JÖNKÖPING UNIVERSITY
School of Health and Welfare

The evidence base of elevated vacuum and pin-lock suspension system in transtibial prosthetic users: A literature review with a systematic approach

PAPER WITHIN: *Prosthetics*
AUTHORS: *Louise Dömstedt and Malin Stafås*
TUTOR: *Saffran Möller*
JÖNKÖPING *2022-04-28*

Abstract

Aim: This review aims to describe the existing evidence base for using elevated vacuum suspension and pin-lock suspension systems in regards to fluctuations of limb volume, balance, effect on gait (spatial and temporal, kinematic, and kinetic data), and in-socket movement (pistoning and transverse forces).
Background: There is a growing population with a TT amputation thus there is an increased demand for TT prosthetic solutions. There are a multitude of different suspension methods with different drawbacks and benefits. This review investigates elevated vacuum suspension (EVS) and pin-lock suspension systems.
Method: A systematic search was conducted in Medline, PubMed, and Scopus, and included or excluded articles per the eligibility criteria. The chosen studies will be carefully read and critically appraised for their quality of evidence.
Results: 13 articles were found that matched the eligibility criteria and aim, 5 articles included pin-lock suspension systems and 9 included EVS systems. 3 looked at limb volume fluctuation, 1 at balance, 4 at in-socket movement (transverse forces and pistoning), and 8 at the quality of gait (temporal and spatial, kinematic, and kinetic).
Conclusion: Several of the articles included in this review indicate that EVS results in better performance on balance tests, higher velocity, and a more stable residual limb volume than other suspension systems. Furthermore, it was shown that prosthetic users with an EVS had more normal values in their ROM during gait and less in-socket movement.

JÖNKÖPING UNIVERSITY
School of Health and Welfare

Evidensbasen för aktiv vakuum och pinnlås suspension för protesanvändare med transtibial amputation: En litteraturöversikt med ett systematiskt tillvägagångssätt

HUVUDOMRÅDE: *Proteser*
FÖRFATTARE: *Louise Dömstedt och Malin Stafås*
HANDLEDARE: *Saffran Möller*
JÖNKÖPING 2022-04-28

Abstrakt

Syfte: Den här litteraturöversikten syftar till att beskriva den befintliga evidensbasen för användning av aktivt vakuum-suspension och pinnlås suspension med avseende på fluktuationer i extremitetvolym, balans, effekt på gång (spatial och temporal, kinematisk, och kinetiska data) och rörelse i hylsan (vertikala och tvärkrafter).
Bakgrund: Det finns en ökande population som genomgår en transtibial amputation alltså finns en ökad efterfrågan på transtibiala-proteslösningar. Det finns en mängd olika suspensionsmetoder med olika nackdelar och fördelar. Denna recension undersöker eleverad vakuum-suspesnion och pin-lås-suspension.
Metod: En systematisk sökning genomfördes i Medline, PubMed och Scopus och inkluderade eller exkluderade artiklar enligt behörighetskriterierna. De valda studierna kommer att läsas noggrant och kritiskt bedömas för deras metodologiska kvalité.
Resultat: 13 artiklar hittades som matchade behörighetskriterierna och syftet. 5 artiklar undersökte pin-lås-suspension och 9 undersökte aktivt vakuum-suspension. 3 tittade på volymfluktuationer i extremiteterna, 1 på balans, 4 på rörelse i socket (vertikala och tvärkrafter) och 8 på kvaliteten på gång (temporal och rumslig, kinematisk och kinetisk).
Slutsats: Denna litteraturöversikt visade att aktiv vakuum resulterar i att prestera bättre vid balanstester, har högre hastighet och en stabilare extremitet volym än andra suspensionsmetoder. Vidare fann man att protesanvändare med ett aktivt vakuum hade fler normala värden i sitt rörelseomfång under gång och har mindre vertikala krafter i hylsan.

Innehåll

Vocabulary

AP= Anteroposterior
CAREN= Computer Assisted Rehabilitation Environment System
CPO= Certified Prosthetic and Orthotist
BBS= Berg Balance Scale
BW= Body Weight
EVS= Elevated Vacuum Suspension
FSST= Four Step Square Test
GC= Gait Cycle
GRF= Ground Reaction Force
KCF= Knee Contact Force
KPa= Kilopascal
MDC= Minimal Detectable Change
MWT= Minute Walk Test
N= Newton
PICO= Patient, Intervention, Control, Outcome
PVS= Passive Vacuum Suspension
SBU=Statens Beredning för medicinsk och social Utvärdering
TT= Transtibial
TUG= Time Up and Go
USA= United States of America

1.Introduction

During the authors clinical placements, they observed inconsistencies between different clinics in Sweden in what they provided in terms of suspension systems for prosthetic users with a unilateral transtibial (TT) amputation. There are several suspension systems available but no clinical guidelines, local or national to guide the decision have been found by the authors. This raised a curiosity about the subject and with further research into the subject there was found to be a lack of literature reviews and meta-analysis to answer this research question.

It may be, as observed during the clinical placement, several times a week a Certified Prosthetist Orthotist (CPO) must decide between different suspension methods. It is important to base that decision on (among patients' preferences, contextual information, and clinical expertise) the best available evidence. This is essential for patient centered care, the choice taken will directly affect the patient (Del Mar et al., 2017; Hoffmann et al., 2017).

This thesis is a literature review with a systematic and transparent approach. The authors have, through discussions with the Jönköping Library, concluded that it would be misleading to name the thesis a systematic review. This is due to several reasons, the foremost being that the study does not and cannot follow the appropriate guidelines for a systematic review such as those provided by Cochrane. This does not prevent the study from having a systematic approach and to follow several of the vital steps to a systematic review, in all parts of the thesis.

2. Background

It is estimated that people living with limb loss in America 2005 will double from 1.6 million and reach 3.6 million by 2050 (Ziegler-Graham et al., 2008). According to the Swedamps register of 2020, with about 8400 registered patients, approximately 63% of all amputations performed on men and 49% of all amputations performed on women in Sweden are at the transtibial (TT) level (Swedamp, 2021).

From 2016-2019 there were 1918 new patients registered with a TT amputation to Swedamp. (2021). Among these 37% have been provided with a prosthesis. In their collected data of suspension methods combined with data of what liner was used (n=2883), around 2.7% used elevated vacuum suspension (EVS) as the suspension method and 21.7% use a distal pin-lock suspension method. In their data over the years, there is a discrepancy between using a vacuum (any kind) compared to a distal pin-lock. Since 2013 there has been a steady decline in pin-lock compared to vacuum. Pin-lock has previously been prescribed more frequently but appear to be phased out by vacuum (Swedamp, 2021).

Not all persons with an amputation use a prosthesis but those who do, prosthetic users, often report having problems with discomfort or issues related to an ill-fitting prosthesis such as skin breakdown (blisters, wounds, bruises, etc.) and pain (Klute et al., 2011). Up to 60% of the lower-limb prosthetic users are not satisfied with their prostheses, including their suspension method (Baars et al., 2018). This may be the result of poor socket manufacturing but can also be caused by an inadequate suspension method (Klute et al., 2011). The residual limb volume may fluctuate as forces are put on the limb, making it increase or decrease in volume over time. During stance and gait, when forces are applied to the residual limb such as torque and ground reaction force, it can displace the prosthesis to the residual limb (Eshragi et al., 2012; Klute et al., 2011).

Vertical movement inside the socket, defined as pistoning, as it resembles the movement of a piston and cylinder in a combustion engine (Dewees, 2020). Pistoning has an overall negative effect as it wears down on the skin and can cause discomfort and altered gait pattern (Dewees, 2020; Eshragi et al., 2012; Klute et al., 2011). Pistoning can be measured in both static and dynamic conditions. Previous studies have investigated static pistoning and encourage further research to be done on the dynamic measurement of pistoning. Measurement tools for dynamic and static measurement can be

radiography, photography, motion analysis techniques, spiral computerized tomography, or photoelectric sensors (Eshragi et al., 2012; Gholizadeh et al., 2012). In addition to pistoning there are transverse forces. Transverse forces can be defined as a rotation that occurs between the residual limb and the socket (DeWees, 2020). This will, as well as pistoning, have a negative effect on the skin and gait pattern (DeWees, 2020).

Prosthetic suspension systems are a method to couple the residual limb to the prosthetic limb. A successful suspension should provide a stable coupling that feels secure to the patient and provides maximum control over the prosthetic limb (DeWees, 2020). There are many methods to utilize when providing a prosthesis for a patient such as looped liner (non-vacuum system), suction socket, distal pin-lock, elevated vacuum, etc. The suspension system is a vital part of the prosthetic design and can influence prosthetic function, mobility, and overall satisfaction. Prosthetic fit and suspension are closely interrelated in terms of both the level of comfort and functional efficiency of the prosthesis (Eshragi et al., 2012). This study will investigate two methods of suspension: a pin-lock suspension system and an EVS system.

Pin-lock suspension is part of a group of suspension methods that can be called locking-liner suspension methods. The base for this type of suspension is a gelliner that is worn as the interface between the residual limb and socket and connects to both the socket and the residual limb. There are a few methods to attach the gelliner to the socket, like a lanyard, magnets, or a pin and shuttle. A pin and shuttle, known as a pin-lock consist of a liner where a pin is attached to the distal end. This pin will then lock into a shuttle placed in the prosthesis. There may be an audible sound when the locking mechanism is activated, informing the wearer that the prosthesis is secured. Once the wearer wishes to doff the prosthesis, a button disengages the lock, and the prosthesis can be taken off the pin. It is a fast donning and doffing process, but it is vital that the user correctly aligns the pin every time (DeWees, 2020). Furthermore, if something gets caught in the locking mechanism, for example, socks, the locking mechanism may cause the pin-lock to get stuck and the wearer unable to doff the prosthesis without professional help (Childers & Wurdeman, 2016). Active users have reported pistoning on their limb when using this suspension method as the prosthesis is primarily attached distally, it produces a gradient pressure on the limb with the highest on the distal end (Childers & Wurdeman, 2016; DeWees, 2020). During swing, the prosthesis weight pulls on the pin, resulting in an elongation of the liner and underlying tissue (DeWees, 2020).

EVS systems are part of the atmospheric pressure suspension systems group. These suspension methods rely on creating a negative pressure in the space between the gelliner and prosthetic socket to suspend the prosthesis to the residual limb. This is done by sealing the space airtight and then evacuating the air to create suction. The air can be evacuated by a passive vacuum suspension (PVS) which relies on the cyclic pumping of the limb to evacuate the air through a one-way valve. Another alternative is to use an EVS. EVS can be defined as the use of an external vacuum pump driven by a mechanical pump or microprocessor-controlled electric motor to actively evacuate the air (DeWees, 2020). Mechanical pumps use the natural motion of compression and decompression that gait produces to pull air from the socket. The microprocessor is powered by rechargeable batteries and can adjust the pressure in the socket and thus providing more control for the user. With an EVS system, the negative pressure can reach up to 80 kilopascal (KPa) and be held at the same level, despite what movement the user is performing. A microprocessor will require some extra building height, and these types of suspension systems require that the air-tight seal is maintained otherwise the system will fail. Pumps can also be built into the pylon or prosthetic foot (Childers & Wurdeman, 2016). Using vacuum leads to a decrease in in-socket motion, which is supposed to decrease skin problems, and improve prosthetic control, balance, and prosthetic comfort. They result in lower peak pressures and lower impact forces compared to traditional suction sockets (DeWees, 2020).

Previous studies have found that using an EVS might improve balance, activity, and gait parameters (such as spatial and temporal, kinematic, and kinetic data) (Young & Loshak, 2020). Spatial and temporal parameters include stride and steps duration, cadence, step length, stride length and step

width. Kinematic data includes the ROM of the joints whilst kinetic data includes forces, masses, acceleration, and moment, such as ground reaction force (GRF) (Whittle et al., 2012a; Whittle et al., 2012b). Earlier research indicate that EVS might reduce pistoning, fear of falling, and the risk of falling, and improve skin health (Young & Loshak, 2020). There is some evidence suggesting that using an EVS increase the limb volume compared to a non-EVS, this in turn will reduce movement on the residual limb and is favorably affecting the pressure distribution (Kahle et al., 2014; Young & Loshak, 2020). Additionally, there might be a difference in balance control. Balance is divided into both static (defined by Rival et al. (2005) as the ability to keep an upright posture within the base of support and dynamic balance, defined by Karimi & Solomonidis. (2011), as the ability to maintain stability throughout weight changes, or when changing the base of support. Young & Loshak. (2020) states that there might be improvements to the dynamic balance using EVS.

EVS might not be the best choice for all users as donning and doffing the prosthesis can be more difficult, it requires regular maintenance and can cause blisters if worn incorrectly (Gholizadeh et al., 2014b; Gholizadeh et al., 2016). As the evidence is unclear what functional effect using an EVS respectively a pin-lock suspension system has in regards to residual limb volume fluctuations, balance, in-socket movement and quality of gait, this study will investigate and describe the existing evidence base (Kahle et al., 2014).

3. Research question

How is the evidence covered for elevated suspension systems and pin-lock suspension systems regarding residual limb volume fluctuations, balance, in-socket movement (pistoning and transverse forces), and quality of gait (spatial and temporal, kinematic, and kinetic data) for prosthetic users with transtibial amputation?

