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Through-knee versus above-knee amputation for vascular and non-vascular major lower limb amputations (Review)

Crane H, Boam G, Carradice D, Vanicek N, Twiddy M, Smith GE

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[Intervention Review]

Through-knee versus above-knee amputation for vascular and non-vascular major lower limb amputations

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ABSTRACT

Background

Diabetes and vascular disease are the leading causes of lower limb amputation. Currently, 463 million adults are living with diabetes, and 202 million with peripheral vascular disease, worldwide. When a lower limb amputation is considered, preservation of the knee in a below-knee amputation allows for superior functional recovery when compared with amputation at a higher level. When a below-knee amputation is not feasible, the most common alternative performed is an above-knee amputation. Another possible option, which is less commonly performed, is a through-knee amputation which may offer some potential functional benefits over an above-knee amputation.

Objectives

To assess the effects of through-knee amputation compared to above-knee amputation on clinical and rehabilitation outcomes and complication rates for all patients undergoing vascular and non-vascular major lower limb amputation.

Search methods

The Cochrane Vascular Information Specialist searched the Cochrane Vascular Specialised Register, CENTRAL, MEDLINE, Embase, and CINAHL databases; the World Health Organization International Clinical Trials Registry Platform; and the ClinicalTrials.gov trials register to 17 February 2021.

We undertook reference checking, citation searching, and contact with study authors to identify additional studies.

Selection criteria

Published and unpublished randomised controlled trials (RCTs) comparing through-knee amputation and above-knee amputation were eligible for inclusion in this study. Primary outcomes were uncomplicated primary wound healing and prosthetic limb fitting. Secondary outcomes included time taken to achieve independent mobility with a prosthesis, health-related quality of life, walking speed, pain, and 30-day survival.

Data collection and analysis

Two review authors independently reviewed all records identified by the search. Data collection and extraction were planned in line with recommendations outlined in the *Cochrane Handbook for Systematic Reviews of Interventions*. We planned to assess the certainty of evidence using the GRADE approach.

Main results

We did not identify RCTs that met the inclusion criteria for this review.

Authors' conclusions

No RCTs have been conducted to determine comparative clinical or rehabilitation outcomes of through-knee amputation and above-knee amputation, or complication rates. It is unknown whether either of these approaches offers improved outcomes for patients. RCTs are needed to guide practice and to ensure the best outcomes for this patient group.

PLAIN LANGUAGE SUMMARY

Does surgical removal of the lower leg (amputation) through the knee offer patients improved surgical recovery and better rehabilitation than amputation above the knee?

Background

Each year, thousands of people worldwide need to have their lower leg surgically removed (lower limb amputation) due to problems such as blockages in blood vessels (vascular disease), diabetes, and injury. When an amputation is planned, a surgeon needs to decide how high up the leg to go, and therefore how much leg to leave behind. This decision is based on a balance between leaving as much of the leg as possible to improve a person's ability to walk with an artificial leg (prosthesis) and removing anything that will not survive or go on to heal. If possible, a surgeon will prefer to preserve the knee, as having a working knee of one's own ensures a person's best chance of walking. In some cases, this is not possible, and currently almost all people in this situation will have an amputation in the middle of the thigh (above the knee). However, another option is an amputation that can be performed through the knee joint itself. This carries potential advantages, as all of the muscles controlling movements of the thighbone are undamaged. A longer remaining leg would be expected to act as a lever to reduce the effort of swinging a prosthetic limb during walking and to aid sitting balance and transfer from bed to chair. By avoiding cutting the muscles, it is possible to minimise the physical trauma of surgery, allowing a procedure with reduced blood loss and less procedure time. In addition, the end of the thighbone and in some cases the knee cap remain. These bones can support the body's weight at the end of the remaining limb through the same mechanism as kneeling down. On the other hand, some surgeons think that problems with healing may be more common with this approach. It is unclear whether amputation through the knee may therefore be a better operation, allowing improved recovery, greater likelihood of being able to walk with an artificial leg, and better quality of life, or whether it is associated with worse outcomes due to wound healing failure and the need for further surgery. The aim of this review was to look at the best available evidence to see how these operations compare.

This review searched for studies that looked at whether through-the-knee or above-the-knee amputation resulted in better wound healing after amputation, improved patient survival, and reduced pain (clinical outcomes), as well as better rates of prosthesis use, walking speed, and quality of life (rehabilitation outcomes).

