclude primary studies may have omitted relevant information. The Stevens et al.[9] guideline also had several additional limitations: there was no clear description of the methods of evidence selection and recommendation formulation, the views and preferences of the target population were not directly considered, and there were

no tools on how the recommendations could be applied in practice. Overall, the methodology used to develop the VA/DoD guidelines[1] was rigorous; however, neither guideline[1,9] explicitly summarized the strengths and limitations of the body of evidence, included discussion of facilitators or barriers to implementation, provided a procedure for updating the guideline in the future, or included monitoring and auditing criteria. Finally, it should be noted that both guidelines[1,9] were developed for use in the United States; therefore, the generalizability of the recommendations to the Canadian context is unclear.

Summary of Findings

The overall findings of the included studies are highlighted below. Detailed summaries of the main findings are available in Appendix 4, Table 8, Table 9, and Table 10.

Clinical Effectiveness of Elevated Vacuum Suspension Systems

Activity levels, balance, and ambulation

Evidence regarding the clinical effectiveness of vacuum suspension systems with respect to activity levels, balance, and ambulation was available from three primary studies[28,30,31] within one systematic review[15] and three additional primary studies.[19,21,25]

The findings of one study[30] suggested that participants with vacuum-assisted sockets had increased confidence in their balance (measured using the Activity Balance Confidence scale) compared to those with pin-lock sockets. Rosenblatt et al.[19] noted that there were no statistically significant differences between vacuum-assisted suspension system (VASS) users and non-VASS users with respect to several locomotor abilities and capabilities (measured with Activities-Specific Balance Confidence scores and the Locomotor Capabilities Index 5); however, users of VASS prosthetics demonstrated significantly faster Timed Up and Go results than sleeve socket users and achieved higher maximum speeds during a 10-minute walk test than users of suction or sleeve sockets. In a non-randomized study by Çalışkan Uçkun et al.,[21] VASS and pin-lock socket users reported similar (i.e., not statistically different) time per week spent doing the metabolic equivalent of walking, moderate activity, vigorous activity, and total activity. Using a before-and-after design, Samitier et al.[25] noted that participants had improved balance and physical capabilities (measured with the Berg Balance Scale, Four Square Step Test, the Timed Up and Go Test, and the 6-Minute Walk Test) when using a VASS socket compared to their previous non-VASS prosthetic; however, subjective measures of locomotor capability (assessed with the Locomotor Capabilities Index) were not significantly different between the groups. The authors of a case study[31] (included in a systematic review[15]) reported improvement in the individual's scores of locomotor capability and activities of daily living following a change from a patellar tendon bearing socket to a VASS. Contradictory to other results, the authors of one study[28] from an included systematic review[15] stated that participants were less active (measured using step activity) and had decreased ambulation while using a VASS compared to pin-lock sockets.

Gait parameters

Four primary studies[11,17,18,32] assessed the effect of VASS prosthetics on various gait parameters. Three randomized crossover trials[11,17,18] conducted by overlapping groups of authors examined gait parameters in participants with unilateral transtibial amputation while walking on level ground,[11] uphill or downhill,[17] or at self-selected speed with medial-lateral translations, rolling hills, and simulated uneven ground.[18] The authors of these studies[11,17,18] concluded that while there were some statistically significant differences observed between

vacuum and suction systems for some gait parameters, the differences were small and were considered not clinically significant. Board et al.[32] reported increased step length symmetry, increased stance duration symmetry, and decreased axial movement of the liner and tibia relative to the socket in participants using a VASS compared to those with total surface bearing sockets with sleeve suspension.

Pistoning and limb-socket movement

The effect of VASS on pistoning and limb-socket movement was examined in two relevant primary studies.[23,28] Klute et al.[28] noted that participants with a VASS socket had significantly improved (i.e., reduced) pistoning compared to those using a total surface bearing pin-lock socket. Similarly, bone-socket displacement as weight was applied to the prosthesis was significantly reduced in participants wearing a VASS compared to a passive suction system in the non-randomized study by Darter et al.,[23] particularly during initial body weight loading.

Fear and risk of falling

Two relevant primary studies[22,30] evaluated the effect of VASS on fear or risk of falling. In the study by Ferraro et al.,[30] participants reported a decreased fear of falling during daily activities with a VASS prosthesis compared to their previous total surface bearing sockets. Participants with transtibial amputation in the non-randomized study by Rosenblatt and Ehrhardt[22] were at decreased risk for having one or more or recurrent falls (i.e., two or more falls) if they were using a VASS prosthetic (compared to a non-VASS prosthetic). This difference was not observed in participants with transfemoral amputation, where there were no statistically significant differences between VASS and non-VASS users with respect to risk of falling.

Quality of life

Outcomes relating to quality of life were assessed in three clinical studies.[19,21,25] The results of these studies[19,21,25] suggested that there were no statistically significant differences between VASS and non-VASS users on various measures of quality of life. Rosenblatt et al.[19] noted that there were no significant differences between VASS users and non-VASS users with respect to self-reported prosthesis-related quality of life (measured with the Prosthetic Evaluation Questionnaire). The results of a non-randomized study[21] indicated that participants with VASS prosthetics had similar SF-36 scores compared to those with pin-lock suspension systems. The authors of the third study[25] reported no significant differences in SAT-PRO scores between VASS and non-VASS users.

Residual limb volume

The effect of suspension type on residual limb volume was examined in three primary studies[28,32,33] summarized in one systematic review.[16] Board et al.[32] reported that participants with a VASS socket had increased residual limb volume compared to those with a total surface bearing socket following a 30-minute treadmill walking test. Gerschutz et al.[33] reported significantly less volume fluctuation with the vacuum system compared with a suction suspension. The authors of the third study[28] concluded that there were no significant differences between participants using a total surface bearing socket and a VASS with respect to residual limb volume following a 30-minute treadmill walking test.

Socket comfort

In the randomized crossover trial by Rosenblatt et al.,[19] study participants reported higher self-reported socket fit comfort scores while wearing the VASS compared to suction or sleeve sockets.

Prosthetic use

Two included clinical studies[19,25] investigated the effect of socket type on prosthetic use using the Houghton Scale. The authors of both studies[19,25] concluded there were no statistically significant differences between VASS users and non-VASS users with respect to prosthetic use within their participant populations.

Skin health

The effect of VASS on residual limb skin health was evaluated in two relevant primary studies.[20,28] In the randomized crossover trial by Rink et al.[20] participants had improved transepidermal water loss and significantly decreased reactive hyperemia with the elevated vacuum system compared to their previous standard of care prosthesis (which were either suction or pin-locking sockets) after 16 weeks of use; however, there were no statistically significant differences between the elevated vacuum system and standard of care sockets with respect to skin perfusion. Similarly, participants in the study by Klute et al.[28] reported increased health of their residual limb while using vacuum sockets compared to pin-lock sockets.

Muscle and cartilage thickness

One included non-randomized study[24] examined the differences in quadriceps muscle and distal femoral cartilage thickness in participants with VASS prosthetics and silicon liner pin systems. The authors observed significantly higher lateral femoral condyle cartilage thickness and medial femoral condyle cartilage thickness in the amputated limbs of participants with the vacuum system (i.e., the unfavourable effects on the cartilage seemed to be worse in users of the silicone liner pin system); however, there were no other statistically significant difference in other measurements of femoral cartilage and quadriceps muscle thickness between groups.

Cost-Effectiveness of Elevated Vacuum Suspension Systems

No relevant evidence regarding the cost-effectiveness of elevated vacuum suspension systems for adults (≥18 years of age) with amputation was identified; therefore, no summary can be provided.

Guidelines Regarding the Use of Elevated Vacuum Suspension Systems

Two evidence-based guidelines[1,9] were identified regarding the use of elevated vacuum suspension systems in prosthetics for adults with amputation.

The guidelines by Stevens et al.[9] include several recommendations regarding socket design, interface, and suspension in prosthetics for transtibial amputees. The first recommendation is that vacuum assisted suspension sockets permit the least amount of pistoning, followed by suction suspension and pin-lock suspension systems. The authors continued by stating that more traditional options, such as supracondylar, cuff and sleeve suspension provide comparatively compromised suspension. The second relevant recommendation states that vacuum assisted suspension sockets are indicated to decrease

daily limb volume changes and facilitate more favourable pressure distribution during gait. The final relevant recommendation from the Stevens et al.[9] guidelines suggests that vacuum assisted suspension sockets are not universally indicated and that awareness and compliance are required from the user of the device. None of these recommendations were graded (i.e., strong or weak); however, they were based on evidence from several systematic reviews.

The guidelines from United States' VA/DoD[1] state that there was insufficient evidence to recommend for or against any particular socket design, suspension system, or interface. This recommendation was in conjunction with a weak recommendation in favour of offering microprocessor knee units over non-microprocessor knee units for ambulation in order to reduce the risk of falls and increase patient satisfaction. This recommendation was based on evidence from five systematic reviews and two primary studies that were identified following a systematic review of the literature.

Limitations

A number of limitations were identified in the critical appraisal (Appendix 3, Table 5, Table 6, and Table 7), however, additional limitations exist.

All included studies were specific to participants with lower-limb amputation (i.e., transfemoral or transtibial). The clinical effectiveness of vacuum suspension systems for adults with other amputations (e.g., transradial, transhumeral) is unknown.

Many of the included studies collected data over short follow-up durations. For example, eight of the clinical studies collected data in a single testing session without providing an acclimation for all tested socket conditions[11,17-19,23] or used a cross-sectional design.[19,21,24,25] There is uncertainty in the long-term clinical effectiveness of elevated vacuum systems, which is a significant limitation given that prosthetic devices are typically designed for use over long periods of time.

Primary studies that reported information on the sex of their participant population enrolled a disproportionately high number of males (83.5% men; 137 males out of 164 study participants). Although this may be reflective of the higher incidence of amputation in males,[40,41] this should be considered when generalizing the findings of the included literature to female patients.

No evidence regarding the cost-effectiveness of elevated vacuum suspension systems for adults (≥18 years of age) with amputation was identified.

Both of the included guidelines[1,9] were intended for users in the United States. Therefore, it is unclear if differences in care pathways or other factors may decrease the generalizability of the recommendations to the Canadian setting.

Conclusions and Implications for Decision or Policy Making

This review was comprised of three systematic reviews,[4,15,16] five randomized controlled trials,[11,17-20] five non-randomized studies,[21-25] and two evidence-based guidelines[1,9] regarding the use of elevated vacuum suspension systems for adults (≥18 years of age) with amputation. No evidence was identified regarding the cost-effectiveness of elevated vacuum suspension systems.