4. Aim

This review aims to describe the existing evidence base for using elevated vacuum suspension and pin-lock suspension in regards to fluctuations of limb volume, balance, effect on gait (spatial and temporal, kinematic, and kinetic data), and in-socket movement (pistoning and transverse forces).

5. Method

5.1 Eligibility criteria

Previous reviews have investigated studies published prior to 2014, therefore, this review will include articles published from 2014. Included studies must be published, have a quantitative study design, be ethically approved, and be peer-reviewed. They must be written in English and accessible through Jönköping University Library. Systematic reviews will not be included in the results.

Cause of amputation, surgical technique, time since amputation, age during amputation, current age, gender, or ethical background is not considered a criterion for this study as its purpose is to be applicable to the general patient population and everyday clinical practice.

5.2 Search strategy

To be able to find relevant articles in the area that fit the eligibility criteria, three online databases will be used to conduct the search (Higgins et al., 2022), Medline, Cinahl, and Scopus. These databases

were used on the recommendation of the Jönköping Library as they consider them to have the most relevant record and thus provide sufficient coverage of the existing evidence base. The free-text search terms used in the databases are constructed using the PICO model. By using the PICO model included studies will align with the patient group, intervention, control, and outcome of the study. The patient group of this study is prosthetic users with TT amputation. The intervention is a TT prosthesis using an EVS, with the control being a TT prosthesis using a pin-lock mechanism as its suspension method. In terms of outcomes, this study investigates fluctuations of limb volume, balance, effect on gait (spatial and temporal, kinematic, and kinetic data), and in-socket movement (pistoning and transverse forces). This method was also applied to the creation of the research question (Table 1) (Del Mar et al., 2017; Hoffmann et al., 2017; Statens beredning för medicinsk och social utvärdering [SBU], 2020).

Table 1

PICO-terms

PICO-terms	PICO-term applied to this review
P- patients	Prosthetic users with a unilateral transtibial amputation
I -intervention	Elevated vacuum suspension system
C- Control	The distal pin-lock suspension system
O- Outcomes	Fluctuations of limb volume, balance, effect on gait (spatial and temporal, kinematic, and kinetic data), and in-socket movement (pistoning and transverse forces).

Note: Structure of the research question based on the PICO (Patients, Intervention, Control, Outcome) model.

Synonyms were used to broaden the search, they were sourced by looking into keywords from relevant published studies, textbooks, Thesaurus, and expert opinions from the Jönköping Library. The synonyms and free-text keywords are combined using Boolean operators. Keyword 1 represents the population (Table 1). Keyword 2 searches for both the intervention (I) and control (C). Outcome (O) is not used in the search as it would possibly minimize the range of the search and not all records would be found. Table 2 is used to structure the keywords and their synonyms (Del Mar et al., 2017; Hoffmann et al., 2017).

Table 2

Search terms for the literature search

Free-text keyword 1	Boolean term	Free-text keyword 2
(Transtibial or below- knee or belowknee or (below and knee)) AND (prosth* or prosthetic user* OR amputee* OR limb loss OR amputation* OR prosthetic user* OR limb amputation* OR artificial limb*)	AND	subatmospheric* OR Vacuum OR Vacum OR (elevated and (vacum or vacuum)) OR VAS OR VASS OR atmospheric OR (active AND suction) OR (active AND vacuum) OR (Pin AND lock) OR

		Pinlock* OR (Distal AND Pin AND lock*) OR (mechanical AND lock*)

Note: VAS = Vacuum assisted suspension VASS=Vacuum assisted suspension system.

To find additional articles this study will implement additional methods to broaden the search:

- Systematic reviews or other literature reviews will be sourced for their references as an additional strategy. If their references meet the criteria of this study they will be included.
- Google scholar will be used as an additional method as it is not an independent search engine, the same result may not be recreated (Levay et al., 2015). PubMed will be used in the same manner as Google Scholar. This is a recommended method to apply, suggested by the Library at Jönköping University.
- Articles recommended by other persons such as librarians, supervisors, etc. that fit the criteria will be included.

Any additional source found by using these methods will be added to the PRISMA flow chart under "additional records" (Hausner & Waffenscmidth, 2021; Levay et al., 2015).

5.3 Screening process

The screening process starts with the two authors searching independently of each other and manually. The searches will be conducted identically in regards to search terms used, their structure, and when the search will be conducted. The search will be saved and presented in appendix 1 with all search parameters and results clearly shown.

Articles will go through a selection process that will be presented in the PRISMA flow chart, this study uses the *PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only* flowchart (Page et al., 2021). In the first step of the process, the authors will select the studies that based on their headline and/or abstract will answer the research question, either in part or fully. The authors will independently remove duplicates from their search. The chosen articles will be read in their full-text version to screen for eligibility and if it answers the research question. Any studies removed at this stage will be documented and a reason will be presented in the flow diagram. Once this selection has been made the two authors meet up to compare articles. All articles will be discussed if they fit the eligibility criteria and answer the research question. Any studies removed at this stage will be documented in the flowchart with an explanation as to why. Any disagreement between the authors will be worked out through discussion.

5.4 Data analysis

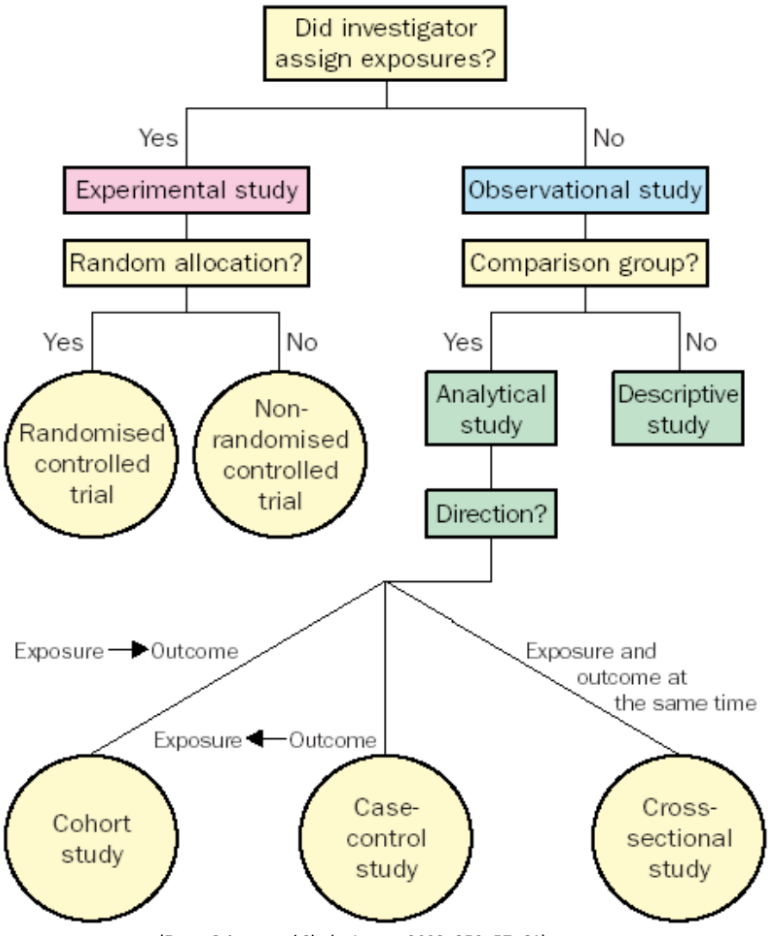
The outcome measures this study will investigate are fluctuations of limb volume, balance, effect on gait (spatial and temporal, kinematic, and kinetic data), and in-socket movement (pistoning and transverse forces). To compile all evidence and make conclusions from it, studies that look into the same outcome measure are going to be compared, and a result will be derived from that. The data and outcome measures in this review are too diverse to make a meta-analysis and therefore the results are going to be presented narratively with different headlines for the different outcome measures. To be able to structurally analyze the different data types a table is going to be used to easily structure the different outcomes to matching data types and validate these together with the article's quality (Bennet et al., 2017; Hoffman & Buchan., 2017; SBU, 2020).

To be able to quality assess the studies an important first step is to get an idea of which type of study design the articles have been used to give a fair judgment. The templates from Statens beredning för medicinsk och social utvärdering (SBU) (*Granskningsmallar och checklistor för bedömning av studier)* that are going to be used for the quality assessment in this study base their questions on the study design of the article and have different templates for different study designs (A, B and C). To be

able to decide the articles study design in an objective and transparent way, a template from Grimes & Schulz. (2002) is going to be used (Figure 1).

Figure 1

Study design chart



Note: Taken from Grimes & Schulz. (2002).

5.4.1 Quality assessment

SBU base their grading tools on methods developed and published by Cochrane Collaboration and GRADE. They have developed the SBU book of methods to write a systematic review based on robust evidence of high quality with different types of studies. Furthermore, they have several available documents that can be used to critically appraise articles. This review will use the resources provided by SBU in the structure of the study and the critical appraisal (Del Mar et al., 2017; Hoffman & Buchan, 2017; Hoffmann et al., 2017; SBU, 2020). The articles in this review will be critically appraised using SBUs' templates *Granskningsmallar och checklistor för bedömning av studier,* which are divided into three separate parts, internal validity, external validity and precision. The three parts have a point system for each question that is summarized for each part for a definitive result to support the decision of the quality assessment (Appendix 2) (Ahlström et al., 2007).
The evaluation and critical appraisal of the articles are going to be made individually by the two authors and then compared and discussed. Any possible differences will be discussed until a conclusion is reached. Studies with higher quality will be given more weight than the ones with lower quality.

5.4.1.1 Internal validity

Bias is a systematic variation or error in the study design. Bias can lead to overestimation or underestimation of effects, which leads to inaccurate results (SBU, 2020). The articles in this review will be critically appraised using SBUs' templates, (*Granskningsmallar och checklistor för bedömning av studier)* The templates examine several different types of bias such as selection and detection bias by several targeted questions that are based on the study design (Ahlström, et al., 2007).

Confounding factors are factors of interest that may cause errors in the interpretation of what may be an accurate measurement. This study will investigate to which extent confounding factors have affected each study by using SBUs templates (*Granskningsmallar och checklistor för bedömning av studier)*. The results will be presented in a table under results (Ahlström et al., 2007; SBU, 2020).

5.4.1.2 External validity

External validity measures the ability and to what extent the study can be generalized and representative of the whole population. Lack of external validity will make the study unable to be applied to other groups than the group in the specific study (SBU, 2020).

This study will use the template (*Granskningsmallar och checklistor för bedömning av studier),* by SBU to assess the external validity of a study. An important aspect in appraising the article's external validity is to assess the eligibility criteria of the study and to investigate, for example, the clarity and reasons for exclusion criteria and if it is clearly defined which subjects or population the studies are investigating (Forsberg & Wengström, 2013). External validity should generally be at the same level as internal validity (SBU, 2020; Schünemann et al., 2013).

5.4.1.3 Precision

Precision is the weighted result of the confidence interval around the assessment of the effect. The more narrow the confidence interval is, the better precision the study has. Even if the confidence interval is narrow, the precision can be lowered by low participation or too few events. If the study is imprecise, the results of the study are uncertain and the quality of the evidence is lowered. This study will use the template *Granskningsmallar och checklistor för bedömning av studier,* by SBU to assess the precision of a study (Ahlström et al., 2007).

5.4.1.4 Ethical considerations

This review uses only existing research and its data, thus there is no need for ethical approval for this study. However, this review will only include articles that have been ethically reviewed and approved by an ethical committee or other frameworks where the ethical considerations have been carefully considered to protect participants to perform ethical studies. In the conduct of research, no foreseeable risk to the participant should exist whether it be physical, psychological, or social (Forsberg & Wengström, 2013; Stanley & Mclaren, 2007).

To be able to act professionally and avoid research misconduct in this literature review, all articles will be presented, whether it supports any previous hypotheses or not. The method and results will be well presented, explanatory, and structured to easily be followed by the reader and to be able to be repeatable and comprehensible. No unauthorized use of the research result from other studies will be handled and fair judgment of other research will be conducted. This review will be objective and not made in an act of personal interest and will be free from manipulation and external influence (Vetenskapsrådets Expertgrupp För Etik, 2017).