Study characteristics and key results

A thorough search of the available literature was performed (up to 17 February 2021) to find studies comparing through-knee with above-knee amputation. We identified no studies comparing these two procedures.

Certainty of the evidence

We were unable to assess the certainty of evidence because of the absence of studies included in this review.

Conclusion

Due to a lack of randomised trials, we are unable to determine if through-knee amputations have different outcomes from above-knee amputations. High-quality randomised controlled trials are required to provide evidence on this topic.

BACKGROUND

Description of the condition

Diabetes and vascular disease are the leading causes of lower limb amputation. Currently, 463 million adults are living with diabetes, and 202 million with peripheral vascular disease, worldwide (Behrendt 2018; International Diabetes Federation 2017). For every 100,000 people in Europe and Australia, between 7 and 41 persons undergo a major amputation every year due to diabetes or vascular disease (Behrendt 2018).

It is estimated that between 30 and 40 million people are living with total or partial limb loss in low-income countries internationally (WHO 2005). The leading cause of amputation in these countries, and the second most common cause in the rest of the world, is severe traumatic injury (Ajibade 2013; Nwosu 2017). The population of people with limb loss due to trauma is large, as they tend to be young with a long life expectancy (Perkins 2012). Diabetes and vascular disease are associated with significant morbidity and mortality. There is a strong link between diabetes and vascular disease, as hyperglycaemia is one of the causal factors for vascular dysfunction (Kirpichnikov 2001). Furthermore, cigarette smoking has been reported to significantly increase rates of vascular disease (Liu 2018). Vascular complications that can lead to amputation include progressive infection, major tissue loss due to infection, ischaemia, loss of limb function, or intractable pain. Lower limb amputation places a significant economic burden on the individual and on healthcare services. The estimated yearly cost of inpatient amputation care from the United Kingdom (UK) National Health Service (NHS) is more than GBP 40 million (Kerr 2019). In 2007, lifetime healthcare costs for a prosthetic user were estimated to be USD 509,275 (MacKenzie 2007).

There are four main levels of major lower limb amputation: below-knee, through-knee, above-knee, and through-hip. These four types of amputation have been shown to provide the best chance of using a prosthesis, which is why amputation is not performed directly at the level of the most distal viable tissue (BSRM 2018). Instead, the level of amputation is chosen to best facilitate primary healing and to optimise rehabilitation potential. Quality of life (QoL) outcomes are reported to be inversely correlated with the level of amputation up the limb. Studies have always considered below-knee versus above-knee amputation in this regard, but a direct comparison of the outcomes of through-knee versus above-knee amputation has never been done (Davie-Smith 2017; Murakami 2016).

Description of the intervention

The level of amputation affects patients' postoperative outcomes. It is accepted that below-knee amputation has preferable outcomes to above-knee amputation (Tisi 2014). People with below-knee amputation achieve a higher level of mobility with an artificial limb (prosthesis), and they report better QoL, compared to those with above-knee amputation (Aulivola 2004; Davie-Smith 2017; Vogel 2014). However, below-knee amputation is not always possible, and a more proximal amputation is sometimes required. In these instances, an above-knee amputation is routinely performed (Aulivola 2004; Kidmas 2004; Yusof 2007).

Above-knee amputation, also referred to as 'transfemoral amputation', is an amputation of the leg through the femur, above the level of the condyles, with removal of the patella. Soft tissue flaps are fashioned by using the muscle from the front and back of the leg to cover the transected bone (Woodburn 2009). Above-knee amputation offers a good chance of primary healing and an even appearance with a prosthesis. However, the transected femur is associated with worse functionality for prosthetic limb users. They cannot use their transected femur as an effective physical endpoint for load-bearing through a prosthesis, and sometimes may need to wear an additional suspension strap to hold the prosthesis in place, to compensate for the short length of the residuum (Gholizadeh 2014). To use a prosthesis safely and effectively following above-knee amputation, the individual must have sufficient cardiovascular fitness and strength, good balance and dexterity, and good cognitive function. Achieving prosthetic ambulation, therefore, becomes more challenging with age (Bowrey 2018). In addition, the above-knee amputation prosthesis is not comfortable to sit in. If a person spends more time sitting than standing and mobilising, he or she most likely will abandon the prosthesis in favour of a wheelchair. For these reasons, prosthetic fitting post above-knee amputation is not always appropriate for the geriatric population (Bowrey 2018; Davies 2003).