Although some of the identified literature indicated that elevated vacuum suspension systems may improve balance,[30] physical capability,[19,25] prosthetic pistoning,[23,28] fear and risk of falling,[22,30] socket comfort,[19] residual limb volume,[32,33] and skin health[20,28] compared to non-vacuum suspension systems, there was inconsistency in the results (i.e., in some instances studies did not detect statistically significant differences between vacuum and non-vacuum groups or reported significant improvements favouring non-vacuum suspension systems [e.g., the authors of one study[28] observed that participants were less active and had decreased ambulation while using a VASS compared to pin-lock sockets]). There were no statistically significant differences in measures of quality of life between users of VASS and non-VASS devices.[19,21,25] The uncertainty of these findings was reflected in the included evidence-based guidelines.[1,9] Stevens et al.[9] provided some support for vacuum-assisted devices; however, they recommended that vacuum-assisted suspension sockets are not universally indicated. The VA/DoD guidelines[1] stated that there was insufficient evidence to recommend for or against any particular suspension system.

The limitations of the included literature[1,4,9,11,15-25] (e.g., the limited number of participants, risk of performance bias due to a lack of blinding of participants and study personnel) should be considered when interpreting the results. Further research investigating the clinical and cost-effectiveness of elevated vacuum suspension systems, especially with clinical trials that recruit larger sample sizes and report long-term outcome data, would provide additional support to clinicians who provide care to adults with amputation.

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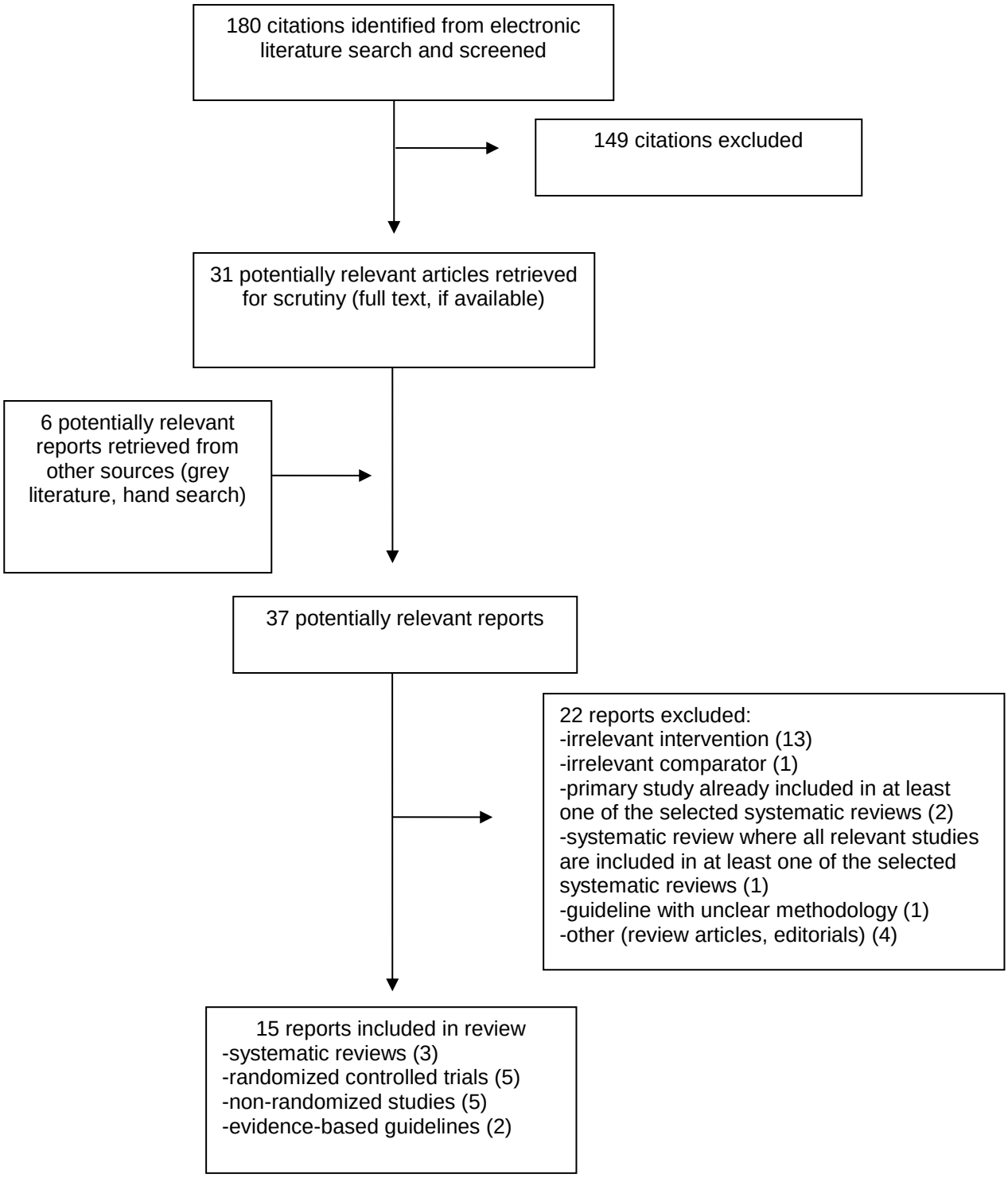
Appendix 1: Selection of Included Studies



Appendix 2: Characteristics of Included Publications

Table 2: Characteristics of Included Systematic Reviews

Study Citation, Country, Funding Source	Objective, Study Design, Search Strategy, Number of Primary Studies Included, Quality Assessment Tool	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Highsmith et al., 2016[4] United States **Funding source**: The American Orthotic and Prosthetic Association (project 111012).	**Objective**: To provide a review of the available evidence regarding the prosthetic management of adults with transtibial amputation. The five domains of interest were alignment, feet and ankles, interface, post-operative care, and pylons. **Study design**: Systematic review and meta-analysis that included other systematic reviews and primary studies. Case studies, retrospective studies, observational and survey only studies, economic studies, and studies deemed as being of low methodological quality (i.e., systematic reviews with a high risk of bias [according to SIGN classification] and primary studies with PEDro score ≤5/10) were excluded. **Literature search strategy**: Authors searched for literature published between January 1st 1997 and January 1st 2013 using PubMed, CINAHL, RECAL Legacy, Cochrane Database of Systematic Reviews, PubMed Central-National Institutes of Health Research Publication Database, and Web of Science between March 11th and March 19th, 2013. The search was repeated after three months. **Number of studies included**: Six systematic reviews and 25 primary studies were included in the qualitative synthesis (three[27-29] of which were relevant to the current report). **Quality assessment tool:** The quality of included systematic reviews was assessed	Adult patients with transtibial amputation who were living in a developed country.	This review included literature that compared various interventions involved in prosthetic management. Interventions were categorized under five main topics (i.e., alignment, feet and ankles, interface, post-operative care, and pylon). Studies relevant to the current report compared vacuum-assisted suspension systems with total surface bearing-designed interfaces that used pin locking suspension mechanisms.	**Outcomes assessed in relevant studies**: - Time to prosthetic fitting - Locomotor skills - Pain - Wound dimensions - Pistoning - Activity level - Residual limb pressures **Follow-up**: NR; varied by individual study.

Table 2: Characteristics of Included Systematic Reviews

Study Citation, Country, Funding Source	Objective, Study Design, Search Strategy, Number of Primary Studies Included, Quality Assessment Tool	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
	with SIGN 50, while both the SIGN 50 and PEDro checklists were used to assess primary studies. Levels of evidence were assigned using the model designed by the Centre for Evidence-Based Medicine.			
Safari and Meier, 2015a[15] Iran **Funding source**: No financial support was received.	**Objective**: To review the literature on transtibial prosthetic socket types to identify which features may be best for various clinical scenarios. This review was specific to qualitative outcomes. **Study design**: Systematic review of relevant randomized and non-randomized studies. This report is complimentary to the Safari and Meier 2015b[16] systematic review. **Literature search strategy**: Literature searches were performed in Medline (PubMed), EMBASE (Ovid Interface), Google Scholar, the Cochrane Library, and Web of Knowledge for articles published from 1998 to July 2013. **Number of studies included**: A total of 35 studies were included in the synthesis; 19 used qualitative outcomes and were included in this systematic review (three[28,30,31] of which were relevant to the current report). **Quality assessment tool**: The Downs and Black checklist was used to assess the risk of bias of the included studies (both randomized and non-randomized).	Individuals with unilateral or bilateral transtibial amputations for any reason who had at least 6 months of prosthesis experience (i.e., those with a mature residual limb).	Studies that evaluated the effectiveness of various prosthetic socket types were included in the systematic review. Studies relevant to the current report compared vacuum-assisted suspension systems with patellar tendon bearing or total surface bearing sockets.	**Outcomes assessed in relevant studies**: - Functional capability - Balance task performances - Pain - Activity level - Fear of falling - Frustration with the socket - Residual limb health **Follow-up**: NR; varied by individual study.
Safari and Meier, 2015b[16] Iran	**Objective**: To review the literature on transtibial prosthetic socket types to identify which features may be best for various clinical scenarios. This review was specific to quantitative outcomes.	Individuals with unilateral or bilateral transtibial amputations for any reason who had at	Studies that evaluated the effectiveness of various prosthetic socket types were included in the systematic review.	**Outcomes assessed in relevant studies**: - Gait symmetry - Limb pistoning

Table 2: Characteristics of Included Systematic Reviews

Study Citation, Country, Funding Source	Objective, Study Design, Search Strategy, Number of Primary Studies Included, Quality Assessment Tool	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Funding source: No financial support was received.	**Study design**: Systematic review of relevant randomized and non-randomized studies. This report is complimentary to the Safari and Meier 2015b[15] systematic review. **Literature search strategy**: Literature searches were performed in Medline (PubMed), EMBASE (Ovid Interface), Google Scholar, the Cochrane Library, and Web of Knowledge for articles published from 1998 to July 2013. **Number of studies included**: A total of 35 studies were included in the synthesis; 27 used quantitative outcomes and were included in this systematic review (five[27,28,32-34] of which were relevant to the current report). **Quality assessment tool**: The Downs and Black checklist was used to assess the risk of bias of the included studies (both randomized and non-randomized).	least 6 months of prosthesis experience (i.e., those with a mature residual limb).	Studies relevant to the current report compared vacuum-assisted suspension systems with total surface bearing sockets.	- Various socket pressure parameters - Residual limb volume **Follow-up**: NR; varied by individual study.

CINAHL = Cumulative Index of Nursing and Allied Health Literature; PEDro = Physiotherapy Evidence Database Scale; SIGN = Scottish Intercollegiate Guidelines Network.