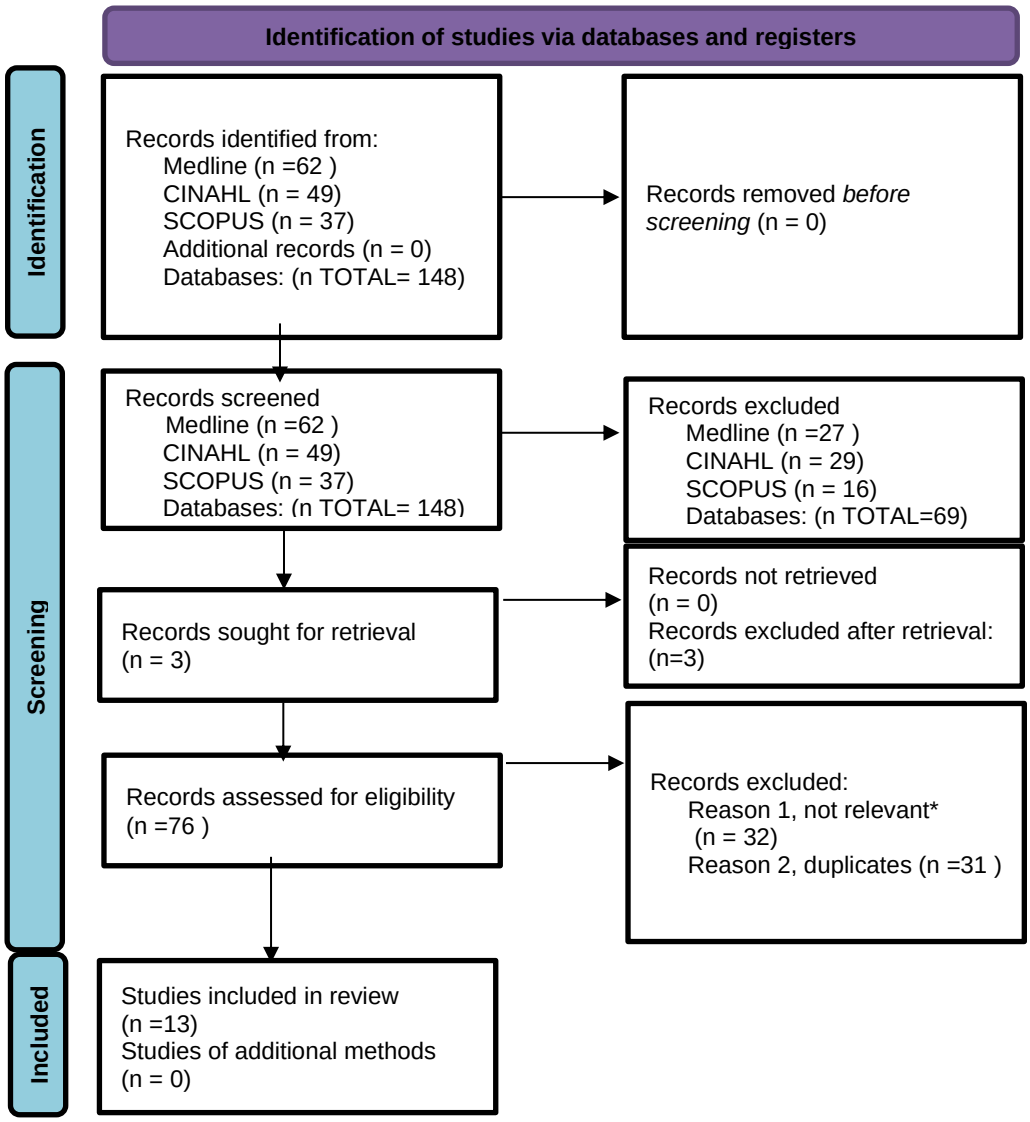
6. Result

6.1 Study selection

During the search 148 records were found over the three databases, (Figure 2). The records were screened to match with the research question and eligibility criteria and 69 records were removed. Out of the remaining 79 records, 3 were sought for retrieval by the help of Jönköping Library but were determined to not match the eligibility criteria or the research question and were excluded after retrieval. 76 articles were assessed for eligibility and relevance by the two authors. 32 articles were excluded due to not being relevant for the study's aim or research question, and 31 duplicates were removed. That resulted in 13 records. No additional records were identified. Figure 2 presents the PRISMA flowchart of the search and Table 3 shows the chosen studies and their characteristics.

Figure 2

Prisma flowchart



Note: * not relevant refers to articles that do not specify any of the suspension methods used, only has a qualitative methodology or does not research any of the specified outcome measures of this study (Page et al., 2021).

Table 3

Articles characteristics

Study	Country of origin	Study design	Number of participants	Intervention /control
Abu Osman et al. (2017)	Canada	Observational Cohort study	10	Pin/lock
Brzostowski et al. (2019)	USA	Randomized controlled trial	15 (12)	Pin/lock
Burçak et al. (2021)	Turkey	Controlled trial without randomization	54 (24 TT)	EVS
Darter et al. (2016)	USA	Controlled Clinical trial	10	EVS
Eshraghi et al. (2014)	Malaysia	Controlled clinical trial without randomization	15 (13)	Pin/Lock
Gholizadeh et al (2014a)	Malaysia	Controlled clinical trial without randomization	10	Pin/Lock
Gholizadeh et al (2020)	Canada	Randomized controlled trial	12	EVS
Gholizadeh et al (2022)	Canada	Randomized controlled trial	12	EVS
Samitier et al. (2016)	Spain	Controlled clinical trial without randomization	16	EVS
Xu et al. (2017a)	China, USA, Taiwan	Controlled trial without randomization	18 (9 amputee 9 able bodies)	EVS
Xu et al. (2017b)	China, USA, Taiwan	Cross sectional study	18 (9 amputee 9 able bodies)	EVS
Youngblood et al (2019)	USA	Controlled trial without randomization	13	EVS/pin-lock
Youngblood et al (2020)	USA	Controlled trial without randomization	12	EVS

Note: the characteristics of each article with the main author, countries, the study design, number of participants and what intervention or control they used. EVS = Elevated vacuum suspension, TT=transtibial, USA=United states of America.

6.2 Quality assessment

In the quality assessment different templates have been used based on the study design, (Appendix 2). The templates do differ somewhat in between, and the results are presented based on what template has been used. For each template there is a score and color that shows what quality the study has in its external validity, internal validity and precision.

6.2.1 Template A

External validity:
Green: Clear or probable external validity (0-1)
Yellow: Uncertain external external validity (2-3)
Red: External validity cannot be assessed (>3)

Internal Validity
Green: Excellent or good internal validity (0-4)
Yellow: Acceptable or Uncertain external validity (5-10)
Red: Uninformative due to flawed internal validity (>10)

Precision
Green: Premeditated and sufficient study size (0-1)
Yellow: Study size of uncertain adequacy (2-3)
Red: Probably underpowered study (>3)

Table 4

Quality assessment of Randomized controlled trials

Main Author	Study design	External validity	Internal validity	Precision
Brzozowski et al. (2019)	Randomized controlled trial	3	15	3
Gholizadeh et al. (2020)	Randomized controlled trial	1	19	5
Gholizadeh et al. (2022)	Randomized controlled trial	9	16	5

Note: quality assessment for all studies identified to be graded with template A.

6.2.2 Template B

External validity:
Green: Clear or probable external validity (0-1)
Yellow: Uncertain external external validity (2-3)
Red: External validity cannot be assessed (>3)

Internal Validity:
Green: Excellent or good internal validity (0-3)

Yellow: Acceptable or Uncertain external validity (4-9)
Red: Uninformative due to flawed internal validity (>9)

Precision:
Green: Premeditated and sufficient study size (0-1)
Yellow: Study size of uncertain adequacy (2-3)
Red: Probably underpowered study (>3)

Table 5

Quality assessment of non-randomized controlled trials

Main author	Study Design	External Validity	Internal Validity	Precision
Abu Osman et al. (2017)	Controlled trial without randomization	3	14	3
Burçak et al. (2019)	Controlled trial without randomization	4	9	3
Darter et al. (2016)	Controlled trial without randomization	4	8	3
Eshraghi et al. (2014)	Controlled trial without randomization	2	6	3
Gholizadeh et al. (2014a)	Controlled trial without randomization	3	11	3
Samitier et al. (2016)	Controlled trial without randomization	0	6	4
Xu et al. (2017a)	Controlled trial without randomization	4	12	5
Youngblood et al. (2019)	Controlled trial without randomization	0	12	3
Youngblood et al. (2020)	Controlled trial without randomization	2	11	3

Note: the quality assessment of all studies identified to be graded with template B.

6.2.3 Template C

External validity:
Green: Clear or probable external validity (0-1)
Yellow: Uncertain external external validity (2-3)
Red: External validity cannot be assessed (>3)

Internal Validity
Green: Excellent or good internal validity (0-3)
Yellow: Acceptable or Uncertain external validity (4-8)
Red: Uninformative due to flawed internal validity (>8)

Precision
Green: Premeditated and sufficient study size (0-1)
Yellow: Study size of uncertain adequacy (2-3)
Red: Probably underpowered study (>3)

Table 6

Quality assessment of Cross-sectional study

Main author	Study design	External validity	Internal validity	Precision
Xu et al. (2017b)	Cross sectional study	2	9	5

Note: the quality assessment of the study that qualified to be assessed by template C.

6.3 Results of the interventions

Several of the studies used in this review investigated more than one outcome measure of interest. Table 7 gives an oversight of the studies intervention or control, their outcome measures and what method was used to capture the data.

Table 7

Studies intervention/control, method and outcomes investigated.

Study	Intervention/control	Method	Outcome 1	Outcome 2	Outcome 3
Abu Osman et al. (2017)	Pin/lock	Tensile testing machine and photographically	Pistoning		
Brzostowski et al. (2019)	Pin/lock	Electrodes with a portable bioimpedance analyzer	Limb volume fluctuation		
Burçak et al. (2021)	EVS	6MWT	Temporal & Spatial		
Darter et al. (2016)	EVS	Digital video fluoroscopy	Pistoning		
Eshraghi et al. (2014)	Pin/Lock	Vicon 612 motion system	Pistoning	Kinematics	Kinetics
Gholizadeh et al. (2014a)	Pin/Lock	Vicon 612 motion system	Temporal & Spatial	Kinematics	Kinetics
Gholizadeh et al. (2020)	EVS	CAREN Extended System and vicon 612 motion system	Temporal & Spatial	Kinematic	Kinetic
Gholizadeh et al. (2022)	EVS	CAREN Extended System	Kinematics		
Samitier et al. (2016)	EVS	BBS, FSST, TUG and 6MWT	Balance	Temporal & Spatial	
Xu et al. (2017a)	EVS	Vicon motion system	Temporal & spatial	Kinematic	Kinetic
Xu et al. (2017b)	EVS	Previously collected data	Kinetic		
Youngblood et al. (2019)	EVS and pin-lock	Electrodes with a portable bioimpedance analyzer	Limb volume fluctuation		
Youngblood et al. (2020)	EVS	Electrodes with a portable bioimpedance analyzer	Limb volume fluctuation		

Note: the studies main author, the intervention and/or control they investigated, what method they employed to capture the data and what outcome measures they investigated.

6.3.1 Limb volume fluctuation

Three studies were found during the search that measured limb volume fluctuation Youngblood et al. (2019), Youngblood et al. (2020) and Brzostowski et al. (2019). Youngblood et al. (2019) and Brzostowski et al. (2019) measured limb volume fluctuation in pin-lock and Youngblood et al. (2020) measured the outcome in EVS. All 3 articles defined and analyzed the limb volume fluctuation the same way (Table 7).

In Youngblood et al. (2019) the result from PVS and EVS was presented together and the data for EVS cannot be retrieved. 7 participants benefited (a beneficial results means maintaining the limb volume better in the experimental session than in the control sessions) from doffing the prosthesis in the short term (1,5h) and 6 participants in long-term (3,5h) when having a pin-lock suspension. 2 participants had no effect both in short-term and long term and one participant did detriment from doffing the prosthesis in the long-term in aspect to manage limb volume change. The article has not stated if the result is statistically significant or not.

The study found that the limb volume fluctuated more in early stages of activity (cycle 1) but stabilized as the participants continued with the activity and tests (cycle 3). This is a statistically significant difference ($p<0,001$) in the rate of limb volume loss in the early stages of activity (cycle 1), which was high, compared to the later stages of activity (cycle 3), which was low (Youngblood et al., 2019)

The conclusion was that intermittent doffing may result in a more stable residual limb volume for pin-lock suspension users and may be an alternative to adding socks in the socket. Also that high activity may cause less limb volume loss then low activity (Youngblood et al., 2019)

Youngblood et al. (2020) reports that there were no significant differences in residual limb fluid volume change between EVS and PVS between different activity types (walking, standing and sitting). However, EVS had the largest fluctuation in the second activity cycle (out of three) where the largest posterior limb volume loss occurred and stabilized in the final activity cycle (cycle 3). There was a statistical significant difference between the two cycles ($p=0.014$) EVS is shown to lose volume faster in the anterior region (-1.1%/h) than posteriorly (-0.9%/h).The overall limb volume increased during walking (+10%/h), decreased when standing (-10%/h) and was stable during sitting (0%/h). The article does not state if these numbers are statistically significant. The article concluded that EVS reduced posterior limb volume change in the final activity cycle (cycle3) compared to PVS ($p=0,03$) which may suggest that EVS are more effective in managing the limb volume fluctuation after an accumulation of activity, though individual differences were observed.

Brzostowski et al. (2019) showed that in the beginning stages of the test there was a general posterior limb volume loss (-0.06%) and as the participants continued the test there was a posterior limb volume increase observed in the later stages of activity (+0.26%), the statistically significant is not stated by the article. The anterior side had an increase in the beginning stages of activity (+.0.04%) and a larger increase in the later stages of activity (+0.41%) the statistically significant is not stated by the article. They concluded that the limb volume was more stabilized in the short term when the socket was released at rest after activity, compared to the control group. At partial return of the socket (102%), the limb volume was more stable in the long term after the socket release ($p<0,05$).