Through-knee amputation is an alternative to above-knee amputation. Conflicting evidence surrounding through-knee amputation describes varying postoperative levels of success. Earlier papers recommended above-knee amputation for the best chance of primary healing (Chilvers 1971; Jamieson 1976), as delayed wound healing increases length of hospital stay, increases time taken to achieve mobility with a prosthesis, and decreases level of mobility achieved (Nijmeijer 2017). However, recent advancements in surgical techniques for through-knee amputation are improving patient outcomes for survival, morbidity, infection, and dehiscence rates (Lim 2018; Nijmeijer 2017).

A true through-knee amputation, also referred to as 'knee disarticulation', consists of surgical removal of the lower half of the leg through the knee joint with the femur left intact. Revised design of this amputation has improved healing rates and prosthetic fit, and variations of the through-knee amputation have been developed (Murakami 2016). Modified techniques, such as that of Mazet, Burgess, and Youkey, involve removing the patella and trimming the femoral condyles to achieve a less bulbous residual end (Burgess 1977; Mazet 1966). With Gritti-Stokes and Nellis/Van De Water amputations, the patella is attached to the distal end of the femur (Middleton 1962; Nellis 2002).

Both above-knee and through-knee surgeries are appropriate for people requiring a major lower limb amputation. However, surgeons tend to perform an above-knee amputation despite the potential functional advantages that a longer, more powerful, end weight-bearing, through-knee residuum offers to a prosthetic or a non-prosthetic user. As a result, through-knee amputations represent less than 2% of all amputations in the United States (US) (Albino 2014; Lim 2018), and less than 1% in the UK (Moxey 2010).

How the intervention might work

Although both through-knee and above-knee amputations are suitable for most patients, an above-knee amputation is often the standard method of treatment, and the small numbers of through-knee amputations performed are reflected in the sample sizes of retrospective evidence (Bae 2007; Moxey 2010). Thus, there is no

consensus regarding who makes a good or a bad candidate for through-knee amputation.

Despite this, through-knee amputation may offer the following potential advantages for patients over above-knee amputation.

- The surgery is less traumatic and the cartilage barrier is maintained, which reduces the risk of infection or bone spurs (Bowker 2000; Jensen 1996; Pinzur 2004).
- The long end-bearing lever arm creates a strong residual limb with reduced propensity to develop hip flexion contracture (Bowker 2000; Hughes 1983; Persson 2001; Smith 2004).
- The longer residuum provides a stable sitting platform, more efficient transfers, and reduced energy requirements (Pinzur 1992; Pinzur 2004; Siev-Ner 2000).
- The residuum supports superior ambulatory stability, prosthetic sockets are more comfortable, and pressure inside the socket is reduced (Hughes 1983; Pinzur 2004; Smith 2004).

However, through-knee amputation may involve the following potential disadvantages for patients when compared to above-knee amputation.

- The prosthesis can have a poor cosmetic finish, and issues with socket fit can occur (Jensen 1996; Persson 2001; Smith 2004).
- Positioning of the prosthetic knee when it is attached to the end of the socket may cause asymmetrical knee levels (Hagberg 1992; Smith 2004).
- This procedure has a reputation for delayed wound healing despite documented evidence of successful healing (Ten Duis 2009).

Why it is important to do this review

People live with postoperative limitations after both through-knee and above-knee amputation procedures. The incidence of return to theatre and of revision to above-knee amputation remains an issue with through-knee amputation (Lim 2018), and it is unknown how all postoperative outcomes compare between above-knee and through-knee amputation. An earlier systematic review compared through-knee techniques to establish whether through-knee amputation is suitable for the dysvascular patient (Murakami 2016). Murakami 2016 reported that a more substantial body of evidence would be necessary to establish the effects of different surgical techniques for mobility outcomes and gait biomechanics to determine whether through-knee amputation is a useful treatment option for dysvascular patients. Murakami 2016 recommended that future research should compare through-knee and above-knee amputation in the dysvascular population over a suitable follow-up period. Retrospective data suggest that reamputation or revision surgery rates range from 0% to 21% for through-knee cases (Murakami 2016), compared to 8% to 12% for above-knee amputations (Conte 2019). However, poor rehabilitation outcomes are common amongst people with above-knee amputation, with less than 30% able to mobilise with a prosthesis outdoors (Davies 2003), whereas through-knee amputation mobility rates have been reported to range from 13% to 75% (Murakami 2016). Sufficient wound healing is essential for successful prosthetic rehabilitation, and these factors must be considered carefully when the level of amputation is decided (Conte 2019). The ability to mobilise with a prosthesis has a direct impact on a person's QoL (Agrawal 2017; Davie-Smith 2017). People with through-knee amputation theoretically have gait biomechanical benefits, although some of these are potentially mitigated by the shorter lower leg segment, limited prosthetic knee joint options, and lack of prosthetist experience (Schuett 2018; Smith 2004). Recent global vascular guidelines for the management of chronic limb-threatening ischaemia set a research priority to determine whether primary healing rates, postoperative mobility and prosthetic use, and quality of life data justify through-knee rather than above-knee amputation (Conte 2019). A recent patient and public involvement (PPI) group conducted by authors of the current review confirmed that QoL, time taken to achieve independent mobility, and level of walking ability are considered research priorities by people post amputation and by their family members. The review authors attended a UK artificial limb centre and spoke with service users in the waiting room to better understand these research priorities. The National Institute for Health Research (NIHR) recommends using PPI to improve the quality and relevance of research (NIHR INVOLVE).