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Randomized Controlled Trials				
Gholizadeh et al., 2019[11] Canada **Funding source**: Financial support was received from Mitacs and Össur.	**Objective**: To investigate the walking performance (on level ground) of unilateral transtibial amputees with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system). **Study design**: Single-centre, single-blinded (participants were blinded), randomized crossover trial. **Setting**: Participants were recruited from the Ottawa Hospital Rehabilitation Centre, Prosthetics and Orthotics Service.	**Inclusion criteria**: Individuals with unilateral transtibial amputation who could walk without walking aids (i.e., were K3 or K4 according to MFCLs), had steady residual limb volume during the previous year, and who used a prosthesis daily. **Excluded**: Those who reported joint pain, stroke, visual impairment, cognitive problems that influenced gait and balance, recent amputation (<1 year), or residual limb volume <10 cm. **Number of participants**: 12. **Mean age, years (SD)**: 57.2 (15.3). **Mean weight, kg (SD)**: 90.6 (16.4). **Sex**: 8.3% female. Note: This participant population is the same as the one in the Gholizadeh 2018[17] and Thibault 2018[18] studies.	**Intervention**: Participants were fitted with an Iceross Seal-In V liner (high or standard profile) and Pro-flex XC foot with Unity pump according to the manufacturer guidelines. **Comparator**: The identical prosthetic system with the vacuum turned off (creating a suction seal). Participants were given a one-month acclimation period prior to testing.	**Clinical outcomes**: - Temporal-spatial gait parameters (e.g., velocity, stride length, step width) - Kinematic and kinetic parameters (e.g., peak plantar flexion, ankle range of motion, hip range of motion) Note: Only level walking data were examined in this publication. **Follow-up**: None. All data were collected using the CAREN Extended System in a laboratory setting.
Gholizadeh et al., 2018[17] Canada **Funding source**: Financial support was received from Mitacs and Össur.	**Objective**: To investigate the walking performance (during uphill and downhill walking activities) of unilateral transtibial amputees with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system). **Study design**: Single-centre, single-blinded	**Inclusion criteria**: Individuals with unilateral transtibial amputation who could walk without walking aids (i.e., were K3 or K4 according to MFCLs), had steady residual limb volume during the previous year, and who used a prosthesis daily. **Excluded**: Those who reported joint pain, stroke, visual impairment, cognitive problems that influenced gait and balance, recent amputation	**Intervention**: Participants were fitted with an Iceross Seal-In V liner (high or standard profile) and Pro-flex XC foot with Unity pump according to the manufacturer guidelines. **Comparator**: The identical prosthetic system with the vacuum	**Clinical outcomes**: - Temporal-spatial gait parameters (e.g., velocity, stride length, step width) - Kinematic and kinetic parameters (e.g., peak plantar flexion, ankle range of motion, hip range of motion)

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
	(participants were blinded), randomized crossover trial. **Setting**: Participants were recruited from the Ottawa Hospital Rehabilitation Centre, Prosthetics and Orthotics Service.	(<1 year), or residual limb volume <10 cm. **Number of participants**: 12. **Mean age, years (SD)**: 57.2 (15.3). **Mean weight, kg (SD)**: 90.6 (16.4). **Sex**: 8.3% female. Note: This participant population is the same as the one in the Gholizadeh 2019[11] and Thibault 2018[18] studies.	turned off (creating a suction seal). Participants were given a one-month acclimation period prior to testing.	Note: Only level walking data were examined in this publication. **Follow-up**: None. All data were collected using the CAREN Extended System in a laboratory setting.
Thibault et al., 2018[18] Canada **Funding source**: This study was funded by Mitacs.	**Objective**: To investigate the walking performance (at self-selected speed with medial-lateral translations, rolling hills, and simulated uneven ground) of unilateral transtibial amputees with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system). **Study design**: Single-centre, single-blinded (participants were blinded), randomized crossover trial. **Setting**: Participants were recruited from the Ottawa Hospital Rehabilitation Centre, Prosthetics and Orthotics Service.	**Inclusion criteria**: Individuals with unilateral transtibial amputation who could walk without walking aids (i.e., were K3 or K4 according to MFCLs), had steady residual limb volume during the previous year, and who used a prosthesis daily. **Excluded**: Those who reported joint pain, stroke, visual impairment, cognitive problems that influenced gait and balance, recent amputation (<1 year), or residual limb volume <10 cm. **Number of participants**: 12. **Mean age, years (SD)**: 57.2 (15.3). **Mean weight, kg (SD)**: 90.6 (16.4). Note: This participant population is the same as the one in the Gholizadeh 2019[11] and Gholizadeh 2018[17] studies.	**Intervention**: Participants were fitted with an Iceross Seal-In V liner (high or standard profile) and Pro-flex XC foot with Unity pump according to the manufacturer guidelines. **Comparator**: The identical prosthetic system with the vacuum turned off (creating a suction seal). Participants were given a one-month acclimation period prior to testing.	**Clinical outcomes**: - Temporal-spatial gait parameters (e.g., velocity, stride length, step width) - Kinematic and kinetic parameters (e.g., peak plantar flexion, ankle range of motion, hip range of motion) Note: Data from walking at self-selected speed with medial-lateral translations, rolling hills, and simulated uneven ground were examined in this publication. **Follow-up**: None. All data were collected using the CAREN Extended System in a laboratory setting.

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Rosenblatt et al., 2017[19] United States **Funding source**: A grant from the American Orthotic and Prosthetic Association Center for Orthotic and Prosthetic Learning/Evidence-Based Practice. Note: this publication included the results from two related studies with some overlap in participants (referred to as "Study 1" and "Study 2" herein).	**Objective**: To quantify the effects of VASS on the metabolic costs of gait, various performance-based outcomes, and self-reported outcomes relating to function, prosthetic use, and mobility. **Study design**: This publication included results from two studies that included overlapping participant populations: 1) An open-label, randomized crossover trial (study 1) 2) A cross-sectional observational study (study 2) **Setting**: Participants were recruited using flyers posted in prosthetic clinics, during face-to-face visits with clinicians, or through online advertisements on the Amputee Coalition website. The first study was conducted in during single session in a laboratory setting. The second study collected data using a survey that was accessible via email.	**Inclusion criteria**: Individuals with a lower limb amputation (transtibial or transfemoral) who had their amputation ≥1 year ago. **Excluded**: Those who were unable to walk without assistance for 6 minutes. **Number of participants**: 36 completed at least one aspect of study 1 or study 2. Study 1 included data from 18 VASS users. Study 2 included data from 18 non-VASS users and an unclear number of VASS users. **Mean age, years (SD)**: 50.7 (13.8) in the VASS group; 48.3 (13.1) in the non-VASS group. **Mean weight, kg (SD)**: 88.8 (10.2) in the VASS group; 83.7 (12.4) in the non-VASS group. **Sex**: NR.	Study 1: **Intervention**: Prosthetic devices equipped with a VASS. **Comparator**: The two control conditions were a suction suspension and a sleeve. For the suction suspension participants' VASS devices had their vacuums inactivated. For the sleeve condition, the vacuum was inactivated and the one-way valve was blocked. Study 2: **Intervention**: Prosthetic devices equipped with a VASS. **Comparator**: Prosthetic devices equipped with non-VASS (e.g., suction systems, pin-lock systems).	Study 1: **Clinical outcomes**: - Kinematics of gait - Functional mobility - Cost of transport at self-selected speeds **Follow-up**: None. All data were collected in a laboratory setting. Study 2: **Clinical outcomes**: - Locomotor abilities - Function relating to prosthetic wear and use - Prosthesis-related quality of life **Follow-up**: None (this was a cross-sectional study).
Rink et al., 2016[20] United States **Funding source**: The Department of	**Objective**: To evaluate skin health and perfusion in individuals with transtibial and transfemoral amputation using an elevated vacuum system	**Inclusion criteria**: Adults (≥18 and ≤65 years of age) with unilateral lower-limb amputation who were able to ambulate on a prosthesis.	**Intervention**: An elevated vacuum suspension socket fit by the study prosthetist (the LimbLogic Vacuum System).	**Clinical outcomes**: - Skin barrier function (e.g., transepidermal water loss) - Residual-limb perfusion

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Veterans Affairs, Center for Innovation (award VA118–12-C-0038) and the Department of Defense office of the Congressionally Directed Medical Research Program (award W81XWH-16-2-0059).	compared to pin-locking or suction sockets. **Study design**: Single centre, open-label, randomized crossover trial. **Setting**: Recruitment took place at The Ohio State University Wexner Medical Center.	**Excluded**: Individuals who smoked, were diagnosed with renal failure, or those with previous experience with an elevated vacuum system prosthesis. **Number of participants**: 10. **Mean age, years (SD)**: 47.1 (12.6). **Mean BMI, kg/m^2 (SD)**: NR. **Sex**: 10% female.	**Comparator**: Participants' current non-elevated vacuum suspension (standard of care) prosthesis. These were suction suspension sockets or pin-locking suspension systems.	- Transcutaneous oxygen measurement - Reactive hyperemia **Follow-up**: 16 weeks intervention.
Non-Randomized Studies				
Çalışkan Uçkun et al., 2019[21] Turkey **Funding source**: No financial support was received for this research.	**Objective**: To compare levels of physical activity and quality of life in individuals with transtibial amputation who are using either a vacuum-assisted or a pin-locking suspension system with able-bodied controls. **Study design**: Single-centre, cross-sectional observational study. **Setting**: Participants were recruited from a tertiary hospital that is a major referral centre for prosthetic services. Able-bodied controls were recruited from the families and friends of participants with amputation.	**Inclusion criteria**: The prosthetic group included adults (≥18 and ≤65 years of age) who used a non-articulated dynamic foot, were employed, MFCL K3 or higher, wore their prosthesis for at least 8 hours a day, and had the ability to walk with the prosthesis at a freely selected speed for at least 10 minutes without assistance. Able-bodied adults (≥18 and ≤65 years of age) were eligible if they had ability to walk without assistance. **Excluded**: Individuals with a history of falls within the past year, significant cognitive impairment, or a medical history of balance, orthopaedic, neurological or general health problems that limited their ability to ambulate. **Number of participants**: 102 (25 in the VASS group; 26 in the pin-lock group; 51 in the able-bodied control group).	**Intervention**: Study participants were grouped by their type of prosthetic device (i.e., VASS versus pin-lock systems). **Comparator**: The control group consisted of able-bodied individuals who were of similar age. This group did not receive an intervention.	**Clinical outcomes**: - Level of physical activity (measured using the IPAQ-SF) - Quality of life (measured using the SF-36) **Follow-up**: None (this was a cross-sectional study).