6.3.2 Balance

There was one study that investigated balance as an outcome measure, Samitier et al. (2016) found the participant had a statistically significant higher score ($p<0.01$) on the Berg Balance scale (BBS) with an EVS compared to a non-EVS, indicating a better balance with the EVS. The results of the four-step square test (FSST) showed participants doing the test statistically significantly ($p<0.01$) faster with an EVS than with a non-EVS indicating a better limb control, balance and lower risk of falling (Table 8).

Samtier et al. (2016) also found that participants with a higher activity level improved their balance using an EVS more than participants with a lower activity level.

Table 8

Results in balance for non-EVS and EVS.

Tests	Non-EVS	EVS	p-value
Berg Balance Scale	45.75	49.06	<0.01
Four Square Step Test (s)	18.18	14.97	<0.01

Note: the result of the Berg Balance Scale and Four-Step Square Test that was reported by the study by Sametier et al (2016).

6.3.3 In socket movement

6.3.3.1 Transverse in-socket movement

None of the articles found had transverse force as an outcome measure.

6.3.3.2 Pistoning

Three studies investigated pistoning, two of them studied pin-lock suspension, Eshragi et al. (2014) and Abu Osman et al. (2017), and one the EVS system, Darter et al. (2016). Each of these studies used different methods to measure pistoning.

Abu Osman et al. (2017) found that a pin-lock suspension had generally more pistoning than that of a looped liner. The pin-lock displacement during the mechanical tensile testing was lower after 180 N had been applied to it (0.65 +- 0.25 cm), compared to looped liners with hooks (0.77 +- 0.37 cm). Darter et al. (2016) found that a PVS method resulted in more pistoning than an EVS. Participants had less displacement when using the EVS ($p<0.0001$) with 1.3 +- 0.2 cm displacement being observed in the EVS and 1.8 +- 0.3 cm of displacement being observed in the PVS tests. Eshragi et al. (2014) found that a pin-lock had more pistoning than a PVS. During the swing phase, the PVS showed 0.2 cm displacement whilst the pin-lock resulted in 0.49 cm displacement ($p=0.002$).

6.3.4 Quality of gait

6.3.4.1 Temporal and Spatial

There were 5 articles that investigated this outcome measure, Burçak et al. (2021), Gholizadeh et al. (2014a), Gholizadeh et al. (2020), Samitier et al. (2016) and Xu et al. (2017a). All articles in this outcome measure investigated EVS except Gholizadeh et al. (2014a) that investigated pin-lock.

Both Burçak et al. (2021) and Samitier et al. (2016) found that participants walked longer distances with an EVS in the 6MWT than with a non-EVS. Burçak et al. (2021) found that participants using a mechanical suspension system walked 367.1 meters, while participants using EVS walked 419.9 meters (p=0.004). Samitier et al. (2016) found that participants walked a statistically significantly longer distance using the EVS, 321.38 meters, than the control non-EVS, 288.53 meters (p<0.01), this may indicate a higher velocity using an EVS than a non-EVS. Furthermore, Gholizadeh et al. (2014a) report a velocity on pin-lock of 0.93 m/s and Gholizadeh et al. (2020) report a velocity on EVS of 1.07 m/s.

In prosthetic users with pin-lock, the prosthetic limb generally takes longer steps than the intact limb, but users with EVS generally have a longer step on the intact limb. Gholizadeh et al. (2014a) presented a between limb difference (step length of the intact limb minus the step length of the residual limb) of (-8) cm for pin-lock, showing that the residual limb took longer steps than the intact limb. However, Gholizadeh et al. (2020) presented 3 cm between limb difference for EVS, showing longer steps taken on the intact limb then the residual limb. In the data presented by Xu et al. (2017a) the step length between limb difference is between 6.1-7.4 cm, depending on the vacuum level, showing the same trend as Gholizadeh et al. (2020).

6.3.4.2 Kinematics

There were five studies that investigated kinematic parameters, Eshraghi et al. (2014), Gholizadeh et al. (2014a), Gholizadeh et al. (2020), Gholizadeh et al. (2022) and Xu et al. (2017a). Eshraghi et al. (2014) and Gholizadeh et al. (2014a) investigated pin-lock whilst Gholizadeh et al. (2020), Gholizadeh et al. (2022) and Xu et al. (2017a) investigated EVS.

In four of the five studies there were kinematic tables presented showing the entire gait cycle and the flexion and extension of the hip, knee and ankle. Two of these studies showed the values for pin-lock (Eshraghi et al. (2014) and Gholizadeh et al. (2014a)) and two showed for EVS (Gholizadeh et al. (2020) and Xu et al. (2017a)).
The EVS results show very similar data except for hip angle at 0% of the gait cycle (GC) and 85% of GC. Xu et al. (2017a) measures about 40° of flexion whilst Gholizadeh et al. (2020) shows 15°, on both times of the GC. The two datasets of pin-lock show no large differences in their reported data.

In hip ROM the results showed that participants walking with pin-lock never fully extended their hip during the GC, whilst the participants with EVS went into hip extension during the gait cycle and had a larger ROM than what was shown for pin-lock users. For knee ROM, the pin-lock suspension users flex their knee slightly more than the participants using EVS (Eshraghi et al., 2014; Gholizadeh et al., 2014a; Gholizadeh et al., 2020; Xu et al., 2017a)

6.3.4.3 Kinetic

Five studies were found that measured Kinetic outcomes, two of the studies measured kinetics in pin-lock, Eshraghi et al. (2014) and Gholizadeh et al. (2014a). Three measured kinetics in EVS, Xu et al. (2017a), Xu et al. (2017b) and Gholizadeh et al. (2020).

Kinetic outcomes at the pin-lock suspension system indicates a higher impact of forces at the sound limb compared to the residual limb when walking. Gholizadeh et al. (2014a) reports a significant difference in the vertical ground reaction at first peak, where the prosthetic limb creates less force (104,2N) then the sound limb (121,7N) (p<0,000). Eshragi et al. (2014) found that the residual limb experiences higher forces when the participant is using a pin-lock suspension compared to a PVS. There is a statistical significant difference (p=0,000) in the first peak of vertical ground reaction force where the participants with pin-lock experience higher forces (126,68%BW) than those with PVS (104,22%BW). However, there is also a statistical significant difference (p=0,000) in the second peak

in horizontal ground reaction force where the participants with pin-lock experience less force on their residual limb (4,66%BW) than those with a PVS (9,34%BW).

Gholizadeh et al. (2020) did not find any statistically significant results between sound limb and residual limb.

Xu et al. (2017a) found a statistically significant difference at the first vertical peak GRF (p=0,035) and second peak vertical GRF (P=0,007) on the intact limb and residual limb in participants with an EVS, indicating that there are higher impact forces on the intact limb compared to the residual limb when walking. Xu et al. (2017b) shows that the peak anterior-posterior knee contact force (AP KCF) was higher in the intact limb than in the residual limb (p=0,003). They also found that the values for the prosthetic users' intact limb were statistically significantly higher than for able bodies (p=0,049).

7. Discussion

This literature review has aimed to describe the existing evidence base for EVS and pin suspension methods in prosthetic users with a transtibial amputation in regards to their effect on fluctuations of limb volume, balance, effect on gait, and in-socket movement. This review found that EVS results in better performance on balance tests, higher velocity and a more stable residual limb volume than other suspension systems. Furthermore, it was found that prosthetic users with an EVS had more normal values in their ROM during gait and have less pistoning.

7.1 Discussion of the results

In this review Youngblood et al. (2020) found limited evidence that supports that EVS users generally have a more stable residual limb volume after activity compared to using a PVS. This is in agreement with previous reviews and published literature. Young & Loshak. (2020) found that EVS may provide a more stable residual limb volume than non-EVS. Dewees states that users with an EVS maintain their residual limb volume since the vacuum prevents the fluid loss that may occur during weight bearing (DeWees, 2020).

Youngblood et al. (2019) observed that donning and doffing the prosthesis during activity is a method to manage limb volume fluctuation for pin-lock users. Brzostowski et al. (2019) found that adjustable sockets are recommended to manage residual limb volume fluctuations in comparison to a non-adjustable socket for users with pin-lock. This may indicate that by using an adjustable socket or donning and doffing intermittently, the residual limb volume can be stabilized whilst using a pin-lock suspension. This indicates that not only the suspension system has a role in keeping the limb volume stable. This relation between socket design and suspension method should be investigated further in future research. Future research should also focus on investigating residual limb volume fluctuations when using different suspension methods, for example comparing PVS, EVS and pin-lock to determine if there is a statistically or clinically significant difference between the suspension systems.

This review found that prosthetic users performed better on balance tests with an EVS than a non-EVS. Samitier et al. (2016) reported an increase in the BBS of 3.31 points from the non-EVS to the EVS suspension system. Although the study does report that this change is statistically significant, it does not prove to be within the minimal detectable change (MDC95) to determine it to be a true change. That would have needed to be a score of 4 or more. Thus, this review cannot say with great confidence that the change was due to the different suspension method (Donoghue & Stokes, 2009).

The FSST showed a decrease in time between using a non-EVS and using an EVS of 3.21 seconds. The MDC95 has been established for persons with lower limb amputation to be 2 seconds. Thus, this study found a true change between using a non-EVS and an EVS. The FSST is often used as a tool to determine how much a person is at risk of falling and a lower number indicates a lower chance of

falling (Sawers et al., 2020). This might indicate that prosthetic users with an EVS are at lower risk of falling, though further research is needed to determine if there is such a relation.

Furthermore, the results can only be applied to the group it was tried on as balance is dependent on several factors and might worsen with age (Konrad et al., 1999). These factors will influence the way that the participants perform on the BBS and FSST and there might be more noticeable differences than if the same test was conducted on a younger population that did not have the same balance related problems. The results shown in this review may not be found in the general patient population.

This review's findings was also reported in Young & Loshak. (2020) and DeWees. (2020) where both sources state that using a EVS will improve balance in the wearer compared to using a non-EVS method. Further research is needed to strengthen these findings. Further studies should be conducted to determine the relation between balance and different suspension methods, this review could not find any balance data specifically on pin-lock suspension.

Even though both previous published literature and studies have described EVS as a suspension method that will decrease in-socket movement (pistoning) compared to pin-lock system (DeWees, 2020; Young & Loshak, 2020) This review found some evidence that indicating less pistoning in EVS compared to PVS and less pistoning in PVS compared to pin-lock suspension systems. It has to be acknowledged that none of the studies in this review directly compare EVS with pin-lock systems. Moreover only 3 of the 13 included studies in this review investigated pistoning.

The results of temporal and spatial parameters show a trend of participants walking faster with an EVS than a non-EVS. For lower limb amputees, one study has determined that the MDC95 for the 6MWT is at 34.7-34.8 meters, the number is much higher for the individual able-bodied patient, where the MDC95 is determined to be 86 meters. Burçak et al. (2021) found a difference of 52.8 meters, which is both statistically significant and above the threshold value for the MDC95 for lower limb amputees. However, Samitier et al. (2016) found a difference of 32.85 meters, which was statistically significant but did not pass the MDC95 threshold. Thus, the change cannot be trusted to be caused by the change in suspension method. There is a need for further research within this area as some change can be seen but its clinical relevance cannot be determined by the evidence base currently available.

According to recorded literature normal hip range of motion in able bodied persons will reach hip extension at around 50% of the GC (Whittle et al., 2012c). When looking at the results, only EVS reaches hip extension at this point in the GC. Thus, it can be argued that the EVS imitates a more “normal” gait than pin-lock. The same pattern can be seen in knee ROM during gait where pin-lock flexes 15 degrees more than the recorded “normal” value for able bodied and EVS flexes 10 degrees more than “normal values” during swing. Again, EVS are coming closer to a “normal” gait pattern than pin-lock (Whittle et al., 2012c). Although this pattern of coming closer to a “normal” gait pattern is observed, this review cannot determine if this difference is statistically or clinically significant.

The observed gait deviations can cause overuse injuries in persons with a transtibial amputation (Farrokhi et al., 2018; Lloyd et al., 2010). This review found that there are higher impact forces and GRF on the intact limb that can possibly accelerate the damage. This review could not determine how much higher the impact forces are on the intact limb compared to the residual limb, nor if there is a difference between suspension systems. It can be argued that imitating a normal, symmetric gait would allow for less compensatory methods and minimize overuse injuries, (Farrokhi et al., 2018; Lloyd et al., 2010) however there is a need for further studies investigating this, both long-term and short-term to find if the observed kinematic and kinetic differences have a clinically relevant effect and the relation to suspension method.

7.2 Discussion of the methodological quality

When looking at the quality assessment none of the articles had a premeditated sufficient study size nor an excellent or good internal validity and only 3 out of 13 articles were randomized controlled trials (Table 2). These limitations have also been seen to be a general problem within the prosthetic field according to Hafner & Sawers. (2016) who describes the difficulty of having sufficient study power. Many articles were uninformative, especially regarding confounding factors but also if all participants did complete all the tests and information about follow ups. Even though Hafner & Sawers. (2016) states that confounding factors are a general issue within the prosthetic field, the bias could have been minimized by stating that they were aware of the confounding factors and in best case have a solution to minimize these. The orders in which the participants conducted the tests could also have been in random orders in most of the cases. Blinding was seldom used and Hafner and Sawers. (2016) describes that it is a challenge to blind the participants as it is often obvious which intervention or control they are given. However, blinding could have been used more frequently on the researchers when analyzing the data.