For these reasons, it is important to determine which level of amputation provides a lower complication rate (in terms of delayed wound healing, pain, and patient survival), alongside improved postoperative, rehabilitation, and QoL outcomes. The aim of this Cochrane Review was to compare clinical and rehabilitation outcomes and complication rates of through-knee amputation with those of above-knee amputation. We collated and evaluated evidence to facilitate discussions and shared decision-making between physicians and patients about which level of amputation offers improved healing rates, a better chance of survival, and better QoL, and improves the potential for successful rehabilitation outcomes. We aimed to present available evidence supporting decision-making for each clinical or patient group. We anticipated that evidence suitable for inclusion in this review would serve as a base on which both amputation levels can be incorporated into a body of consensus guidelines, such as the Vascular Society of Great Britain and Northern Ireland (VSGBI), the British Association of Chartered Physiotherapists in Amputation Rehabilitation (BACPAR), the British Orthopaedic Association (BOA), and the British Association of Plastic Reconstructive and Aesthetic Surgeons (BAPRAS).

OBJECTIVES

To assess the effects of through-knee amputation compared to above-knee amputation on clinical and rehabilitation outcomes and complication rates for all patients undergoing vascular and non-vascular major lower limb amputation.

METHODS

Criteria for considering studies for this review

Types of studies

We aimed to include only randomised controlled trials (RCTs) that compare through-knee amputation with above-knee amputation for all aetiologies. We planned to incorporate studies that include amputations at all above-knee levels if through-knee outcomes were reported separately. We planned to exclude studies for which we were unable to obtain separate through-knee amputation data.

Types of participants

We aimed to include participants of both sexes and all ages undergoing major unilateral lower limb amputation at or above the knee (between but not including the levels of below-knee and through-hip) in all countries of origin. We aimed to include participants with any level of preexisting function and comorbidities, with the exception of major lower limb amputation on the contralateral side. Indications for amputation included vascular or diabetic indications, such as infection, tissue loss, pain, and ischaemia, as well as non-vascular indications, such as trauma, malignancy, and congenital malformation. Participants may have had previous major or minor lower limb surgery, including salvage attempts, limb reconstruction, revascularisation, or below-knee or other distal lower limb amputations.

Types of interventions

We aimed to include RCTs that compared through-knee amputation versus above-knee amputation. We planned to use the umbrella term 'through-knee amputation' to refer to all variations including:

- standard through-knee (through-knee, knee disarticulation);
- modified through-knee (Mazet, Burgess, Youkey); and
- Gritti-Stokes and Nellis/Van De Water.

Above-knee amputations are amputations at all levels through the femur for all aetiologies. We excluded below-knee and through-hip amputations (hip disarticulation). We planned to compare any variation on a through-knee amputation with any above-knee amputation.