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
		Mean age, years (SD): 44.8 (12.6) in the VASS group; 50.3 (13.7) in the pin-lock group; 44.4 (11.4) in the able-bodied control group. **Mean BMI, kg/m^2 (SD)**: 26.1 (5.0) in the VASS group; 26.7 (5.2) in the pin-lock group; 28.1 (5.0) in the able-bodied control group. **Sex**: 20.0% female in the VASS group; 3.8% female in the pin-lock group; 19.6% female in the able-bodied control group.		
Rosenblatt and Ehrhardt, 2017[22] United States **Funding source**: A grant from the American Orthotic and Prosthetic Association Center for Orthotic and Prosthetic Learning/Evidence-Based Practice.	**Objective**: To evaluate the relative risk of falling between patient cohorts with VASS and non-VASS (e.g., pin-lock, suction) prosthetic devices. **Study design**: Prospective, longitudinal cohort study. **Setting**: Participants completed bi-weekly surveys in the community setting. The method of recruitment was not described.	**Inclusion criteria**: Users of lower limb prostheses who reported the ability to walk unaided for six minutes and had a time since amputation ≥1 year. **Excluded**: Individuals with bilateral amputation. **Number of participants**: 27 (15 in the VASS group; 12 in the non-VASS group). **Mean age, years (SD)**: 52.3 (12.7) in the VASS group; 49.8 (11.1) in the non-VASS group. **Mean BMI, kg/m^2 (SD)**: 27.3 (3.8) in the VASS group; 26.3 (3.2) in the non-VASS group. **Sex**: 26.7% female in the VASS group; 50.0% female in the non-VASS group.	**Intervention**: Prosthetic devices equipped with a VASS. **Comparator**: Prosthetic devices equipped with non-VASS (e.g., suction systems, pin-lock systems).	**Clinical outcomes**: - Relative rate of falls and stumbles - Relative risk of falling and stumbling **Follow-up**: 1 year.
Darter et al., 2016[23] Untied States	**Objective**: To investigate the differences in limb-socket movement between	**Inclusion criteria**: Individuals (≥18 and ≤45 years of age) with traumatic	**Intervention**: Prosthetic devices with a modified total surface bearing	**Clinical outcomes**:

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
Funding source: Financial support was received from the Military Amputee Research Program and the National Center for Advancing Translational Sciences.	VASS and passive suction systems in individuals with traumatic transtibial amputation. **Study design**: Non-randomized crossover trial. **Setting**: Method and location of recruitment were not described.	transtibial amputation(s) who were able to walk without assistive devices. **Excluded**: Those who did not have normal range of motion in the hip and knee of the tested limb. **Number of participants**: 10. **Mean age, years (SD)**: 31 (6). **Mean weight, kg (SD)**: 92.5 (8.5). **Sex**: 0% female.	socket in an elevated vacuum suspension mode. **Comparator**: Prosthetic devices with a modified total surface bearing socket in a passive suction suspension mode. Participants were given a three-week acclimation period prior to testing.	- Socket fit (i.e., axial bone–socket displacement) **Follow-up**: None. All data were collected using digital video fluoroscopy recording in a laboratory setting.
Şahin Onat et al., 2016[24] Turkey **Funding source**: No financial support was received for this research.	**Objective**: To investigate the effect of various prosthesis types on quadriceps muscle and distal femoral cartilage thickness in patients with transtibial amputation. **Study design**: Cross-sectional observational study. **Setting**: Method and location of recruitment were not described.	**Inclusion criteria**: Individuals with transtibial amputation who had been using a below-knee prosthesis with vacuum or modular system suspension systems for at least 6 months. **Excluded**: Individuals with bilateral amputation, rheumatic disease, previous lower limb surgery in addition to amputation, and contracture that limited knee hyperflexion. **Number of participants**: 38 (13 in the vacuum system group; 25 in the modular system group). **Mean age, years (SD)**: 41.9 (11.8) in the vacuum group; 40.6 (11.6) in the modular group. **Mean BMI, kg/m^2 (SD)**: 27.9 (5.3) in the vacuum group; 28.5 (3.7) in the modular group.	**Intervention**: Vacuum system type prostheses. **Comparator**: Modular system type prostheses (i.e., a silicon liner pin system).	**Clinical outcomes**: - Femoral cartilage thickness - Quadriceps muscle thicknesses **Follow-up**: None (this was a cross-sectional study).

Table 3: Characteristics of Included Primary Clinical Studies

Study Citation, Country, Funding Source	Objective, Study Design, Setting	Population Characteristics	Intervention and Comparator(s)	Clinical Outcomes, Length of Follow-Up
		Sex: 15.4% female in the vacuum group; 20.0% female in the modular group.		
Samitier et al., 2016[25] Spain **Funding source**: No financial support was received from any funding agency.	**Objective**: To evaluate the effect of VASS on mobility (e.g., gait, balance) in patients over 50 years of age with dysvascular transtibial amputation. **Study design**: Quasi-experimental before-and-after intervention study. **Setting**: Participants were recruited during routine follow-up visits at the Amputee Unit of a Rehabilitation and Physical Medicine Department.	**Inclusion criteria**: Individuals (≥50 years of age) with unilateral transtibial amputation, prosthesis use for at least 6 months prior to enrollment, and the ability to walk indoors with or without supervision or ambulation aids. **Excluded**: Those with cognitive impairments that would hinder their ability to follow instructions or perform the tests. **Number of participants**: 16. **Mean age, years (SD)**: 65.12 (10.15). **Mean BMI, kg/m^2 (SD)**: NR. **Sex**: 12.5% female.	**Intervention**: A VASS device (Ottobock Harmony P2 & HD) adapted for each participant using the manufacturer's instructions. A 4-week accommodation period was provided with the new device prior to evaluation. **Comparator**: Participants' usual non-VASS prosthesis.	**Clinical outcomes**: - Overall mobility grade (based on MFCLs) - Balance (using the BBS and FSST) - Gait and transfers (using the TUG and 6-Minute Walk Test) - Locomotor capability (with the LCI) - Patient satisfaction (with the SAT-PRO Scale) - Use of prosthesis (using the Houghton Scale) **Follow-up**: None (this was a cross-sectional study).

BBS = Berg Balance Scale; BMI = Body Mass Index; CAREN = Computer-Assisted Rehabilitation Environment; FSST = The Four Square Step Test; IPAQ-SF = International Physical Activity Questionnaire Short Form; LCI = Locomotor Capabilities Index; MFCL = Medicare Functional Classification Level; NR = not report; SAT-PRO = Satisfaction with Prosthesis; SD = standard deviation; SF-36 = Short Form 36; TUG = Timed Up and Go Test; VASS = vacuum-assisted suspension system.

Table 4: Characteristics of Included Guidelines

Guideline Citation, Country, Funding Source	Scope, Intended Users, Target Population	Evidence Collection, Selection, Synthesis, and Quality Assessment	Recommendations Development and Evaluation	Recommendation Grading System, Guideline Validation
Stevens et al., 2019[9] United States **Funding source**: Study authors were employees of Hangar Clinic during the development of the guideline. No external funding was received.	**Scope**: The guideline provides recommendations regarding socket design, interface, and suspension of definitive transtibial prostheses. **Intended users**: Prosthetists, surgeons, therapists, physicians, case managers, and policy makers. **Target population:** Individuals with transtibial amputation as a result of traumatic event, poor vascular status, or other etiologies.	Literature searches were conducted in Medline on May 2nd, 2017. Retrieved articles were screened for secondary knowledge sources (i.e., systematic reviews, meta-analyses, and scoping reviews) to be considered in the guideline development. In total, 10 systematic reviews (one with a meta-analysis) and one scoping review were included. Quality assessment of the included evidence was not conducted as part of guideline development.	Following a review of the summarized literature, the study authors synthesized six evidence-based recommendations regarding various aspects of definitive transtibial prostheses. Three considerations were addressed when drafting the recommendations: 1) comparative effectiveness, 2) benefits of treatments, 3) harms of treatments. The methodology for developing and evaluating these recommendations was not reported.	**Recommendation grading system**: Recommendations were not graded. **Guideline validation**: There was no mention of guideline validation
The Department of Veterans Affairs and the Department of Defense, 2017[1] United States **Funding source**: The United States federal government	**Scope**: The guideline covers a wide-range of topics regarding the rehabilitation of individuals with lower limb amputation. **Intended users**: Clinicians who provide care to patients in rehabilitation for lower limb amputation. **Target population**: Adults who are eligible for care within the Veterans Affairs and the Department of	A series of extensive literature searches were conducted in The Cochrane Database of Systematic Reviews, CINAHL, EMBASE, Health Technology Assessment Database, MEDLINE, PsycINFO and PubMed to identify relevant literature published between January 2007 and July 2016. After full-text screening, a total of 74 studies (in 77 publications) were included in the systematic review. The quality of individual primary studies was not assessed.	Face-to-face meetings were convened with various members of the clinical guideline work group to draft recommendations. As the recommendations were formulated, they were assigned a grade based on a modified GRADE and USPSTF methodology. Recommendations were graded by assessing the quality of the supporting evidence, the associated benefits and harms, the variation in values and preferences, and other implications.	**Recommendation grading system**: Recommendations were classified as one of the following (based on the GRADE system): - Strong For (i.e., "We recommend offering this option") - Weak For (i.e., "We suggest offering this option") - Weak Against (i.e., "We suggest not offering this option") - Strong Against (i.e., "We recommend against offering this option")

Table 4: Characteristics of Included Guidelines

Guideline Citation, Country, Funding Source	Scope, Intended Users, Target Population	Evidence Collection, Selection, Synthesis, and Quality Assessment	Recommendations Development and Evaluation	Recommendation Grading System, Guideline Validation
	Defense healthcare delivery systems.			**Guideline validation:** There was no mention of guideline validation

GRADE = Grading of Recommendations Assessment, Development and Evaluation; USPSTF = US Preventive Services Task Force.

Appendix 3: Critical Appraisal of Included Publications

Table 5: Strengths and Limitations of Systematic Reviews using AMSTAR II[12]

Strengths	Limitations
Highsmith et al., 2016[4]	
• The objectives and inclusion criteria were clearly stated and included components of population, intervention, comparator, and outcomes • The choice of included study designs (i.e., systematic reviews and high-quality clinical studies) was explained • Multiple databases were searched (PubMed, CINAHL, RECAL Legacy, Cochrane Database of Systematic Reviews, PubMed Central-National Institutes of Health Research Publication Database, and Web of Science) • Key search terms and the dates of search were provided (between March 11 and March 19, 2013) • Study selection, data extraction, and quality assessment processes were described and conducted in duplicate • A flow chart of study selection was provided • The quality of included studies was assessed using the SIGN 50 (for systematic reviews) and PEDro (for systematic reviews and primary studies) checklists • Review authors reported on the sources of funding for included studies • Risk of bias and limitations of primary study methodology were considered when discussing the results • Review authors stated that they had no conflicts of interest related to this review • Source of funding was disclosed (the American Orthotic and Prosthetic Association) and was unlikely to have had an effect on the findings of the review	• It was unclear whether the review methods were established prior to conducting the review (no mention of a protocol) • A grey literature search was not completed • A list of excluded studies was not provided (although the reasons for exclusion were) • Included studies were not described in adequate detail. Several key study characteristics were not summarized in the review (e.g., study design, number of included participants) • There was no discussion on the possibility of publication bias • The countries in which relevant primary studies were conducted were not described; the generalizability to the Canadian setting is unclear
Safari and Meier, 2015a[15]	
• The objectives and inclusion criteria were clearly stated and included components of population, intervention, comparator, and outcomes • Review methods were established prior to conducting the review (a protocol was prospectively registered) • The choice of included study designs (i.e., randomized and non-randomized studies) was explained • Multiple databases were searched (Medline [PubMed] and EMBASE [Ovid Interface], Google Scholar, the Cochrane Library, and Web of Knowledge) • Key search terms were provided • The study selection process was described and conducted in duplicate • Data extraction was completed by one author and then checked by a second author • A flow chart of study selection was provided • The quality of included studies was assessed using the Downs and Black checklist	• Dates of literature searches were not provided • It was unclear if quality assessment was done in duplicate • A grey literature search was not completed • A list of excluded studies was not provided (although the reasons for exclusion were) • Included studies were not described in adequate detail. Several key study characteristics were not summarized in the review (e.g., number of included participants, summary statistics) • Review authors did not report on sources of funding for the included primary studies • There was no discussion on the possibility of publication bias • Relevant primary studies were conducted outside of Canada; the generalizability to the Canadian setting is unclear