The articles included in this review have in general an unclear methodology, where they do not state all the steps taken and most of the articles use different methods. Few of the articles motivate the choice of method and do not state if their method is validated. This can be seen in articles assessing pistoning as video fluoroscopy is used by one article (Eshragi et al., 2014), while the other use a photographic method (Abu Osman et al., 2017) or a Vicon motion system (Darter et al., 2016). The articles do not disclose the reasoning behind the choice of the method nor if it is validated. Eshragi et al. (2014) states in their article that they cannot compare their findings to data of previous research as the methodology is too different. The articles do not always specify the suspension method used or separate them when they are presenting their data. Furthermore, the components of the prosthesis are not always presented. This is a large and common confounding factor. The studies do not always define the terminology that they use which inites assumption from the readers. This has been presented to be a general problem in the prosthetic field in the article from Hafner & Sawers. (2016).

7.3 Limitations

This review was limited by time, as it had to be conducted in ten weeks. This resulted in a prioritization done by the authors to a clear and slim focus of the review. Some outcome measures became prioritized by the authors to be included in the review and the quality assessment tool had to be chosen so it could be done in a timely manner. This results in a risk of performing an inadequate search and an inadequate quality assessment. The quality assessment tool may be limited by the fact that it does not assess each individual outcome measure of each study. Systematic reviews generally do this as different bias and confounding factors can be found in different outcome measures within the same study (SBU., 2020). This review has done an overall assessment of the whole quality of the articles. Articles may also have been missed due to lack of knowledge of all the terminology in the prosthetic field.

7.4 Translation of evidence into clinical practice

This review aimed to give insight to some quantitative aspects in regards to suspension method but the integration of qualitative and quantitative evidence base will give a more comprehensive understanding of the vital aspects in choosing a suspension method. Although this review has identified several important qualitative aspects it is vital to consider this knowledge together with the qualitative aspects. Evidence based practice states that evidence should be considered in combination with experience and the patient's preferences (Hoffmann et al., 2017). With this review, the current evidence base has been covered, critically appraised and discussed to give clinicians and patients the best understanding of the evidence possible to make an informed decision that benefits the patient.

8. Conclusion

Several articles included in this review indicate that EVS results in better performance on balance tests, higher velocity and a more stable residual limb volume compared to other suspension methods. Furthermore, some of the articles suggest that prosthetic users with an EVS had more normal values in their ROM during gait and have less pistoning. This review also determined varied and often low methodological quality. For example, many of the studies did not use a randomized order nor blind the participants or the researchers. They did noy consider several confounding factors. This review concludes that further research is needed.

9. References

Abu Osman, N. A., Gholizadeh, H., Eshraghi, A., & Wan Abas, W. A. B. (2017). Clinical evaluation of a prosthetic suspension system: Looped silicone liner. *Prosthetics and Orthotics International, 41*(5), 476–483. https://doi.org/10.1177/0309364616670396

Ahlström, H., Bergqvist, D., Delle, M., Eckerlund, I., Gottsäter, A., I., Holst, J., Jogestrand, T., Jörneskog, G., Klevsgård, R., Marké, L. Å., Mattiasson, I., Rolandsson, O., Syversson, A., Säwe, J., Troëng, T., & Wahlberg, E. (2007). *Benartärsjukdom - diagnostik och behandling: en systematisk litteraturöversikt.* (Rapport nr. 187) Statens Beredning För Medicinsk Utvärdering (SBU) https://www.sbu.se/contentassets/90b6bf93bc274c4f96daa32eb4e27a11/benartarrapporten.pdf

Baars, E. C., Schrier, E., Dijkstra, P. U., & Geertzen, J. H. B. (2018). Prosthesis satisfaction in lower limb amputees. *Medicine, 97*(39). https://doi.org/10.1097/md.0000000000012296

Bennett, S., Hannes, K. & O´Connor. (2017). Appraising and interpreting systematic reviews. In Hoffman, T., Bennett, S., Del Mar, C (Eds.), *Evidence Based Practice Across the Health Professions* (3:rd ed., pp. 292-322). Elsevier.

Brzostowski, J. T. , Larsen, B. G. , Youngblood, R. T. , Ciol, M. A. , Hafner, B. J., Gurrey, C. J., McLean, J. B., Allyn, K. J. & Sanders, J. E. (2019). Adjustable sockets may improve residual limb fluid volume retention in transtibial prosthesis users. *Prosthetics and Orthotics International, 43*(3), 250-256. DOI: 10.1177/0309364618820140

Burçak, B., Kesikburun, B., Köseoğlu, B. F., Öken, Ö., & Doğan, A. (2021). Quality of life, body image, and mobility in lower-limb amputees using high-tech prostheses: A pragmatic trial. *Annals of Physical and Rehabilitation Medicine, 64*(1). https://doi.org/10.1016/j.rehab.2020.03.016

Childers, W.L., & Wurdeman, S.R. (2016). Transtibial amputaion: Prosthetic management. In Krajbich, J.I., Pinzur, M.S., Potter, B.K. & Stevens, P.M. (Eds.). *Atlas of amputations and limb deficiencies. Surgical, prosthetic, and rehabilitation principles* (4:th ed., pp. 493-508). American Academy of Orthopeadic Surgeons.

Darter, B. J., Sinitski, K., & Wilken, J. M. (2016). Axial bone-socket displacement for persons with a traumatic transtibial amputation: The effect of elevated vacuum suspension at progressive body-weight loads. *Prosthetics and Orthotics International, 40*(5), 552–557. https://doi.org/10.1177/0309364615605372

Del Mar, C., Hoffman, T., Glasziou, P., (2017). Information needs asking questions, and some basics of research studies. In Hoffman, T., Bennett, S., Del Mar, C (Eds.), *Evidence Based Practice Across the Health Professions* (3:rd ed., pp. 16-40). Elsevier.

DeWees, T. (2020). Transtibial Prosthetics. In Chui, K.K., Jorge, M., Lusardi M.M. & Yen, S.C. (Eds.), *Orthotics and Prosthetics in Rehabilitation* (4:th ed., pp. 605–634). https://doi.org/10.1016/b978-0-323-60913-5.00023-4

Donoghue, D., & Stokes, E. (2009). How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people. *Journal of Rehabilitation Medicine, 41*(5), 343–346. https://doi.org/10.2340/16501977-0337

Eshraghi, A., Abu Osman, N. A., Gholizadeh, H., Karimi, M., & Ali, S. (2012). Pistoning assessment in lower limb prosthetic sockets. *Prosthetics and Orthotics International, 36*(1), 15–24. https://doi.org/10.1177/0309364611431625

Eshraghi, A., Abu Osman, N. A., Karimi, M., Gholizadeh, H., Soodmand, E., & Wan Abas, W. A. B. (2014). Gait biomechanics of individuals with transtibial amputation: effect of suspension system. *PloS One, 9*(5). https://doi.org/10.1371/journal.pone.0096988

Farrokhi, S., Mazzone, B., Eskridge, S., Shannon, K., & Hill, O. T. (2018). Incidence of Overuse Musculoskeletal Injuries in Military Service Members With Traumatic Lower Limb Amputation. *Archives of Physical Medicine and Rehabilitation*, *99*(2), 348-354. https://doi.org/10.1016/j.apmr.2017.10.010

Forsberg, C., & WengströmY. (2016). *Att göra systematiska litteraturstudier: värdering, analys och presentation av omvårdnadsforskning* (4th ed.). Natur & Kultur.

Gholizadeh, H., Abu Osman, N. A., Eshraghi, A., Ali, S., Sævarsson, S. K., Abas, W. A. B. W., & Pirouzi, G. H. (2012). Transtibial prosthetic suspension: Less pistoning versus easy donning and doffing. *The Journal of Rehabilitation Research and Development, 49*(9), 1321-1330. https://doi.org/10.1682/jrrd.2011.11.0221

Gholizadeh, H., Abu Osman, N. A., Eshraghi, A., & Ali, S. (2014a). The effects of suction and pin/lock suspension systems on transtibial amputees' gait performance. *PloS One, 9*(5). https://doi.org/10.1371/journal.pone.0094520

Gholizadeh, H., Abu Osman, N. A., Eshraghi, A., Ali, S., & Razak, N. A. (2014b). Transtibial prosthesis suspension systems: Systematic review of literature. *Clinical Biomechanics, 29*(1), 87–97. https://doi.org/10.1016/j.clinbiomech.2013.10.013

Gholizadeh, H., Lemaire, E. D., & Eshraghi, A. (2016). The evidence-base for elevated vacuum in lower limb prosthetics: Literature review and professional feedback. *Clinical Biomechanics, 37*(2016), 108–116. https://doi.org/10.1016/j.clinbiomech.2016.06.005

Gholizadeh, H., Lemaire, E. D., Sinitski, E. H., Nielen, D., & Lebel, P. (2020). Transtibial amputee gait with the unity suspension system. Disability and Rehabilitation. *Assistive Technology, 15*(3), 350–356. https://doi.org/10.1080/17483107.2019.1579000

Gholizadeh, H., Lemaire, E. D., & Nantel, J. (2022).Effects of Unity Prosthetic Elevetad Vacuum Suspension System on Minimum Swing Toe Clearance. *Canadian Prosthetic & Orthotics Journal, 5(1)*. https://doi.org/10.33137/cpoj.v5i1.36847

Grimes, D. A., & Schulz, K. F. (2002). An overview of clinical research: the lay of the land. *The Lancet*, *359*(9300), 57–61. https://doi.org/10.1016/s0140-6736(02)07283-5

Hafner, B. J., & Sawers, A. B. (2016). Issues affecting the level of prosthetics research evidence. *Prosthetics & Orthotics International*, *40*(1), 31–43. https://doi.org/10.1177/0309364614550264

Hausner, E., Cooper, C., Harboe, I., Halfpenny, N., Waffenschmidt, S., Wong, R. (2021, October 29). *Value of using different search approaches*. SuRe Info: Summarized Research in Information Retrieval for Health Technology Assessment. Retrieved 2022, March 22 from: https://www.sure-info.org//value-of-using-different-search-approaches

Higgins, J.P.T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M.J., Welch, V.A. (2022). *Cochrane Handbook for Systematic Reviews of Interventions* (version 6.3). John Wiley & Sons. www.training.cochrane.org/handbook.

Hoffman, T. & Buchan, H. (2017). Clinical practice guidelines. In Hoffman, T., Bennett, S., Del Mar, C (Eds.), *Evidence Based Practice Across the Health Professions* (3:rd ed., pp. 323-336). Elsevier.

Hoffman, T., Bennett, S., Del Mar, C. (2017). Introduction to evidence-base practice. In Hoffman, T., Bennett, S., Del Mar, C (Eds.), *Evidence Based Practice Across the Health Professions* (3:rd ed., pp. 1-15). Elsevier.

Kahle, J. T., Orriola, J. J., Johnston, W., & Highsmith, M. J. (2014). The effects of vacuum-assisted suspension on residual limb physiology, wound healing and function: A systematic review. *Technology & Innovation, 15*(4), 333–341. https://doi.org/10.3727/194982413x13844488879177

Karimi, K.T., Solomonidis, S. (2011). The relationship between parameters of static and dynamic stability tests. *Journal of Research in Medical Sciences 16*(4), 530-535. https://pureportal.strath.ac.uk/en/publications/the-relationship-between-parameters-of-static-and-dynamic-stabili

Klute, G. K., Berge, J. S., Biggs, W., Pongnumkul, S., Popovic, Z., & Curless, B. (2011). Vacuum-Assisted Socket Suspension Compared With Pin Suspension for Lower Extremity Amputees: Effect on Fit, Activity, and Limb Volume. *Archives of Physical Medicine and Rehabilitation, 92*(10), 1570–1575. https://doi.org/10.1016/j.apmr.2011.05.019

Konrad, H. R., Girardi, M., & Helfert, R. (1999). Balance and Aging. *The Laryngoscope*, *109*(9), 1454–1460. https://doi.org/10.1097/00005537-199909000-00019

Levay, P., Ainsworth, N., Kettle, R., & Morgan, A. (2015). Identifying evidence for public health guidance: a comparison of citation searching with Web of Science and Google Scholar. *Research Synthesis Methods, 7*(1), 34-35. DOI:10.1002/jrsm.1158

Lloyd, C. H., Stanhope, S. J., Davis, I. S., & Royer, T. D. (2010). Strength asymmetry and osteoarthritis risk factors in unilateral trans-tibial, amputee gait. *Gait & Posture*, *32*(3), 296–300. https://doi.org/10.1016/j.gaitpost.2010.05.003

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & McGuinness, L. A. (2021). The PRISMA 2020 statement: an Updated Guideline for Reporting Systematic Reviews. *BMJ*, *372*(71). https://doi.org/10.1136/bmj.n71

Rival, C., Ceyte, H., & Olivier, I. (2005). Developmental changes of static standing balance in children. *Neuroscience Letters*, *376*(2), 133–136. https://doi.org/10.1016/j.neulet.2004.11.042

Samitier, C. B., Guirao, L., Costea, M., Camós, J. M., & Pleguezuelos, E. (2016). The benefits of using a vacuum-assisted socket system to improve balance and gait in elderly transtibial amputees. *Prosthetics and Orthotics International, 40*(1), 83–88. https://doi.org/10.1177/0309364614546927

Sawers, A., Kim, J., Balkman, G., & Hafner, B. (2020). Interrater and Test-Retest Reliability of Performance-Based Clinical Tests Administered to Established Users of Lower Limb Prostheses. *Physical Therapy*, *100*(7), 1206–1216. https://doi.org/10.1093/ptj/pzaa063

Schünemann, H., Brożek, J., Guyatt, G., Oxman, A (eds.). (2013). *GRADE handbook for grading quality of evidence and strength of recommendations*. The GRADE Working Group. Retrieved 2022, March 14 from: https://gdt.gradepro.org/app/handbook/handbook.html

Stanley, R., & Mclaren, S. (2007). Ethical issues in health and social care research. In Leathard, A., & McLaren, S (Eds.), *Ethics: Contemporary challenges in health and social care* (pp. 35–52). Policy Press. https://ebookcentral-proquest-com.proxy.library.ju.se/lib/jonhh-ebooks/detail.action?docID=419301

Statens beredning för medicinsk och social utvärdering [SBU]. (2020). *Utvärdering av metoder i hälso- och sjukvården och insatser i socialtjänsten: en metodbok*. https://www.sbu.se/metodbok.