Types of outcome measures

Primary outcomes

- Limb-fitted and not limb-fitted: measured as whether patients are referred for limb fitting and are successfully fitted with a prosthetic limb, or are not fitted with a prosthetic limb
- Uncomplicated primary wound healing (30 days)

Secondary outcomes

- Time taken to achieve independent mobility with a prosthesis, with or without use of a walking aid
- Health-related QoL: reported by a validated QoL outcome measure, including those relevant to life as a prosthetic limb user, such as the 36-Item Short Form Survey (SF-36), the EuroQol-5D (EQ-5D), or the Prosthetic Patient Satisfaction Survey
- Walking speed: measured as the distance walked during a time period divided by the time taken to walk that distance. This will be converted and reported as metres per second (m/s) (Peel 2012)
- Pain (postoperative, phantom limb, and pain associated with prosthetic limb-wearing) reported on a validated pain measure such as the visual analogue scale (VAS) or the Short Form McGill Pain Questionnaire
- 30-Day patient survival

Search methods for identification of studies

Electronic searches

The Cochrane Vascular Information Specialist conducted systematic searches of the following databases for RCTs and controlled clinical trials without language, publication year, or publication status restrictions.

- Cochrane Vascular Specialised Register, via the Cochrane Register of Studies (CRS-Web) (searched 17 February 2021).
- Cochrane Central Register of Controlled Trials (CENTRAL; 2021, Issue 1), in the Cochrane Library, via the Cochrane Register of Studies Online (CRSO).
- MEDLINE (Ovid MEDLINE Epub Ahead of Print, In-Process & Other Non-Indexed Citations; Ovid MEDLINE Daily; and Ovid MEDLINE) (searched 17 February 2021).
- Embase Ovid (searched 17 February 2021).
- Cumulative Index to Nursing and Allied Health Literature (CINAHL) Ebsco (searched 17 February 2021).

The Information Specialist developed search strategies for other databases from the search strategy designed for MEDLINE. When appropriate, these were combined with adaptations of the highly sensitive search strategy designed by Cochrane for identifying RCTs and controlled clinical trials (as described in the *Cochrane Handbook for Systematic Reviews of Interventions,* Chapter 4; Lefebvre 2021). Search strategies for major databases are provided in Appendix 1.

The Information Specialist searched the following trials registries on 17 February 2021.

- World Health Organization International Clinical Trials Registry Platform (who.int/trialsearch).
- ClinicalTrials.gov (clinicaltrials.gov).

Searching other resources

Two review authors (HC, GB) independently checked the bibliographies of included trials and non-Cochrane systematic reviews for further references of interest. When necessary, we contacted study authors to request any unpublished data that may be available. We also canvassed professionals within relevant specialities to identify any as yet unpublished RCTs.

Data collection and analysis

Selection of studies

Two review authors (HC, GB) independently reviewed the titles and abstracts and determined which studies were eligible for inclusion, discussing any conflicts with the review team to reach consensus when necessary. This process was repeated with full texts of studies that were initially evaluated as appropriate for inclusion, with illustration of the study selection process in a PRISMA diagram (Liberati 2009). Records of all articles excluded after full-text assessment were reported in a 'Characteristics of excluded studies' table along with reasons for their exclusion.

Data extraction and management

We planned for two review authors (HC, GB) to independently extract and collect relevant data from the included studies using a data extraction form provided by Cochrane Vascular. We planned

to contact study authors to request raw data if through-knee amputation outcomes were used within the population but were not reported. We aimed to resolve any disagreement by discussion within the review team. We planned to extract the following information.

- Publication details: year, country, study authors.
- Methods: study design, randomisation, total duration of study, number of study centres and locations, study settings, withdrawals, dates of study.
- Participants: number, setting, demographic characteristics, aetiology, presence or absence of multi-morbidities, previous lower limb surgery, inclusion criteria, exclusion criteria.
- Interventions: amputation level, surgical technique.
- Outcomes: primary and secondary outcomes specified and collected, time points reported.

Assessment of risk of bias in included studies

We planned for two review authors (HC, GB) to independently assess the included studies for risk of bias using Cochrane's 'Risk of bias' tool, as defined in Section 8.5 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). We aimed to rate each domain as having low risk, high risk, or unclear risk of bias. Again, we planned to resolve any disagreements between two review authors by discussion and, if necessary, by consultation with the wider review team. We intended for a senior author to review a random subset of papers (10% to 20%) for risk of bias, as quality control.

We planned to assess risk of bias in the following domains.

- Random sequence generation.
- Allocation concealment.
- Blinding of participants and personnel.
- Blinding of outcome assessment.
- Incomplete outcome data.
- Selective reporting.
- Other sources of bias.

We aimed to report the judgement for each individual study in 'Risk of bias' tables located in the 'Characteristics of included studies' section. We planned to contact study authors for further clarification if required.