Table 5: Strengths and Limitations of Systematic Reviews using AMSTAR II[12]

Strengths	Limitations
• Risk of bias and limitations of primary study methodology were considered when discussing the results • Review authors stated that they had no conflicts of interest related to this review • Source of funding was disclosed (there was no funding received for this review)	
Safari and Meier, 2015b[16]	
• The objectives and inclusion criteria were clearly stated and included components of population, intervention, comparator, and outcomes • Review methods were established prior to conducting the review (a protocol was prospectively registered) • The choice of included study designs (i.e., randomized and non-randomized studies) was explained • Multiple databases were searched (Medline [PubMed] and EMBASE [Ovid Interface], Google Scholar, the Cochrane Library, and Web of Knowledge) • Key search terms were provided • The study selection process was described and conducted in duplicate • Data extraction was completed by the one author and then checked by a second author • A flow chart of study selection was provided • The quality of included studies was assessed using the Downs and Black checklist • Risk of bias and limitations of primary study methodology were considered when discussing the results • Review authors stated that they had no conflicts of interest related to this review • Source of funding was disclosed (there was no funding received for this review)	• Dates of literature searches were not provided • It was unclear if quality assessment was done in duplicate • A grey literature search was not completed • A list of excluded studies was not provided (although the reasons for exclusion were) • Included studies were not described in adequate detail. Several key study characteristics were not summarized in the review (e.g., number of included participants, summary statistics) • Review authors did not report on sources of funding for the included primary studies • There was no discussion on the possibility of publication bias • Relevant primary studies were conducted outside of Canada; the generalizability to the Canadian setting is unclear

AMSTAR II = A MeaSurement Tool to Assess systematic Reviews II; CINAHL = Cumulative Index of Nursing and Allied Health Literature; PEDro = Physiotherapy Evidence Database Scale; SIGN = Scottish Intercollegiate Guidelines Network.

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
Randomized Controlled Trials	
Gholizadeh et al., 2019[11]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, weight, years since amputation, cause of amputation) were clearly described • The order in which participants received interventions was randomized • Due to the nature of the study design (i.e., a randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • No participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Participants were blinded to the order in which they received interventions • The length of follow-up was consistent across interventions • Compliance with the assigned treatment was reliable • The study was conducted in Ottawa, Ontario; there should be relatively high generalizability to Canadian settings • The authors declared that they had no potential conflicts of interest	• A limited number of participants were recruited (N = 12) • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • No power calculation was performed • A four-week acclimation period was provided for the vacuum system, but none was given for the suction system. Participants may have performed better with the vacuum system due to increased familiarity • Financial support for the study was received from an orthopaedics manufacturer
Gholizadeh et al., 2018[17]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, weight, years since amputation, cause of amputation) were clearly described • The order in which participants received interventions was randomized • Due to the nature of the study design (i.e., a randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • No participants were lost to follow-up	• A limited number of participants were recruited (N = 12) • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • No power calculation was performed • A four-week acclimation period was provided for the vacuum system, but none was given for the suction system. Participants may have performed better with the vacuum system due to increased familiarity • Financial support for the study was received from an orthopaedics manufacturer

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
• Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Participants were blinded to the order in which they received interventions • The length of follow-up was consistent across interventions • Compliance with the assigned treatment was reliable • The study was conducted in Ottawa, Ontario; there should be relatively high generalizability to Canadian settings • The authors declared that they had no potential conflicts of interest	
Thibault et al., 2018[18]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, weight, years since amputation, cause of amputation) were clearly described • The order in which participants received interventions was randomized • Due to the nature of the study design (i.e., a randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • No participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Participants were blinded to the order in which they received interventions • The length of follow-up was consistent across interventions • Compliance with the assigned treatment was reliable • The study was conducted in Ottawa, Ontario; there should be relatively high generalizability to Canadian settings • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• A limited number of participants were recruited (N = 12) • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • No power calculation was performed • A four-week acclimation period was provided for the vacuum system, but none was given for the suction system; participants may have performed better with the vacuum system due to increased familiarity
Rosenblatt et al., 2017[19]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided	• A limited number of participants were recruited (N = 32 between the two studies) • The number of participants in each individual study was unclear as the publication only presented participant characteristics for both studies in aggregate

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
• Participant characteristics (e.g., age, sex, weight, years since amputation, cause of amputation) were clearly described • The order in which participants received interventions in study one was randomized • For study one (i.e., the randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • Adverse events (i.e., discontinuation due to pain) relating to use of the VASS were documented • Participants who withdrew from the study were documented • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • The length of follow-up was consistent across interventions • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• The distribution of potential confounders in participants of study two was not adequately described • Patient characteristics for those who withdrew from the study were not reported • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed • No acclimation period was provided after altering the suspension type (which may have influenced the findings) • Single-centre studies (conducted in the United States); the generalizability to the Canadian setting was unclear
Rink et al., 2016[20]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, cause of amputation) were clearly described • The order in which participants received interventions was randomized • Due to the nature of the study design (i.e., a randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., confidence intervals) and actual probability values (*P*-values) were reported • The major findings of the study were presented in graphic form and clearly described • No participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • The length of follow-up was consistent across interventions (16 weeks) • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• A limited number of participants were recruited (N = 10) • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed • Single-centre study (conducted in the United States); the generalizability to the Canadian setting was unclear • Several study authors were employees of the company that manufactures and sells elevated vacuum suspension systems

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
Non-Randomized Studies	
Çalışkan Uçkun et al., 2019[21]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, BMI, years since amputation) were clearly described and were tested for statistically significant differences between groups (there were no significant differences) • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in graphic and tabular form and clearly described • A power calculation was performed • Due to the nature of the study design (i.e., a cross-sectional observational study), no participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• Intervention assignment was not done at random; therefore, a number of uncontrolled factors may have contributed to the findings of the study • Adverse events (e.g., pain, discomfort) relating to the use of either socket system were not assessed • This was an open-label study with no blinding of study participants or outcome assessors • The study was conducted in Turkey; the generalizability to the Canadian setting was unclear
Rosenblatt and Ehrhardt, 2017[22]	
• The objectives, interventions, controls, inclusion/exclusion criteria, and main outcomes were clearly described • Participant characteristics (e.g., age, sex, BMI) were clearly described and were tested for statistically significant differences between groups • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented narratively and were clearly described • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• Methods used for patient recruitment were unclear • Intervention assignment was not done at random; therefore, a number of uncontrolled factors may have contributed to the findings of the study • Adverse events in addition to risk of falling (e.g., pain, discomfort) relating to the use of various socket systems were not assessed • The characteristics of participants lost to follow-up (i.e., those who stopped responding to the surveys) were not described • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed • The study was conducted in the United States; the generalizability to the Canadian setting was unclear
Darter et al., 2016[23]	
• The objectives, interventions, controls, inclusion/exclusion criteria, and main outcomes were clearly described	• A limited number of participants were recruited (N = 10) • Methods used for patient recruitment were unclear

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
• Participant characteristics (e.g., age, sex, weight, type of amputation, years since amputation) were clearly described • Due to the nature of the study design (i.e., a non-randomized crossover trial), both interventions groups included the same participants • Estimates of random variability (e.g., confidence intervals) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • No participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• Intervention assignment was not done at random; therefore, a number of uncontrolled factors may have contributed to the findings of the study • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed • The study was conducted in the United States; the generalizability to the Canadian setting was unclear
Şahin Onat et al., 2016[24]	
• The objectives, interventions, controls, inclusion/exclusion criteria, and main outcomes were clearly described • Participant characteristics (e.g., age, sex, BMI, type of amputation, years since amputation) were clearly described and were tested for statistically significant differences between groups • Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • Due to the nature of the study design (i.e., a cross-sectional observational study), no participants were lost to follow-up • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• Methods used for patient recruitment were unclear • Intervention assignment was not done at random; therefore, a number of uncontrolled factors may have contributed to the findings of the study • Adverse events (e.g., pain, discomfort) relating to the use of either socket system were not assessed • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed • The study was conducted in Turkey; the generalizability to the Canadian setting was unclear
Samitier et al., 2016[25]	
• The objectives, interventions, controls, and main outcomes were clearly described • Detailed methodology on patient recruitment and assessment of inclusion/exclusion criteria was provided • Participant characteristics (e.g., age, sex, cause of amputation, years since amputation) were clearly described • Due to the nature of the study design (i.e., a before-and-after study), both interventions groups included the same participants	• A limited number of participants were recruited (N = 16) • Because this was a before-and-after study, a number of biases may have affected the results (e.g., repeat testing bias, maturation bias) • It was unclear if there were any adverse events (e.g., pain, discomfort) relating to the intervention • This was an open-label study with no blinding of study participants or outcome assessors • No power calculation was performed

Table 6: Strengths and Limitations of Clinical Studies using the Downs and Black Checklist[13]

Strengths	Limitations
• Estimates of random variability (e.g., standard deviations) and actual probability values (*P*-values) were reported • The major findings of the study were presented in tabular form and clearly described • Study participants, care providers, and setting appear to be representative of the population and care setting of interest • Compliance with the assigned treatment was reliable • The authors declared that they had no potential conflicts of interest • Sources of funding were disclosed and were unlikely to have had an effect on the findings of the study	• The study was conducted in Spain; the generalizability to the Canadian setting was unclear

BMI = Body Mass Index; N = number of participants; VASS = vacuum-assisted suspension system.

Table 7: Strengths and Limitations of Guidelines using AGREE II[14]

Item	Guideline	
	Stevens et al., 2019[9]	VA/DoD, 2017[1]
Domain 1: Scope and Purpose		
1. The overall objective(s) of the guideline is (are) specifically described.	Yes	Yes
2. The health question(s) covered by the guideline is (are) specifically described.	Yes	Yes
3. The population (patients, public, etc.) to whom the guideline is meant to apply is specifically described.	Yes	Yes
Domain 2: Stakeholder Involvement		
4. The guideline development group includes individuals from all relevant professional groups.	No	Yes
5. The views and preferences of the target population (patients, public, etc.) have been sought.	No	Yes
6. The target users of the guideline are clearly defined.	Yes	Yes
Domain 3: Rigour of Development		
7. Systematic methods were used to search for evidence.	Yes	Yes
8. The criteria for selecting the evidence are clearly described.	No	Yes
9. The strengths and limitations of the body of evidence are clearly described.	No	No
10. The methods for formulating the recommendations are clearly described.	No	Yes
11. The health benefits, side effects, and risks have been considered in formulating the recommendations.	Yes	Yes
12. There is an explicit link between the recommendations and the supporting evidence.	Yes	Yes
13. The guideline has been externally reviewed by experts prior to its publication.	Yes	Yes
14. A procedure for updating the guideline is provided.	No	No
Domain 4: Clarity of Presentation		
15. The recommendations are specific and unambiguous.	Yes	Yes
16. The different options for management of the condition or health issue are clearly presented.	Yes	Yes
17. Key recommendations are easily identifiable.	Yes	Yes
Domain 5: Applicability		
18. The guideline describes facilitators and barriers to its application.	No	No
19. The guideline provides advice and/or tools on how the recommendations can be put into practice.	No	Yes
20. The potential resource implications of applying the recommendations have been considered.	No	Yes

Table 7: Strengths and Limitations of Guidelines using AGREE II[14]

Item	Guideline	
	Stevens et al., 2019[9]	VA/DoD, 2017[1]
21. The guideline presents monitoring and/or auditing criteria.	No	No
Domain 6: Editorial Independence		
22. The views of the funding body have not influenced the content of the guideline.	Yes	Yes
23. Competing interests of guideline development group members have been recorded and addressed.	Yes	Yes

VA/DoD = the Department of Veterans Affairs and the Department of Defense.