Swedamp. (2021). *Årsrapport 2020 Ampuatations- och protesregister för nedre extrimiten ett kvalitetsregister*. https://swedeamp.com/wp-content/uploads/2021/08/SwedeAmp-Arsrapport-2020.pdf

Taghi Karimi, M., & Solomonidis, S. (2011). The relationship between parameters of static and dynamic stability tests. *Journal of Research in Medical Sciences*, *16*(4), 530–535. https://www.proquest.com/docview/867415571/fulltextPDF/2E132A449C214A73PQ/1?accountid=11754

Vetenskapsrådets Expertgrupp För Etik. (2017). *God forskningssed*. Vetenskapsrådet. https://www.vr.se/download/18.5639980c162791bbfe697882/1555334908942/Good-Research-Practice_VR_2017.pdf

Whittle, M., Levine, D., Richards, J. (2012a) Basic sciences. In Levine, D., Richards, J., Whittle, M. (eds.), *Whittle's Gait Analysis* (5:th ed., pp. 1-28). Elsevier.

Whittle, M., Levine, D., Richards, J. (2012b) Methods of gait analysis. In Levine, D., Richards, J., Whittle, M. (eds.), *Whittle's Gait Analysis* (5:th ed., pp. 83-112). Elsevier.

Whittle, M., Levine, D., Richards, J. (2012c) Normal gait. In Levine, D., Richards, J., Whittle, M. (eds.), *Whittle's Gait Analysis* (5:th ed., pp. 29-63). Elsevier.

Xu, Greenland, K., Bloswick, D., Zhao, J., & Merryweather, A. (2017b). Vacuum level effects on knee contact force for unilateral transtibial amputees with elevated vacuum suspension. *Journal of Biomechanics., 57*, 110–116. https://doi.org/10.1016/j.jbiomech.2017.04.013

Xu, H., Greenland, K., Bloswick, D., Zhao, J., & Merryweather, A. (2017a). Vacuum level effects on gait characteristics for unilateral transtibial amputees with elevated vacuum suspension. *Clinical Biomechanics (Bristol, Avon), 43*, 95–101. https://doi.org/10.1016/j.clinbiomech.2017.02.008

Young, C., & Loshak, H. (2020). *Elevated Vacuum Suspension Systems for Adults with Amputation: A Review of Clinical Effectiveness, Cost-Effectiveness, and Guidelines* (CADTH rapid response report: summary with critical appraisal). Canadian Agency for Drugs and Technologies in Health. https://www.ncbi.nlm.nih.gov/books/NBK558325/

Youngblood, R. T., Brzostowski, J. T., Hafner, B. J., Czerniecki, J. M., Allyn, K. J., Foster, R. L., & Sanders, J. E. (2020). Effectiveness of elevated vacuum and suction prosthetic suspension systems in managing daily residual limb fluid volume change in people with transtibial amputation. *Prosthetics and Orthotics International*, *44*(3), 155–163. https://doi.org/10.1177/0309364620909044

Youngblood, R. T., Hafner, B. J., Allyn, K. J., Cagle, J. C., Hinrichs, P., Redd, C., Vamos, A. C., Ciol, M. A., Bean, N., & Sanders, J. E. (2019). *Prosthetics and Orthotics International, 43*(1), 28–38. https://doi.org/10.1177/0309364618785729

Ziegler-Graham, K., MacKenzie, E. J., Ephraim, P. L., Travison, T. G., & Brookmeyer, R. (2008). Estimating the Prevalence of Limb Loss in the United States: 2005 to 2050. *Archives of Physical Medicine and Rehabilitation*, *89*(3), 422–429. https://doi.org/10.1016/j.apmr.2007.11.005

Appendix 1: Search strategy

A first search was made with index words in Medline (called MeSh terms). This search made the result to include a lot of irrelevant articles and a decision was made to only use free-text words for the final search (Figure 3-5).

Figure 3

The search in Medline

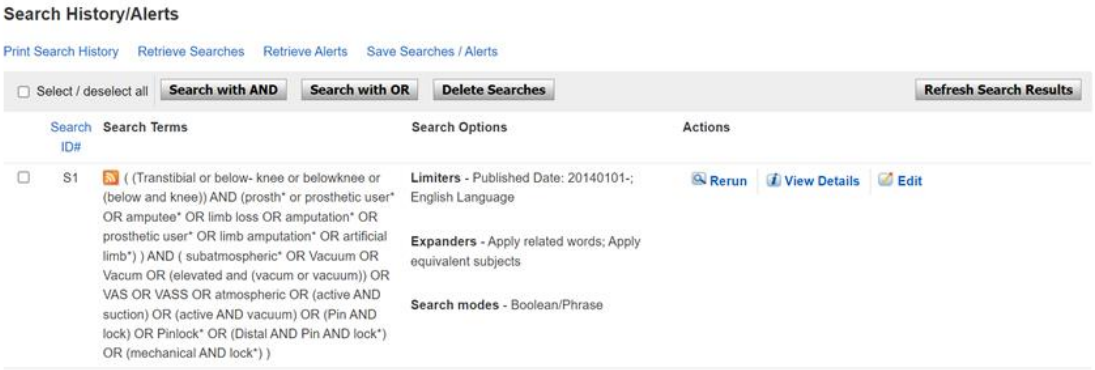


Figure 4

The search in CINAHL

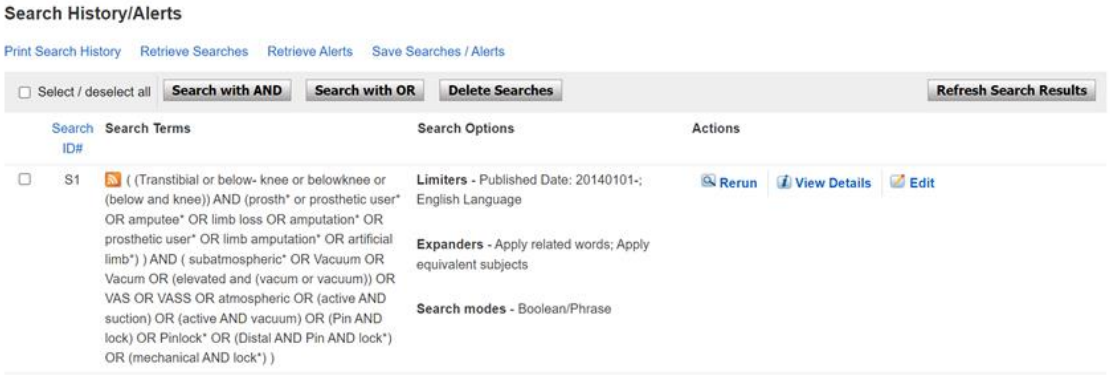
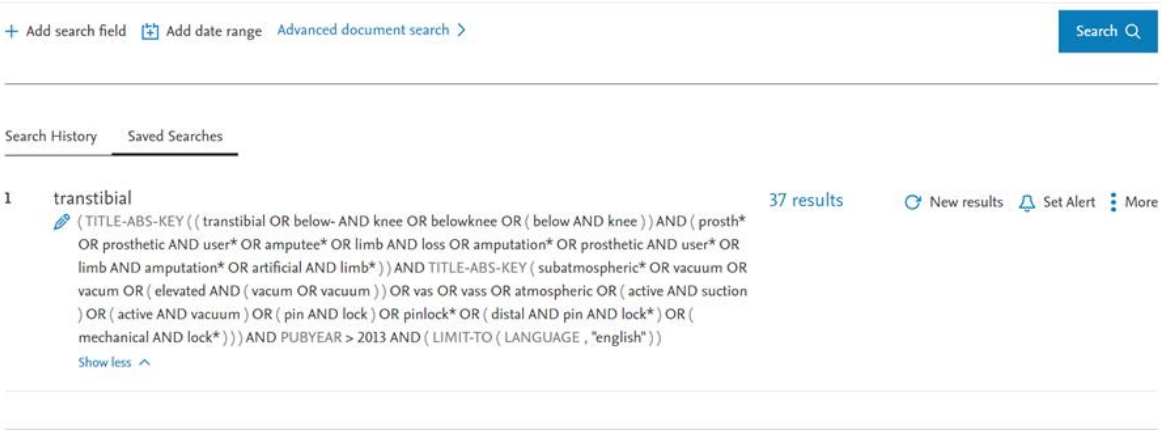


Figure 5

The search in SCOPUS



Appendix 2: SBU Bilaga 2: Granskningsmallar och checklistor för bedömning av studier

The following templates are sourced from Ahlström et al. (2007).
Section A= Template A
Section B=Template B
Section C=Template C

Section A (randomized clinical trial)

External validity

Short form answer:

- ❑ Clear external validity (0)
- ❑ Probable external validity (1)
- ❑ Uncertain external validity (3)
- ❑ External validity cannot be assessed (5)

If uncertain, answer questions under Item 1.
Otherwise go to Internal validity (after Item 1)

1. Accrual of study subjects

a. Eligibility/inclusion criteria clearly stated (eg, if trial of treatment of a specified disease, is the definition acceptable)?
   - ❑ Yes = 0
   - ❑ No = 2

b. Consecutive eligible subjects?
   - ❑ Yes = 0
   - ❑ No = 1
   - ❑ Not stated = 1

c. Numbers and reasons for non-participation given?
   - ❑ Yes = 0
   - ❑ No = 2

d. Exclusion criteria clearly stated and acceptable?
   - ❑ Yes = 0
   - ❑ No = 2

e. Are numbers of excluded persons given by reason (as prescribed in the CONSORT statement)?
   - ❑ Yes = 0
   - ❑ No = 2

Total sum of section 1
0 = Clear external validity
1 = Probable external validity
2–3 = Uncertain external validity
≥4 = External validity cannot be assessed

Internal validity

Short form answer:

- ❑ Excellent internal validity (0)
- ❑ Good internal validity (1)
- ❑ Acceptable internal validity (2)
- ❑ Uncertain internal validity (4)
- ❑ Uninformative due to flawed internal validity (10)

If uncertain, answer questions under Items 2–9.
Otherwise go to Precision (after Item 9)

2. Treatment/exposure assignment

a. Were details about randomization procedure given?
   - ❑ Yes = 0
   - ❑ No = 1

b. Could the randomization be manipulated?
   - ❑ Yes (eg, tossing of coin or throwing of dice) = 1
   - ❑ No (eg, opaque envelopes, computer-generated list kept by others than investigators) = 0

c. Did randomization lead to unpredictable treatment assignment?
   - ❑ Yes = 0
   - ❑ No, treatment could potentially be deduced in some or all = 2

d. Were there exclusions/withdrawals after randomization?
   - ❑ Yes = 2
   - ❑ No = 0

3. Comparability of groups

a. Was there an account of the comparability of groups with regard to all conceivable factors that might affect the outcome?
   - ❑ Yes = 0
   - ❑ No = 1

b. Were there any important differences?
   - ❑ Yes = 2
   - ❑ No = 0
   - ❑ No data given = 0 (already scored under 3a)

c. Were any attempts in the analysis phase to adjust for imbalances between treatment arms with regard to important determinants for the outcome (eg, through multi-variate modelling)?
- ❑ Not needed (no important imbalances) = 0
- ❑ Yes = –1 (subtract 1 if you scored 2 under 3b)
- ❑ No, despite a need = 1

4. Blinding

a. Were there any attempts to blind the patients/investigators to treatment allocation?
- ❑ No (open study) = 2
- ❑ Only study subjects were blinded (single-blind) = 1
- ❑ Blinding only of investigators who evaluated the outcome ("blind observer") =0
- ❑ Double-blind = 0
- ❑ Triple-blind (breaking of the code first after completion of all analyses) = 0

b. Was there any reason to believe that the blinding had failed (eg, due to characteristic side-effects of active treatment or dissimilarities of active and reference tablets)?
- ❑ Yes = 1
- ❑ No = 0

c. Was the blinding tested (eg, through asking the subjects at the end of the study what they believed they had received)?
- ❑ Yes = 0
- ❑ No = 0