Measures of treatment effect

We aimed to calculate and report odds ratios (ORs) with 95% confidence interval (CIs) to investigate the pooled estimate of effect for dichotomous data (limb-fitted and not limb-fitted, uncomplicated primary wound healing, and 30-day patient survival). We intended to calculate mean differences (MDs) between treatment groups with 95% CIs for continuous outcome measures (health-related QoL, walking speed, and pain). We planned to use standardised mean differences (SMDs) if different scales were used to measure the same concept. We aimed to calculate time-to-event outcomes (time to achieve independent mobility) as hazard ratios (HRs) with 95% CIs. If sufficient data were not reported, we planned to contact study authors.

Unit of analysis issues

We planned to consider the unit of analysis within each trial to be the participant. If a trial allowed participants who have a through-knee amputation that is reamputated to an above-knee amputation in the same admission to remain in the trial, they would also be included.

Dealing with missing data

We planned to analyse all available data and to contact study authors to request any missing data, allowing six weeks for response before treating the data as missing. We aimed to perform an intention-to-treat analysis and to report incidents of loss to follow-up.

Assessment of heterogeneity

We planned to consider clinical, methodological, and statistical heterogeneity of included studies. We planned to assess heterogeneity using Chi^2 and I^2, and to use the below guidance for interpretation as described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011).

- 0% to 40%: might not be important.
- 30% to 60%: may represent moderate heterogeneity.
- 50% to 90%: may represent substantial heterogeneity.
- 75% to 100%: showing considerable heterogeneity.

Assessment of reporting biases

Reporting biases may occur when dissemination of research findings is influenced by the nature and direction of results (Higgins 2011). We aimed to examine small-study effects by using funnel plots and to seek statistical advice for their interpretation for outcomes with more than 10 studies (Higgins 2011).

Data synthesis

We planned to synthesise data using Review Manager 5 software (Review Manager 2014), and to use statistical analysis in agreement with statistical guidelines provided in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). We aimed to use the fixed-effect model of meta-analysis when there was minimal or no heterogeneity. When there was a high level of heterogeneity, we aimed to use a random-effects model. We aimed to adopt a narrative approach if it was not possible to perform a meta-analysis.

Subgroup analysis and investigation of heterogeneity

We aimed to perform the following subgroup analyses if sufficient data were available.

- Aetiology. We anticipated that participants' surgical, QoL, and mobility outcomes may differ between underlying causes of amputation. The large range of reamputation rates for through-knee amputation (0% to 21%) is due to differences between aetiologies from studies using single aetiology samples (Murakami 2016). Similarly, we expected that participants would be more likely to experience delayed wound healing or to require reamputation if the presenting cause for the amputation was diabetes or a vascular cause rather than a non-vascular cause or trauma. We aimed to investigate any effects on outcomes from vascular or non-vascular causes of amputation by using subgroup analysis when possible.

- Gender (Heidari 2016). It has been reported that a female person with an amputation is less likely to mobilise with a prosthesis, and that they are less satisfied with the cosmetic appearance of a through-knee amputation (Singh 2008). However, Davie-Smith 2017 described being male as one of the most significant factors to negatively affect QoL post major lower limb amputation. We aimed to carry out subgroup analysis to provide evidence for any gender impact.
- Age. It is claimed that through-knee amputation is more suitable for paediatric patients to retain growth plates (Smith 2004). We aimed to investigate any effects on outcomes due to age of participants at the time of amputation by comparing participants under age 18 with those age 18 years and older (Le 2015; NHS 2013; Rijnders 2000).
- Surgical technique. We aimed to use subgroup analyses to investigate any effect differences between through-knee, modified through-knee, Gritti-Stokes, and Nellis/Van De Water amputation techniques.

Sensitivity analysis

We aimed to use sensitivity analysis to investigate the robustness of findings for primary and secondary outcomes by excluding studies that we judge to have high risk of methodological bias. We aimed to classify trials as being at high risk of methodological bias if they were at high risk of bias for random sequence generation and allocation concealment.