Appendix 4: Main Study Findings and Authors' Conclusions

Table 8: Summary of Findings Included Systematic Reviews

<table>
<tr><th>Main Study Findings</th><th>Authors' Conclusion</th></tr>
<tr><td colspan="2">Highsmith et al., 2016[4]</td></tr>
<tr><td>Systematic review and meta-analysis that investigated evidence regarding the prosthetic management of adults with transtibial amputation. The five domains of interest were alignment, feet and ankles, interface, post-operative care, and pylons.

Relevant primary studies: The systematic review included three relevant primary studies[27-29] that compared prosthetics with VASSs versus total surface bearing-designed interfaces that used pin locking suspension mechanisms. Findings were not quantitatively synthesized across all relevant studies; therefore, results are summarized individually by primary study.
<table>
<tr><th>Primary study citation</th><th>Summary of relevant findings</th></tr>
<tr><td>Beil et al., 2002[27]
(N = NR)</td><td>• VASS reduced impulse and peak positive pressures in stance phase and increased magnitude of impulse, average, and peak negative pressures in swing phase compared to TSB sockets</td></tr>
<tr><td>Klute et al., 2011[28]
(N = NR)</td><td>• The VASS decreased limb pistoning compared to the pin-lock socket
• Participants reported increased preference for the pin-lock system, had increased step count, and required less check sockets</td></tr>
<tr><td>Traballesi et al., 2012[29]
(N = NR)</td><td>• Compared with TSB sockets, VASS allowed earlier fitting into the prosthetic device</td></tr>
</table>
N= number of participants; NR = not reported; TSB = total surface bearing; VASS = vacuum-assisted suspension system.

Based on the findings of the article synthesis, study authors stated that compared with TSB interfaces with pin-locking suspension systems, VASS reportedly reduced time to prosthetic fitting, improved mobility postoperatively or post-ulceration, decreased step activity, decreased pistoning, and decreased positive pressure in stance phase and increased negative pressure in swing phase when walking in individuals with transtibial amputation.</td><td>"Regarding interfaces, use of gel liners compared with specific weight-bearing sockets improves load distribution, comfort, ambulatory independence, and suspension. Use of VASS interfaces relative to TSB reduces pistoning and time to prosthetic fitting but may come with reduced step activity. Of the topics studied, the interface topic had the highest attrition and bias risk, identifying this as an area to which greater research focus may be needed."[4] (p. 178)</td></tr>
<tr><td colspan="2">Safari and Meier, 2015a[15]</td></tr>
<tr><td>Systematic review that summarized studies with qualitative outcomes regarding the effectiveness of transtibial prosthetic socket types.

Relevant primary studies: The systematic review included three relevant primary studies[28,30,31] that compared prosthetics with VASSs versus total surface bearing-designed interfaces that used pin locking suspension mechanisms. No meta-analysis was conducted; therefore, results are summarized individually by primary study.
<table>
<tr><th>Primary study citation</th><th>Summary of relevant findings</th></tr>
<tr><td>Ferraro, 2011[30]
(N = NR)</td><td>• Participants reported a significantly decreased fear of falling during daily activities with a VAS socket compared to their previous TSB sockets. Additionally, participants scored higher on the Activity Balance Confidence scale while using a VAS socket.</td></tr>
<tr><td>Klute et al., 2011[28]
(N = NR)</td><td>• Participants were twice as active using TSB sockets than when using VAS over a two-week period (measured using step activity)
• Ambulation scores of the PEQ were higher for the TSB socket than the VAS socket (the statistical significance of this finding was not tested)</td></tr>
</table></td><td>"Results of studies with weak evidence indicate that active participants with short and pressure-sensitive residual limbs and skin problems could also benefit from VAS sockets [39]. Generally, it was reported that they feel more confident in performing [activities of daily living] when using VAS sockets [37]. Although the level of evidence on VAS sockets is not strong enough yet, the results are promising. The observed benefits of the</td></tr>
</table>

Table 8: Summary of Findings Included Systematic Reviews

Main Study Findings		Authors' Conclusion
	• Participants reported increased health of their residual limb and that they experienced significantly less frustration with the TSB socket compared to the VAS socket	VAS socket could be because of the elevated vacuum and/or the socket shape."[15] (p. 503)
Sutton et al., 2011[31] (N = 1)	• After changing from a PTB socket to a VASS the individual reported increased scores of locomotor capability and activities of daily living, improved prosthesis linkage, and no pain or swelling in the contralateral limb. Additionally, the individual's Amputee Mobility Predictor with Prosthesis score improved after long-term (1 year) use of the new device	
N= number of participants; NR = not reported; PEQ = Prosthesis Evaluation Questionnaire; PTB = patellar tendon bearing; TSB = total surface bearing; VASS = vacuum-assisted suspension system.		
Safari and Meier, 2015b[16]		
Systematic review that summarized studies with quantitative outcomes regarding the effectiveness of transtibial prosthetic socket types. **Relevant primary studies**: The systematic review included five relevant primary studies[27,28,32-34] that compared prosthetics with VASSs versus total surface bearing-designed interfaces that used pin locking suspension mechanisms. No meta-analysis was conducted; therefore, results are summarized individually by primary study.		"The included studies have low to moderate methodological rigor. Most studies were conducted on PTB and TSB sockets, with only a few studies conducted on VAS and [hydrostatic] socket designs. The VAS socket had the best suspension of all reported socket designs, followed by a TSB suction socket, a TSB socket with sleeve suspension, and a TSB socket with pin lock liner. The least suspension is provided by a PTB socket with sleeve suspension or a PTB socket with [supracondylar] design. Based on the few studies available for VAS sockets, the results seem to indicate that they improve gait symmetry, control residual limb volume fluctuations, and seem to affect residual limb health positively compared with other socket designs."[16] (p. 523)
Primary study citation	Summary of relevant findings	
Beil et al., 2002[27] (N = NR)	• Compared with TSB sockets, VASS significantly reduced positive pressures in the stance phase and increased the negative pressure impulse and the peak and average peak pressure in the swing phase	
Board et al., 2001[32] (N = NR)	• Compared with the TSB socket with sleeve suspension, participants had significantly increased step length symmetry and stance duration symmetry while using the VAS socket. Additionally, axial movement of the liner and tibia in relation to the socket was smaller in the VAS socket • Following a 30-minute treadmill walking test, participants had increased residual limb volume with the VAS socket compared to the TSB socket	
Gerschutz et al., 2010[33] (N = 1)	• The participant experienced less residual limb volume fluctuation with the vacuum system compared with a suction suspension	
Klute et al., 2011[28]	• Participants had significantly larger pistoning while using the TSB socket compared to the VAS socket • Following testing with a 30-minute treadmill walk test, the author concluded that neither socket type had a significant effect on residual limb volume changes	
Sanders et al., 2011[34]	• Compared with TSB sockets, participants' residual limb fluid significantly increased during short walks while using a VAS socket (in those not affected by any chronic diseases)	
N= number of participants; NR = not reported; TSB = total surface bearing; VASS = vacuum-assisted suspension system.		

PTB = patellar tendon bearing; TSB = total surface bearing; VAS = vacuum-assisted suction; VASS = vacuum-assisted suspension system.

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
Randomized Controlled Trials	
Gholizadeh et al., 2019[11]	

A single-centre, single-blinded (participants were blinded), randomized crossover trial that investigated the walking performance (on level ground) of unilateral transtibial amputees (N = 12) with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system).
 	
Summary of findings:
• Significant differences were found between the VASS and suction socket system conditions regarding various temporal-spacial gait parameters
  ○ These differences had small or medium effect sizes in most cases (Cohen's *d* ≤ 0.5), with the exception of step time and swing time where large effect sizes were observed
  ▪ Step time in the prosthetic limb (s):
  • VASS: 0.59 (SD = 0.07)
  • Suction 0.57 (SD = 0.06)
  • *P*-value = 0.000
  • Cohen's *d* = 0.7
  ▪ Swing time in the prosthetic limb (s):
  • VASS: 0.40 (SD = 0.04)
  • Suction: 0.39 (SD = 0.03)
  • *P*-value = 0.000
  • Cohen's *d* = 0.6
  ○ Symmetry index indicated a more symmetrical step length in the vacuum condition (SI = 7.42 [SD = 5.41]) than in the suction condition (SI = 10.29 [SD = 8.14]). The statistical significance of this finding was not reported.
• A majority of outcomes relating to kinetic and kinetic parameters were insignificant between the VASS and suction conditions. Where significant differences did exist the effect sizes were small and were not considered clinically meaningful by the study authors.
	"Gait parameters were expected to change when walking on a level treadmill with the elevated vacuum system compared to walking with the vacuum off. While some of these gait parameters were statistically different, the differences were small and not clinically significant. Only step length symmetry between prosthetic and intact limbs improved when walking with the elevated vacuum system. Future investigations across other surfaces encountered in daily living, such as slopes, are also needed to better determine the effects of active vacuum on gait parameters."[11] (p. 6)

Gholizadeh et al., 2018[17]	

A single-centre, single-blinded (participants were blinded), randomized crossover trial that evaluated the walking performance (during uphill and downhill walking activities) of unilateral transtibial amputees (N = 12) with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system).
 	
Summary of findings:
• Significant differences were found between the VASS and suction socket system conditions regarding various temporal-spatial parameters
  ○ These differences had small effect sizes in all cases (Pearson *r* ≤ 0.35)
  ○ Symmetry index was < 10% for both test conditions downhill; however, step length was only symmetrical in the vacuum condition
• Significant differences were found between the VASS and suction socket system conditions regarding various kinematic and kinetic gait parameters; however, the effect sizes were small (Pearson *r* ≤ 0.35)
	"The hypothesis of this study was that gait parameters with active vacuum suspension would be different than inactive vacuum during uphill and downhill walking. While some parameters were statistically different, the differences were small and may not be clinically significant. However, elevated vacuum improved gait symmetry for uphill walking. Therefore, the Unity approach for elevated vacuum suspension was beneficial when slope walking is considered. Since only small differences

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
	were found for kinematic and kinetic parameters, and knee range of motion was not restricted, the Unity system should maintain appropriate walking even with vacuum failure, until limb volume changes adversely affect socket fit (i.e., elevated vacuum helps control limb volume fluctuations over time)."[17] (p. 210)
Thibault et al., 2018[18]	

A single-centre, single-blinded (participants were blinded), randomized crossover trial that sought to investigate the walking performance (at self-selected speed with medial-lateral translations, rolling hills, and simulated uneven ground) of unilateral transtibial amputees (N = 12) with the Unity elevated vacuum system when the vacuum was active or inactive (i.e., a suction socket system).
 	