5. Compliance

a. Was there any account of the completeness of treatment/compliance?
- ❑ Yes = 0
- ❑ No = 2

b. Was the completeness acceptable (>80% of the subjects receiving >80% of the prescribed treatment)?
- ❑ Yes = 0
- ❑ No = 3
- ❑ Completeness/compliance data not given = 0 (scored under 5a)

6. Drop-outs/losses to follow-up

a. Was there an account of the numbers of subjects who dropped out (and the reasons for dropping out)?
- ❑ Yes = 0
- ❑ No = 3

b. What was the drop-out rate?
- ❑ <10% = 0
- ❑ 10–19% = 2
- ❑ 20–29% = 3
- ❑ ≥30% → study is deemed uninformative, excluded
- ❑ Drop-out rate not stated = 0 (scored under 6a)

7. Evaluation of outcome

a. Was there an acceptable definition of the outcome?
- ❑ Yes = 0
- ❑ No = 3

b. Was the outcome clinically relevant?
- ❑ Yes = 0
- ❑ Of questionable relevance = 2
- ❑ Irrelevant → study is deemed uninformative, excluded

c. Was the reporter of the outcome (eg, the investigator, the study subject) unaware of the treatment given?
- ❑ Yes = 0
- ❑ No = 2

d. Are there reasons to believe that there might have been misclassification of the outcome (eg, due to retrospective reporting over too long periods)?
- ❑ Yes = 1
- ❑ No = 0

8. Evaluation of side-effects

a. Was there acceptable reporting of side effects?
- ❑ Yes, with open-ended questions = 0
- ❑ Yes, with fixed response alternatives = 0
- ❑ Yes, response alternatives not stated = 0
- ❑ No = 3

9. Analysis

a. Was the main outcome variable defined in advance and was the conclusion of the study based on the analysis of this variable?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 2

b. Was there a prior hypothesis?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 1

c. Were the secondary variables defined in advance?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 1
- ❑ Not applicable, there was no secondary outcome variable = 0

d. Were all randomized subjects included in the analysis and retained in the treatment arm to which they were initially allocated ("intention-to-treat analysis")?
- ❑ Yes = 0
- ❑ No = 4

Total sum of Items 2–9 (internal validity)
0–1 = Excellent internal validity
2–4 = Good internal validity
5–7 = Acceptable internal validity
8–10 = Uncertain internal validity
≥10 = Uninformative due to flawed internal validity

Precision

Short form answer:

- ❑ Premeditated and sufficient study size (0)
- ❑ Sample size of uncertain adequacy (2)
- ❑ Probably underpowered study (4)

If uncertain, answer questions under Items 10–11

10. Smallest clinically relevant effect

a. Was the smallest clinically relevant effect defined?
- ❑ Yes = 0
- ❑ No = 1

b. Was the stated smallest clinically relevant effect reasonable?
- ❑ Yes = 0
- ❑ No = 1
- ❑ Not defined = 0 (scored under 10a)

11. Study power

a. Were the deliberations behind the sample size decision clearly described?
- ❑ Yes = 0
- ❑ No = 2

b. What was the power to detect a reasonably-sized smallest clinically relevant effect?
- ❑ Not stated because there was a strong and statistically significant effect = 0
- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ <70% = 3
- ❑ Not stated despite a non-significant finding = 4

Total sum of Items 10–11 (precision)
0–1 = Premeditated and sufficient study size
2–3 = Sample size of uncertain adequacy
≥4 = Probably underpowered study

Section B (observational cohort study or controlled clinical trial without randomisation)

External validity

Short form answer:

- ❑ Clear external validity (0)
- ❑ Probable external validity (1)
- ❑ Uncertain external validity (3)
- ❑ External validity cannot be assessed (5)

If uncertain, answer questions under Item 1. Otherwise go to Internal validity (after Item 1)

1. Accrual/selection of study subjects

a. Was the studied exposure well defined (eg, if follow-up of a specified disease, is the definition of the disease acceptable)?
- ❑ Yes = 0
- ❑ No = 2

b. Eligibility/inclusion criteria clearly stated?
- ❑ Yes = 0
- ❑ No = 1

c. Consecutive eligible subjects included?
- ❑ Yes = 0
- ❑ No = 1
- ❑ Not stated = 1

d. Numbers and reasons for non-participation given?
- ❑ Yes = 0
- ❑ No = 1

e. Exclusion criteria clearly stated and acceptable?
- ❑ Yes = 0
- ❑ No = 1

f. Are numbers of excluded persons given by reason (as prescribed in the CONSORT statement)?
- ❑ Yes = 0
- ❑ No = 1

Total sum of section 1
0 = Clear external validity
1 = Probable external validity
2–3 = Uncertain external validity
≥4 = External validity cannot be assessed

Internal validity

Short form answer:

- ❑ Excellent internal validity (0)
- ❑ Good internal validity (1)
- ❑ Acceptable internal validity (2)
- ❑ Uncertain internal validity (4)
- ❑ Uninformative due to flawed internal validity (10)

If uncertain, answer questions under Items 2–6. Otherwise go to Precision (after Item 6)

2. Exposure assessment

a. Was the studied exposure satisfactorily measured/recorded?
- ❑ Yes = 0
- ❑ Yes, with minor criticism = 1
- ❑ No = 3

b. Were all in the exposed group really exposed?
- ❑ Yes = 0
- ❑ Yes, probably = 1
- ❑ No, probably not = 2
- ❑ No = 2

c. Were all in the reference category really unexposed?
- ❑ Yes = 0
- ❑ Yes, probably = 1
- ❑ No, probably not = 2
- ❑ No = 2

3. Comparability of groups/selection bias/confounding

a. Was there an account of the comparability of groups with regard to factors that might conceivably affect the outcome (potential confounding factors)? (If only one cohort was studied and compared with the background population or historical controls – was there data to support the comparability with the reference category).
- ❑ Yes = 0
- ❑ No = 3

b. Did the investigators consider all important potential confounding factors (potential confounding factors = factors that are independent causes of/risk factors for/protective factors against the outcome, AND not a link in the causal chain between the studied exposure and the outcome)?
- ❑ Yes = 0
- ❑ Probably = 1
- ❑ No = 3
- ❑ No data given = 0 (already scored under 3a)

c. Were the relevant confounding factors satisfactorily measured/recorded?
- ❑ Yes = 0
- ❑ Yes, with minor criticism = 1
- ❑ No = 3

d. Were the potential confounding factors unevenly distributed among exposed and /non-exposed/ reference group (confounding arises if factors described under 3b are unevenly distributed among exposed and unexposed [ie, linked to the exposure])?
- ❑ Yes = 2
- ❑ No = 0
- ❑ No data given = 0 (already scored under 3a)

e. Were attempts in the analysis to adjust for imbalances between exposure groups with regard to potential confounding factors (eg, through restriction, stratified analyses, or multivariate modelling)?
- ❑ Not needed (no important imbalances) = 0
- ❑ Yes = –2 (subtract 2 if you scored 2 under 3d)
- ❑ No, despite a need = 2

4. Evaluation of outcome, ascertainment/detection bias

a. Was there an acceptable definition of the outcome?
- ❑ Yes = 0
- ❑ No = 3

b. Was the outcome clinically relevant?
- ❑ Yes = 0
- ❑ Of questionable relevance = 2
- ❑ Irrelevant → study is deemed uninformative, excluded

c. Were the evaluators of the outcome aware of exposure status of the cohort members?
- ❑ Yes = 1
- ❑ Probably = 1
- ❑ No = 0

d. Was there any reason to believe that there was important ascertainment/ detection bias (eg, exposure linked to smoking, and smoking, in turn, linked to higher frequency of health care visits, and thus a more intense surveillance)
- ❑ Yes = 2
- ❑ No = 0

5. Losses to follow-up

a. Was there an account of the numbers of subjects who were lost to follow-up?
- ❑ Yes = 0
- ❑ No = 3

b. What proportion was lost to follow-up?
- ❑ <10% = 0
- ❑ 10–19% = 1
- ❑ 20–29% = 2
- ❑ 30–39 = 3
- ❑ ≥40% → study is deemed uninformative, excluded
- ❑ Proportion not stated = 0 (scored under 5a)

6. Analysis

a. Was the main outcome variable defined in advance and was the conclusion of the study based on the analysis of this variable?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 1

b. Was there a prior hypothesis?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 1

c. Was the statistical method adequate?
- ❑ Yes = 0
- ❑ No = 3

Total sum of Items 2–6 (internal validity)
0–1 = Excellent internal validity
2–3 = Good internal validity
4–6 = Acceptable internal validity
7–9 = Uncertain internal validity
≥10 = Uninformative due to flawed internal validity

Precision

Short form answer:

- ❑ Premeditated and sufficient study size (0)
- ❑ Sample size of uncertain adequacy (2)
- ❑ Probably underpowered study (4)

If uncertain, answer questions under Items 7–8

Total sum of Items 7–8 (precision)
0–1 = Premeditated and sufficient study size
2–3 = Sample size of uncertain adequacy
≥4 = Probably underpowered study

7. Smallest clinically relevant effect

a. Was the smallest clinically relevant effect defined?
- ❑ Yes = 0
- ❑ No = 1

b. Was the stated smallest clinically relevant effect reasonable?
- ❑ Yes = 0
- ❑ No = 1
- ❑ Not defined = 0 (scored under 10a)

8. Study power

a. Were the deliberations behind the sample size decision clearly described?
- ❑ Yes = 0
- ❑ No = 2

b. What was the power to detect a reasonably-sized smallest clinically relevant effect?
- ❑ Not stated because there was a strong and statistically significant effect = 0
- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ <70% = 3
- ❑ Not stated despite a non-significant finding = 4

Section C (case-control or cross-sectional studies)

External validity

Short form answer:

- ❑ Clear external validity (0)
- ❑ Probable external validity (1)
- ❑ Uncertain external validity (3)
- ❑ External validity cannot be assessed (5)

If uncertain, answer questions under Item 1.
Otherwise go to Internal validity (after Item 1)

1. Type of cases studied

a. Was there an acceptable definition of the outcome (that rendered subjects case/control status)?
- ❑ Yes = 0
- ❑ No = 2

b. Did the studied cases correspond to cases in the population to which the investigators wished to generalise their findings?
- ❑ Yes = 0
- ❑ Yes, probably = 1
- ❑ No, probably not = 2
- ❑ No, definitely not = 3

Total sum of section 1
0 = Clear external validity
1 = Probable external validity
2–3 = Uncertain external validity
≥4 = External validity cannot be assessed

Internal validity

Short form answer:

- ❑ Excellent internal validity (0)
- ❑ Good internal validity (1)
- ❑ Acceptable internal validity (2)
- ❑ Uncertain internal validity (4)
- ❑ Uninformative due to flawed internal validity (10)

If uncertain, answer questions under Items 2–6.
Otherwise go to Precision (after Item 6)

2. Study base (NOTE, not relevant to cross-sectional studies; if so, skip 2–3)

The study base is defined as the group of people (the "virtual cohort") who – if they developed the outcome condition – would necessarily have become cases in the study.

a. Was the study base (the "virtual cohort" [a defined source population followed for a defined time period] *that generated the cases)* well defined (geographically, age-wise, gender, other characteristics)?
- ❑ Yes, quite clear (eg, an already established cohort, or definition through an existing, well-functioning population register) = 0
- ❑ Yes, reasonably (eg, hospital-based study with strict catchment areas and no important selections of cases or controls) = 1
- ❑ Yes, probably (eg, hospital-based study without clear catchment areas, and/or inability to rule out some less important selection among cases and/or controls; control selection via random digit dialing or through neighbourhood controls whereupon some minor mismatch [for instance socioeconomic] between cases and controls might have occurred) = 2
- ❑ No, it is impossible to tell if the cases and controls come from the same study base and if there are important selection mechanisms for either of these categories = 4

b. Are the cases representative of all cases in the study base?
- ❑ Yes, they represent all or virtually all new (incident) cases of the outcome that occurred in the study base = 0
- ❑ Yes, although it is difficult to tell if they represent all cases, there is no reason to suspect that they are unrepresentative of all cases in the study base = 1
- ❑ Yes, they represent prevalent cases in the study base, but there is no reason to suspect that they are unrepresentative = 1
- ❑ No, there are reasons to suspect that they are unrepresentative of all cases in the study base = 3
- ❑ No, definitely unrepresentative → study is deemed uninformative, excluded

c. Do the control subjects come from the very same study base as the cases?
- ❑ Yes, definitely = 0
- ❑ Yes, probably = 1
- ❑ Uncertain = 3
- ❑ Probably not = 4
- ❑ No, definitely not → study is deemed uninformative, excluded

d. Were the control subjects representative of the entire study base?
- ❑ Yes, they were selected randomly from a defined sampling frame (note that stratified random sampling in order to achieve frequency matching is acceptable) = 0
- ❑ Yes, probably, but they were selected in some other way = 1
- ❑ Uncertain = 3
- ❑ Probably not = 4
- ❑ No, the probability of being selected as control is linked to the subjects' exposure status → study is deemed uninformative, excluded