Summary of findings and assessment of the certainty of the evidence

We aimed to present review findings in a 'Summary of findings' table, based on the methods presented in Chapter 11 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). We aimed to create a table for the comparison 'Through-knee versus above-knee amputation for vascular and non-vascular major lower limb amputations'. If sufficient data were available, we aimed to create separate tables for specific through-knee variations (such as Gritti-Stokes, etc.) versus any above-knee amputation. We aimed to include the following outcomes in each table: limb-fitted or not limb-fitted, uncomplicated primary wound healing within 30 days, time taken to achieve independent mobility, QoL, walking speed, pain, and 30-day patient survival. We planned to assess the certainty of evidence for each outcome by using the GRADE approach (Atkins 2004; Higgins 2011). We aimed to assign the certainty of evidence as high, moderate, low, or very low based on overall risk of bias, inconsistency, indirectness, imprecision, and publication bias. We aimed to prepare 'Summary of findings' tables by using GRADEpro GDT software (GRADEpro GDT 2015). A draft 'Summary of findings' table can be viewed in Table 1.

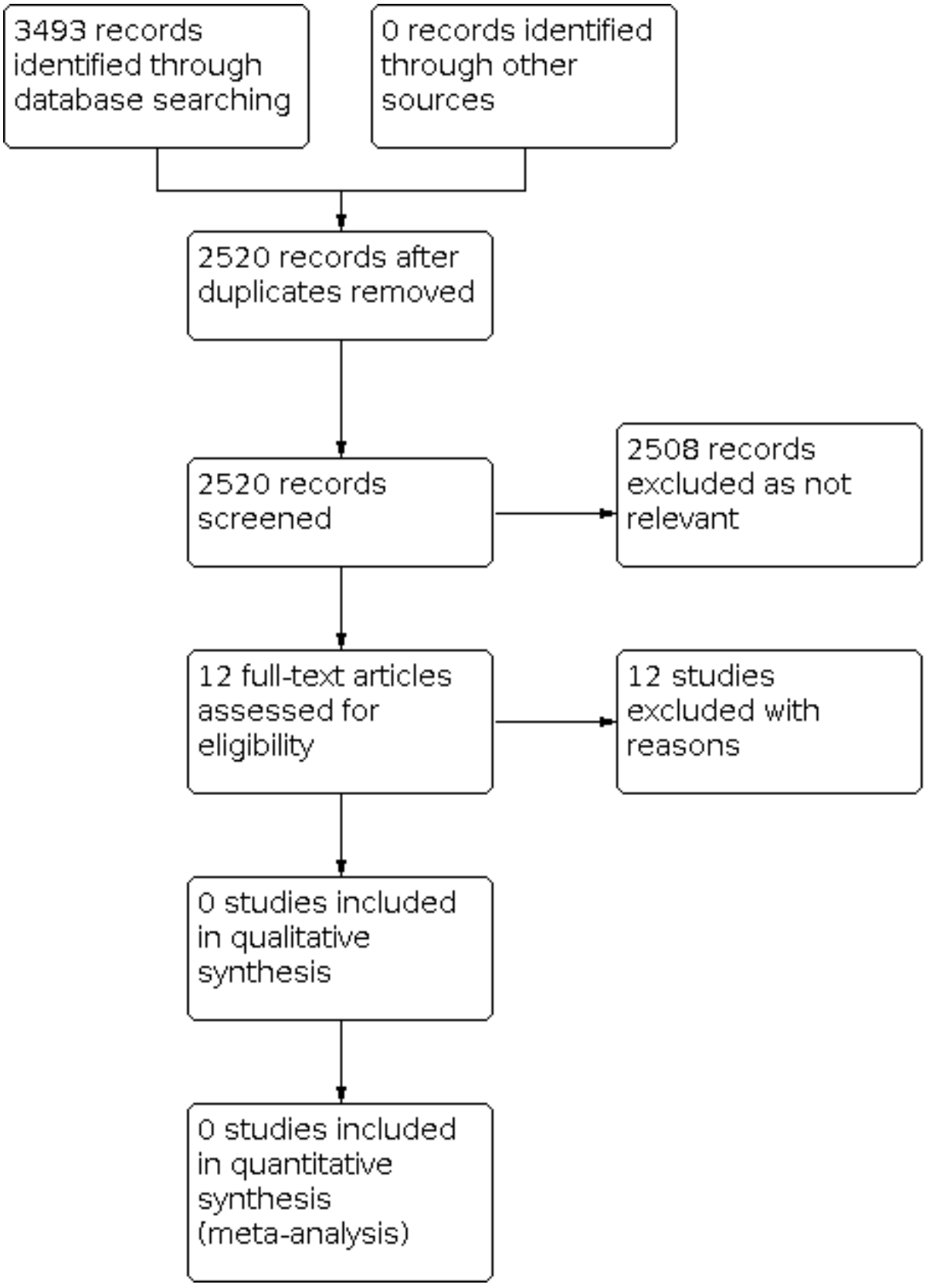
RESULTS

Description of studies

Results of the search

The PRISMA flow diagram (Figure 1) shows the number of studies assessed within this review. The search strategy identified 3493 references. From these, we removed 973 duplicates, and we screened 2520 studies by title and abstract. We obtained the full text for 12 studies; however we subsequently excluded all and noted reasons for exclusion in the Characteristics of excluded studies table.