Summary of findings:
• No significant differences were found between the VASS and suction socket system conditions when participants were walking with medial-lateral translations for all temporal-spatial gait parameters
• Significant differences were observed between the VASS and suction socket system conditions for stride length, swing time, and step width during rolling hills walking; however, the effect sizes were small (Cohen's *d* < 0.5)
  ○ Stride length in the prosthetic limb (m):
  ▪ VASS: 1.11 (SD = 0.20)
  ▪ Suction: 1.13 (SD = 0.26)
  ▪ *P*-value = 0.026
  ▪ Cohen's *d* = 0.3
  ○ Swing time in the prosthetic limb (s):
  ▪ VASS: 0.40 (SD = 0.04)
  ▪ Suction: 0.39 (SD = 0.03)
  ▪ *P*-value = 0.034
  ▪ Cohen's *d* = 0.3
  ○ Step width in the prosthetic limb (cm):
  ▪ VASS: 13.55 (SD = 7.27)
  ▪ Suction: 15.03 (SD =7.69)
  ▪ *P*-value = 0.005
  ▪ Cohen's *d* = 0.4
• Good symmetry (SI < 10%) between the prosthetic and intact limbs was observed in both the VASS and suction conditions
• Significant differences were found between the VASS and suction socket system conditions regarding various kinematic and kinetic gait parameters; however, the effect sizes were very small and not considered clinically significant
	"This study examined transtibial amputee gait when walking with the Össur Unity elevated vacuum system in active and inactive vacuum conditions, for three continuous perturbation walking surfaces. Significant differences were found between vacuum ON and OFF for few gait parameters, but the differences were small and were considered not clinically significant. Therefore, gait performance in a high functioning amputee population would not be immediately affected following a mechanical vacuum pump failure. However, if the vacuum were off for an extended period the residual limb volume would be expected to fluctuate, resulting in inferior socket fit [5]. Further research on elevated vacuum effects on amputee comfort would be beneficial to assist in clinical decision-making."[18] (p. 11)

Rosenblatt et al., 2017[19]	
This authors of this report aimed to quantify the effects of VASS on the metabolic costs of gait, various performance-based outcomes, and self-reported outcomes relating to function, prosthetic	"In absence of active vacuum, current users of

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
use, and mobility. Two studies were conducted on overlapping participant populations (N = 36; 18 VASS users and 18 non-VASS users): 1) An open-label, randomized crossover trial (study 1) 2) A cross-sectional observational study (study 2) <u>Study 1:</u> Summary of findings: • There were no statistically significant differences between the VASS, suction, and sleeve conditions with respect to cost of transport and self-selected speed • Self-reported socket fit comfort scores were higher in the VASS condition (8.77 [SD = 1.2) than in the suction (7.1 [SD = 1.3]) or sleeve conditions (6.1 [SD = 2.1]) • The VASS condition had significantly faster timed up and go results than the sleeve condition (9.3 s [SD = 2.3] versus 10.1 s [SD = 2.7]; *P*-value = 0.02) • The maximum speed achieved during the 10-miute walk speed was significantly higher in the VASS condition compared to both the suction (1.65 m/s [SD = 0.28] versus 1.58 m/s [SD = 0.29]; *P*-value = 0.027) and sleeve conditions (1.65 m/s [SD = 0.28] versus 1.54 m/s [SD = 0.33]; *P*-value = 0.011) • There were no significant differences between suspension conditions with respect to SI for step length, stance time, or step time <u>Study 2:</u> Summary of findings: • There were no statistically significant differences between VASS users and non-VASS users with respect to the self-reported outcomes assessed using the survey ○ These outcomes included locomotor abilities (measured with Activities-Specific Balance Confidence scores), functional locomotor capabilities (using the Locomotor Capabilities Index 5), prosthetic use (measured with the Houghton Scale), and prosthesis-related quality of life (measured with the Prosthetic Evaluation Questionnaire)	VASS experience an immediate reduction in comfort, presumably reflecting worse fit, and this may limit their ability to attain faster walking speeds. There is no immediate negative effect of loss of vacuum on the cost of transport or any clear difference in self-reported measures with and without VASS. Therefore, acute loss of vacuum may not negatively impact patients' ability to perform daily tasks before visiting their prosthetist. At the same time, providing VASS could benefit prosthetic users who feel limited by the ability to achieve faster speeds, although a specific study is warranted to test this idea. The self-reported measures used to quantify the effects of suspension on prosthetic use, locomotor capabilities, and domains reflecting prosthesis-related quality of life may not be well suited for identifying difference in the high-functioning, heterogeneous population considered in the current study."[19] (p. 71)
Rink et al., 2016[20]	

A single centre, open-label, randomized crossover trial that evaluated skin health and perfusion in individuals with transtibial and transfemoral amputation (N = 10) using an elevated vacuum system compared to pin-locking or suction sockets (SoC).
 	
Summary of findings:
• Compared to SoC sockets, participants using the elevated vacuum system had improved transepidermal water loss after 16 weeks
  ○ Elevated vacuum system: 16.1 $g*m^{-2}*hr^{-1}$
  ○ SoC: 20.0 $g*m^{-2}*hr^{-1}$
  ○ *P*-value < 0.05
• There were no statistically significant differences between the elevated vacuum system and SoC with respect to skin perfusion (measured using laser Doppler flowmetry) at baseline or after 16 weeks
• Participants demonstrated significantly decreased reactive hyperemia (measured using hyperspectral images) in the residual limb skin compared to SoC sockets (*P*-value < 0.05)
	"In summary, this prospective randomized trial in people with lower-limb amputation quantitatively assesses residual-limb skin barrier function and perfusion in response to [elevated vacuum suspension]. Taken together, in- and out-of-socket perfusion measurements support long-term use of [elevated vacuum suspension] in improving residual-limb skin

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
	oxygenation and attenuating socket-induced reactive hyperemia. Furthermore, [elevated vacuum suspension] preserved skin barrier function of the residual limb as compared to SoC after 16 wk of use. These findings suggest that in addition to improved fit and performance benefits [5–8] ascribed to [elevated vacuum suspension], long-term use may also impart physiological benefits to residual-limb health in people with lower-limb amputation."[20] (p. 1129)
Non-Randomized Studies	
Çalışkan Uçkun et al., 2019[21]	
A single-centre, cross-sectional observational study that compared levels of physical activity and quality of life in individuals with transtibial amputation who are using either a vacuum-assisted (N = 25) or a pin-locking (N = 26) suspension system with able-bodied controls (N = 51). Summary of findings: • There were no statistically significant differences between pin-lock suspension system users and VASS with respect to IPAQ-SF and SF-36 scores. Data was presented for the following outcomes: ○ Time spent doing the metabolic equivalent of walking (min/week): ▪ VASS: 726.0 (SD = 663.1) ▪ Pin-lock: 941.7 (SD = 1088.3) ▪ *P*-value: 1.000 ○ Time spent doing the metabolic equivalent of moderate activity (min/week): ▪ VASS: 172.8 (SD = 441.0) ▪ Pin-lock: 50.0 (SD = 129.6) ▪ *P*-value: 0.380 ○ Time spent doing the metabolic equivalent of vigorous activity (min/week): ▪ VASS: 115.2 (SD = 398.7) ▪ Pin-lock: 395.3 (SD = 1432.8) ▪ *P*-value: 0.560 ○ Time spent doing the metabolic equivalent of total activity (min/week): ▪ VASS: 1014.1 (SD = 978.9) ▪ Pin-lock: 1387.2 (SD = 2352.2) ▪ *P*-value: 1.000 ○ SF-36, physical functioning: ▪ VASS: 69.6 (SD = 19.6) ▪ Pin-lock: 65.5 (SD = 28.8) ▪ *P*-value: 1.000 ○ SF-36, role limitation due to physical health: ▪ VASS: 65.0 (SD = 42.0) ▪ Pin-lock: 64.4 (SD = 43.6)	"Our findings showed that VASS compared to PIN/LOCK did not provide benefit to users regarding [physical activity] and [quality of life]. Moreover, participants using PIN/LOCK also reported total [physical activity] (not statistically significant) and SF-36 bodily pain scores more closely to those of the controls than those using VASS. The findings, therefore, may improve our understanding of the effects of different prosthetic suspension systems on [physical activity] levels and [quality of life], and guide the clinician when prescribing prosthesis. However, additional studies which include direct measurement of [physical activity], condition-specific measures of [quality of life] and address potential confounders are needed to confirm the findings from the present study."[21] (p. 525-526)

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
▪ *P*-value: 1.000 ○ SF-36, pain: ▪ VASS: 70.2 (SD = 27.5) ▪ Pin-lock: 83.3 (SD = 20.0) ▪ *P*-value: 0.087 ○ SF-36, general health status: ▪ VASS: 62.0 (SD = 23.0) ▪ Pin-lock: 64.8 (SD = 14.3) ▪ *P*-value: 1.000 ○ SF-36, vitality: ▪ VASS: 62.6 (SD = 18.5) ▪ Pin-lock: 60.7 (SD = 17.5) ▪ *P*-value: 1.000 ○ SF-36, role limitation due to emotional problems: ▪ VASS: 63.9 (SD = 42.7) ▪ Pin-lock: 67.8 (SD = 42.7) ▪ *P*-value: 1.000 ○ SF-36, social relations: ▪ VASS: 72.6 (SD = 24.6) ▪ Pin-lock: 79.0 (SD = 17.5) ▪ *P*-value: 0.526 ○ SF-36, mental health: ▪ VASS: 64.8 (SD = 18.6) ▪ Pin-lock: 69.0 (SD = 16.1) ▪ *P*-value: 1.000	
Rosenblatt and Ehrhardt, 2017[22]	
Prospective, longitudinal cohort study that evaluated the relative risk of falling between patient cohorts with VASS (N = 15) and non-VASS (e.g., pin-lock, suction; N = 12) prosthetic devices. Summary of findings: • There were no statistically significant differences between VASS and non-VASS users with respect to rates of stumbles or the risk of stumbling for individuals with either transtibial or transfemoral amputation • Compared to those with non-VASS prostheses, the risk for having ≥1 fall and the risk of recurrent falls (≥2 falls) were significantly reduced in VASS users with transtibial amputation (*P*-values = 0.02 and 0.009, respectively) • There were no statistically significant differences between VASS and non-VASS users in those with transfemoral amputation	"The current results are intended to provide initial evidence that VASS may reduce fall risk in [transtibial amputation]. Larger more controlled observational studies that account for suspension type, components, fall history prior to receiving VASS and/or different study designs are warranted to determine the true effect of VASS on falls for [transtibial amputation] as well as [transfemoral amputation]."[22] (p. 102)
Darter et al., 2016[23]	
Non-randomized crossover trial that investigated the differences in limb-socket movement between VASS and passive suction systems in individuals with traumatic transtibial amputation (N = 10). Summary of findings: • There were statistically significant differences between VASS and passive suction systems with respect to bone-socket displacement as weight was applied to the prosthesis	"Maintaining residual limb position within the socket remains an important consideration with prosthetic design. The study results suggest elevated vacuum suspension improved socket