3. Non-participation

a. Were all eligible cases occurring in the study base identified and enumerated?
- ❑ Yes = 0
- ❑ Yes, probably = 1
- ❑ No = 3

b. What was the participation rate among all eligible cases?
- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ 60–69% = 3
- ❑ 50–59% = 4
- ❑ <50% → study is deemed uninformative, excluded
- ❑ Proportion not stated → study is deemed uninformative, excluded

c. Was anything done to insure that major selection bias was not introduced through non-participation among cases?
- ❑ Not needed because participation among cases was >80% = 0
- ❑ Participation ≤80%, but authors provide data about non-participants that seem to rule out important selection bias = –1 (subtract from sum)
- ❑ Participation ≤80%, and no data is given about non-participants = 0

d. What was the participation rate among all selected controls?
- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ 60–69% = 3
- ❑ 50–59% = 4
- ❑ <50% → study is deemed uninformative, excluded
- ❑ Proportion not stated → study is deemed uninformative, excluded

e. Was anything done to insure that major selection bias was not introduced through non-participation among controls?
- ❑ Not needed because participation among controls was >80% = 0
- ❑ Participation ≤80%, but authors provide data about non-participants that seem to rule out important selection bias = –1 (subtract from sum)
- ❑ Participation ≤80%, and no data is given about non-participants = 0

4. Participation in cross-sectional study (skip if regular case-control study)

- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ 60–69% = 3
- ❑ 50–59% = 4
- ❑ <50% → study is deemed uninformative, excluded
- ❑ Proportion not stated → study is deemed uninformative, excluded

5. Exposure assessment

a. How was exposure information collected?
- ❑ From existing databases with data obtained before cases developed outcome = 0
- ❑ Face-to-face or telephone interviews with interviewers blinded to case/control status = 0
- ❑ Face-to-face or telephone interviews where interviewers were aware of case/control status = 1
- ❑ Postal questionnaire = 2
- ❑ Other ways or not stated = 3

b. Use of substitute responders?
- ❑ No = 0
- ❑ ≤20% = 1
- ❑ >20% = 3

c. Are there good reasons to suspect biased recall (ie, cases remember/report exposures systematically different compared to controls)?
- ❑ No = 0
- ❑ No, probably not = 1
- ❑ Uncertain = 2
- ❑ Yes, recall bias likely = 4
- ❑ Yes, high probability of recall bias → study is deemed uninformative, excluded

6. Confounding

a. Did the investigators consider all important potential confounding factors (potential confounding factors = factors that are independent causes of/risk factors for/protective factors against the outcome, AND not a link in the causal chain between the studied exposure and the outcome)?
- ❑ Yes = 0
- ❑ Probably = 1
- ❑ No = 3
- ❑ No data given = 4

b. Were the relevant confounding factors satisfactorily measured/recorded?
- ❑ Yes = 0
- ❑ Yes, with minor criticism = 1
- ❑ No = 3

c. Were attempts in the study design or analysis to identify and handle confounding factors (eg, through matching, restriction, stratified analyses, or multivariate modelling)?
- ❑ Yes, adequately = 0
- ❑ Yes, but not sufficiently = 2
- ❑ No → study is deemed uninformative, excluded

7. Ascertainment/detection bias

a. Was there any reason to believe that there was important ascertainment/detection bias (eg, exposure linked to smoking, and smoking, in turn, linked to higher frequency of health care visits, and thus a more intense surveillance)?
- ❑ Yes = 2
- ❑ No = 0

8. Rare disease assumption

a. Was the rare disease assumption fulfilled (the outcome affected less than 10% of the population in the study base)?
- ❑ Yes = 0
- ❑ Unknown = 1
- ❑ No or probably not = 3 (effects are likely exaggerated!)

9. Analysis

a. Was there a prior hypothesis?
- ❑ Yes = 0
- ❑ No (or not mentioned in the report) = 1

b. Was the statistical method adequate?
- ❑ Yes = 0
- ❑ No = 3

Total sum of Items 2–9 (internal validity) – CASE-CONTROL STUDY
0–2 = Excellent internal validity
3–4 = Good internal validity
5–7 = Acceptable internal validity
8–10 = Uncertain internal validity
≥11 = Uninformative due to flawed internal validity

Total sum of Items 2–9 (internal validity) – CROSS-SECTIONAL STUDY
0–1 = Excellent internal validity
2–3 = Good internal validity
4–5 = Acceptable internal validity
6–8 = Uncertain internal validity
≥9 = Uninformative due to flawed internal validity

Precision

Short form answer:
- ❑ Premediated and sufficient study size (0)
- ❑ Sample size of uncertain adequacy (2)
- ❑ Probably underpowered study (4)

If uncertain, answer questions under Items 10–11

10. Smallest clinically relevant effect

a. Was the smallest clinically relevant effect defined?
- ❑ Yes = 0
- ❑ No = 1

b. Was the stated smallest clinically relevant effect reasonable?
- ❑ Yes = 0
- ❑ No = 1
- ❑ Not defined = 0 (scored under 10a)

11. Study power

a. Were the deliberations behind the sample size decision clearly described?
- ❑ Yes = 0
- ❑ No = 2

b. What was the power to detect a reasonably-sized smallest clinically relevant effect?
- ❑ Not stated because there was a strong and statistically significant effect = 0
- ❑ ≥90% = 0
- ❑ 80–89% = 1
- ❑ 70–79% = 2
- ❑ <70% = 3
- ❑ Not stated despite a non-significant finding = 4

Total sum of Items 10–11 (precision)
0–1 = Premeditated and sufficient study size
2–3 = Sample size of uncertain adequacy
≥4 = Probably underpowered study

Appendix 3: Form for Self-Assessment of Ethical Issues in Degree Projects1 at the School of Health and Welfare

JÖNKÖPING UNIVERSITY
School of Health and Welfare

Form for Self-Assessment of Ethical Issues in Degree Projects[1] at the School of Health and Welfare

Date:	2022-03-15
Title of the degree project	Comparison between active vacuum suspension systems and pin-lock suspension systems in prosthetic users with a unilateral transtibial amputation: A literature review with a systematic approach
Student(s)[2]:	Louise Dömstedt and Malin Stafås
Student's/Students' e-mail address:	Dolo19rn@student.ju.se and stma19jq@student.ju.se
Degree programme:	Prosthetic and orthotics
Education cycle:	Semester 6
Supervisor:	Saffran Möller
Supervisor's e-mail address:	Saffran.moller@ju.se

Degree projects at the School of Health and Welfare, Jönköping University, must comply with the ethical principles expressed in the Act concerning the Ethical Review of Research Involving Humans (Etikprövningslagen, "EtRAct"). This form is a tool for reviewing ethical issues related to the degree project.

The student and the supervisor carefully go through the form together, identify potential ethical problems, and agree on how these should be addressed. If there is still doubt, the course examiners needs to be consulted.

Research that falls within the EtRAct must be reviewed by the Swedish Ethical Review Authority[3].

The distinction and boundary between research and degree projects are described in Part A.

Part B deals with what falls under the EtRAct and ethical principles that are important to consider **before** conducting a study/degree project.

The Self-Assessment of Ethical Issues in Degree Projects should always be approved by the course examiner before the degree project is started.

[1] The form also applies to quality improvement projects in health care and social welfare.
[2] Alternatively, the implementer of quality improvement projects in health care and social welfare.
[3] https://etikprovning.se/

Part A: Is this a research study?

The purpose of the questions in Part A is to determine if the study is to be regarded as research. A degree project is not usually considered as research and thus cannot be reviewed by the Swedish Ethical Review Authority. Under certain circumstances, however, a degree project may be research, namely if:

1. the intention is to publish it in a scientific journal **NO**
2. it addresses a scientific question and has a design that can answer that question **YES**
3. it is led by researchers within the discipline, either as part of a larger project or with a researcher as the supervisor. **YES**

Is the study research in these three respects?

☐ YES (The study needs to be reviewed by the Swedish Ethical Review Authority.)

☒ **NO (Proceed to Parts B and C.)**

Part B: Does the degree project contain what is regarded as ethically sensitive according to the Ethical Review of Research Involving Humans?

The questions in Part B aim to examine;

1. if the degree project has such ethical problems that if it were research - it would require to be reviewd by the Ethics Review Authority. In these cases, the degree project must not be completed.
2. how ethical principles are handled in the degree project.

If any of the questions are answered with "not sure" or "yes" (questions 1-13) and with "not sure" or "no" (questions 14-23), an in-depth ethical reflection involving students and supervisors should be carried out on how these ethical risks and problems must be managed or how the study can be modified to counteract identified risks. In these cases, the course examiner should also be involved in the self-assessment and the ethical reflection to make a final decision on the implementation of the degree project. **The ethical self-assessment must always be approved by the examiner before the degree project begins.**

		Yes	Not sure	No
1	Does the study intend to process what the General Data Protection Regulation (GDPR) considers to be sensitive personal data, i.e., data that at any stage can be linked to a person and that reveals racial or ethnic origin, political opinions, religious or philosophical beliefs, trade union membership, or information about an individual's health or sex life?	☐	☐	☒

		Yes	Not sure	No
2	Does the study intend to collect and process personal data relating to violations of the law that involve criminal offences, convictions in criminal proceedings, penal law sanctions, or administrative deprivation of liberty?	☐	☐	☒
3	Does the study intend to include people who can be identified as vulnerable groups and / or people who are dependent on the person who recruits or carries out the data collection	☐	☐	☒
4	Does the study intend to include children (persons under the age of 18)	☐	☐	☒
5	Does the study involve a physical intervention on the participants, eg some type of physical examination or sampling (also something that is part of normal routines, but is also part of the study)	☐	☐	☒
6	Is the purpose of the study to affect the participants physically or psychologically eg, ?	☐	☐	☒
7	Are there an apparent risk to harm the participants physically or psychilogically?	☐	☐	☒
8	Will the study use biological material that can be traced to an identifiable individual or deceased person (e.g., blood samples or tissue specimens)?	☐	☐	☒
9	Can voluntariness be questioned (e g., vulnerable groups, such as children, people with cognitive impairment or mental disabilities, or individuals in a dependent relationship to the principal investigator, such as a patient or student)?	☐	☐	☒
10	Will the study involve individuals with limited autonomy (for instance individuals with cognitive difficulties, minors), whose understanding of the meaning of the consent is limited?	☐	☐	☒
	Selection of participants and social vulnerability			
11	Do the participants belong to a particularly vulnerable or disadvantaged group in society (a minority group)?	☐	☐	☒
12	Will the study involve the establishment of a personal register where data can be linked to a physical person?	☐	☐	☒
	Informed consent			
13	Does the information letter contain persuasive formulations (implying that the person must or should participate, without showing full respect for the choice, for example mildly persuasive formulations, such as "thanks in advance")?	☐	☐	☒
14	Is the study described in such a manner so that the participants understand its purpose and structure, and what participation in the project entails (e.g., number of visits, duration of the project, and written in easy-to-understand Swedish without technical terms or professional jargon)?	☐	☐	☒
15	Is it clearly stated in the written information to the participant that the participation in the study is entirely voluntary?	☐	☐	☒
16	Will informed consent be obtained as a part of the study (in other words, will the participants receive full information about the study and/or the opportunity to opt out from participation?	☐	☐	☒
17	Is it clearly stated that the participants may choose not to participate, without prejudice to the participants' being offered care or treatment or, if relating to students, it affecting their grades?	☐	☐	☒

		Yes	Not sure	No
18	Is it clearly stated that the participants may discontinue the participation at any time and without the need to state any reason, without prejudice to the participants' being offered care or treatment or, if relating to students, it affecting their grades?	☐	☐	☒
	Confidentiality and the security of the participants			
19	Are there procedures in place to ensure confidentiality in the collection of data?	☐	☐	☒
20	Are the results/findings described in such a manner so that the participants' identity remains confidential, meaning that they cannot be identified afterwards (including a minimal potential for reverse identification)?	☐	☐	☒
21	Are there procedures to ensure confidentiality?	☐	☐	☒
22	Are there clear routines for ensuring that the collected data material is handled according to GDPR?	☐	☐	☒
	Degree project results and/or findings			
23	Are there reasons to offer participants the opportunity to obtain a copy of or otherwise gain access to the degree project results/findings?	☐	☐	☒

Comments

This study is a literature review, and no participants will be a part of the study directly as only existing research will be used. This study will base its research on other published studies, thus none of the questions above are applicable to this thesis as it uses no participants and contains no ethical issues connected to having participants.

However, this study recognizes the importance of ethical approval and considerations so all studies included in the review must be ethically reviewed and approved by an ethical committee or other frameworks where the ethical considerations have been carefully considered. Multiple frameworks are available for this worldwide, the one used should be valid and of good quality.

The questions under section B, have been responded truthfully and discussed with supervisor.

JÖNKÖPING UNIVERSITY
School of Health and Welfare

Place and date: Jönköping 2022-03-15

Signature Student

Signature Student

Signature Supervisor

Signature Examiner