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion
○ Bone-socket displacement between 0% to 20% of body weight (cm): ▪ VASS: 0.8 (SD = 0.2) ▪ Passive suction: 1.1 (SD = 0.3) ▪ Difference: 0.4 (95% CI = 0.2 to 0.6) ▪ *P*-value: <0.0001 ○ Bone-socket displacement between 20% to 40% of body weight (cm): ▪ VASS: 0.3 (SD = 0.1) ▪ Passive suction: 0.3 (SD = 0.1) ▪ Difference: 0.0 (95% CI = -0.2 to 0.2) ▪ *P*-value: 0.70 ○ Bone-socket displacement between 40% to 60% of body weight (cm): ▪ VASS: 0.1 (SD = 0.1) ▪ Passive suction: 0.1 (SD = 0.1) ▪ Difference: 0.0 (95% CI = -0.2 to 0.2) ▪ *P*-value: 0.75 ○ Bone-socket displacement between 60% to 80% of body weight (cm): ▪ VASS: 0.1 (SD = 0.1) ▪ Passive suction: 0.2 (SD = 0.2) ▪ Difference: 0.1 (95% CI = -0.1 to 0.3) ▪ *P*-value: 0.16 ○ Bone-socket displacement between 0% to 100% of body weight (cm): ▪ VASS: 1.3 (SD = 0.2) ▪ Passive suction: 1.8 (SD = 0.3) ▪ Difference: 0.5 (95% CI = 0.2 to 0.7) ▪ *P*-value: <0.0001	fit by reducing axial limb–socket motion between non-weight-bearing and BW experienced during early stance phase of walking. However, there was no evidence elevated vacuum suspension systems differ from passive suction systems in reducing limb–socket motion past initial loading."[23] (p. 556)
Şahin Onat et al., 2016[24]	
Cross-sectional observational study that investigated the effect of various prosthesis types on quadriceps muscle and distal femoral cartilage thickness in patients with transtibial amputation. Of the 38 participants, 13 used a vacuum system while 25 used a silicone liner pin system. Summary of findings: • There were statistically significant differences between the VASS and silicon liner pin system cohorts with respect to lateral femoral condyle and medial femoral condyle cartilage thickness ○ Lateral femoral condyle cartilage thickness in the amputated limb (mm): ▪ VASS: 1.92 (SD = 0.46) ▪ Silicon liner pin system: 1.60 (SD = 0.45) ▪ *P*-value: 0.049 ○ Medial femoral condyle cartilage thickness in the amputated limb (mm): ▪ VASS: 2.04 (SD = 0.51) ▪ Silicon liner pin system: 1.65 (SD = 0.51) ▪ *P*-value: 0.035 • There were no statistically significant differences in the other measurements of femoral cartilage and quadriceps muscle thickness between the VASS and silicon liner pin system users	"In summary, we imply that distal femoral cartilage and quadriceps muscle thicknesses are decreased on the amputated sides of transtibial amputee subjects and that the unfavorable effects on the cartilage seem to be worse in the silicon liner pin system users. Future studies with larger samples and functional assessment (also including other prosthesis types) are awaited to better understand the clinical relevance of this difference and also to better guide the prosthetic prescription/use in this group of amputees."[24] (p. 488)
Samitier et al., 2016[25]	
A quasi-experimental before-and-after intervention study that evaluated the effect of VASS on mobility (e.g., gait, balance) in patients over 50 years of age with dysvascular transtibial amputation (N = 16).	"In conclusion, the Harmony® P2 & HD is a useful device in dysvascular

Table 9: Summary of Findings of Included Primary Clinical Studies

Main Study Findings	Authors' Conclusion

Summary of findings:
• There were statistically significant differences between study participants outcomes while using their previous non-VASS prosthetic and the VASS device with respect to balance (measured using the Berg Balance Scale and the Four Square Step Test) and functional evaluation of gait and transfers (measured using the Timed Up and Go Test and the 6-Min Walk Test)
  ○ Berg Balance Scale scores:
  ▪ VASS: 49.06 (SD = 5.62)
  ▪ Non-VASS: 45.75 (SD = 6.91)
  ▪ *P*-value: <0.01
  ○ Time to complete the Four Square Step Test (s):
  ▪ VASS: 14.97 (SD = 3.9)
  ▪ Non-VASS: 18.18 (SD = 3.84)
  ▪ *P*-value: <0.01
  ○ Time to complete the Timed Up and Go Test (s):
  ▪ VASS: 11.56 (SD = 2.46)
  ▪ Non-VASS: 14.30 (SD = 3.29)
  ▪ *P*-value: 0.01
  ○ Distance during 6-Min Walk Test (m):
  ▪ VASS: 321.38 (SD = 72.81)
  ▪ Non-VASS: 288.53 (SD = 59.57)
  ▪ *P*-value: <0.01
• There were no statistically significant differences between the prosthetic devices with respect to several subjective evaluations, including locomotor capability (measured with the Locomotor Capabilities Index), patient satisfaction with the prosthesis (measured with the Satisfaction with Prosthesis questionnaire), and prosthetic use (measured with the Houghton Scale)
  ○ Locomotor Capabilities Index scores:
  ▪ VASS: 47.44 (SD = 7.97)
  ▪ Non-VASS: 43.31 (SD = 10.32)
  ▪ *P*-value: >0.05
  ○ Satisfaction with Prosthesis Scale scores:
  ▪ VASS: 27.69 (SD = 14.97)
  ▪ Non-VASS: 27.50 (SD = 12.44)
  ▪ *P*-value: >0.05
  ○ Houghton Scale scores:
  ▪ VASS: 9.88 (SD = 1.78)
  ▪ Non-VASS: 9.31 (SD = 1.62)
  ▪ *P*-value: >0.05
	transtibial amputees over 50 years of age. In our study, the use of VASS improved balance, gait, and transfers in patients with MFCL-3 mobility grade and balance and prosthesis use in patients with MFCL-2 activity level. In patients with a lower activity level, the use of an additional distal valve in the socket should be considered."[25] (p. 87)

CI = confidence interval; IPAQ-SF = Short form of the International Physical Activity Questionnaire; MCFL = Medicare Functional Classification Level; N = number of participants; SD = standard deviation; SF-36 = Short Form 36; SI = symmetry index; SoC = standard of care; VASS = vacuum-assisted suspension system.

Table 10: Summary of Recommendations in Included Guidelines

Relevant Recommendations	Strength of Evidence and Recommendations
Stevens et al., 2019[9]	

Evidence-based guideline regarding socket design, interface, and suspension of definitive transtibial prostheses.
 	
This guideline includes three recommendation relevant to elevated vacuum suspension systems, as follows:
• **"**Among modern suspension options, vacuum assisted suspension sockets permits the least amount of pistoning within the socket, followed by suction suspension and then pin-lock suspension. The traditional suspension options of supracondylar, cuff and sleeve suspension provide comparatively compromised suspension."[9] (p. 172)
  ○ Recommendation strength: **NR**
  ○ This recommendation is informed by evidence summarized in four systematic reviews[4,16,42,43] (one of which also conducted a meta-analysis[4])
• "[Vacuum assisted suspension] sockets are indicated to decrease daily limb volume changes of the limb in the socket while facilitating more favorable pressure distribution during gait."**[9]** (p. 172)
  ○ Recommendation strength: **NR**
  ○ This recommendation is informed by evidence summarized in six systematic reviews[4,16,42-45] (one of which also conducted a meta-analysis[4])
• "[Vacuum assisted suspension] sockets require both awareness and compliance on the part of the end user and are not universally indicated."[9] (p. 172)
  ○ Recommendation strength: **NR**
  ○ This recommendation is informed by evidence summarized in one systematic review[44]
	These recommendations were informed by a review of the published literature (which consisted of one systematic review and meta-analysis, nine systematic reviews, and one scoping review); however, the quality of the evidence and the strength of the recommendations was not reported.

The Department of Veterans Affairs and the Department of Defense, 2017[1]	

Evidence-based guideline regarding the rehabilitation of individuals with lower limb amputation.
 	
This guideline includes one recommendation relevant to elevated vacuum suspension systems, as follows:
• **"**We suggest offering microprocessor knee units over non-microprocessor knee units for ambulation to reduce risk of falls and maximize patient satisfaction. There is insufficient evidence to recommend for or against any particular socket design, prosthetic foot categories, and suspensions and interfaces."[1] (p. 39)
  ○ Recommendation strength: **(Weak for)**
  ○ This recommendation is informed by five systematic reviews[4,46-49] (one of which also conducted a meta-analysis[4]) and two primary studies[50,51]
	The quality of the evidence base was assessed using the GRADE system, which considers the balance of desirable and undesirable outcomes, the confidence in the quality of the evidence, patient or provider values and preferences, and various other implications. Drafted recommendations are classified as one of the following:
	• Strong For (i.e., "We recommend offering this option")
	• Weak For (i.e., "We suggest offering this option")
	• Weak Against (i.e., "We suggest not offering this option")
	• Strong Against (i.e., "We recommend against offering this option")

GRADE = Grading of Recommendations Assessment, Development and Evaluation; NR = not reported.

Appendix 5: Overlap between Included Systematic Reviews

Table 11: Relevant Primary Study Overlap between Included Systematic Reviews

Primary Study Citation	Systematic Review Citation		
	Highsmith et al. 2016[4]	Safari et al., 2015a[15]	Safari et al., 2015b[16]
Beil et al., 2002[27]	X		X
Board et al., 2001[32]			X
Ferraro, 2011[30]		X	
Gerschutz et al., 2010[33]			X
Klute et al., 2011[28]	X	X	X
Sanders et al., 2011[34]			X
Sutton et al., 2011[31]		X	
Traballesi et al., 2012[29]	X		

X = the primary study was included in the systematic review and relevant data were extracted for the current review.

Appendix 6: Additional References of Potential Interest

Review Articles

Healy A, Farmer S, Eddison N, et al. A scoping literature review of studies assessing effectiveness and cost-effectiveness of prosthetic and orthotic interventions. *Disabil Rehabil Assist Technol*. 2019:1-7.

Eshraghi A, Osman NA, Gholizadeh H, Karimi M, Ali S. Pistoning assessment in lower limb prosthetic sockets. *Prosthet Orthot Int*. 2012;36(1):15-24.

Andrysek J. Lower-limb prosthetic technologies in the developing world: a review of literature from 1994–2010. *Prosthet Orthot Int*. 2010; 34(4):378-398.