Figure 1. Figure 1: PRISMA flow diagram.



Included studies

We identified no eligible studies for inclusion.

Excluded studies

We excluded the 12 full-text studies for the following reasons: two studies included an incorrect intervention (NCT03900845; NCT04023045); eight used an incorrect design (Anderson 2005; Baumgartner 1979; Dustmann 1985; Hagberg 1992; Houghton 1989; Jeans 2011; Knahr 1979; NCT04120558); one used the wrong comparators (Campbell 1987); and the full text of one study could not be obtained (Kahle 2016), despite attempts to contact the study author; therefore it was excluded.

Risk of bias in included studies

No studies met the inclusion criteria.

Effects of interventions

No studies met the inclusion criteria.

DISCUSSION

Summary of main results

Despite the potential benefits of through-knee amputation, we identified no RCTs comparing through-knee amputation with above-knee amputation; therefore there we can make no conclusions regarding the comparative performance of these two procedures for people requiring lower limb amputation at a site more proximal to the below-knee level. As a result of this lack of evidence, people undergoing above-knee amputation as “standard care” may be missing out on potentially superior rehabilitation outcomes of through-knee amputation, and people undergoing through-knee amputation performed by enthusiasts for this procedure may be at risk of increased complication rates and revisional surgery than if they had received the default “standard care” of above-knee amputation.

Overall completeness and applicability of evidence

Currently no high-quality evidence compares through-knee amputation and above-knee amputation in the literature.

Quality of the evidence

Currently no high-quality evidence compares through-knee amputation and above-knee amputation in the literature.

Potential biases in the review process

The risk of bias in this review was minimised. The Cochrane Information Specialist conducted a comprehensive search of the literature. Two review authors independently reviewed all study titles found by the searches against the inclusion and exclusion criteria that had been prospectively published in the peer-reviewed protocol (Crane 2021). We planned to resolve disagreement by consensus or with the arbitration of a third review author. This was not necessary, and both review authors' findings were consistent.

Agreements and disagreements with other studies or reviews

We found no other reviews or non-randomised studies comparing outcomes of through-knee versus above-knee amputation. Previous randomised studies have involved individuals with through-knee and above-knee amputations (Hargrove 2015; Highsmith 2012; Prinsen 2015; Prinsen 2017; Seelen 2009). However, the aim of these studies was to compare differences between a microprocessor-controlled prosthetic knee and a non-microprocessor-controlled prosthetic knee. One RCT examined differences between primary and delayed wound closure but did not include through-knee amputation (Katiyar 2020). Another RCT investigated wound healing in Gritti-Stokes and knee disarticulation amputations but did not include above-knee amputation as a comparator group (Campbell 1987).

AUTHORS' CONCLUSIONS

Implications for practice

For planning a lower limb amputation in a clinical situation in which a below-knee amputation is unsuitable, no RCT evidence is available to inform the decision as to whether a through-knee or an above-knee amputation will offer the best outcomes for a patient. Clinicians need to rely on clinical experience in the absence of high-quality evidence on which to base practice. It is therefore possible that there is a significant risk that patients may not be offered the best operation for them, and their clinical and rehabilitation outcomes may suffer as a result.

Implications for research

We found no RCTs from which we could draw conclusions regarding the review objectives. High-quality research is needed to inform clinical decision-making for this group of patients to ensure optimal outcomes, maximise quality of life for patients and their families, and ensure the best use of both health and social care expenditures. Although studies have recruited participants with through-knee amputation and above-knee amputation, no high-certainty evidence is available to support surgical practice of one type over the other. RCTs are required to determine whether a through-knee amputation offers any advantage for patient outcomes compared to an above-knee amputation. Future RCTs for patients who are eligible for either a through-knee amputation or an above-knee amputation would help to determine the true differences in outcomes between these two levels of amputation.

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CHARACTERISTICS OF STUDIES

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Anderson 2005	Wrong study design - not an RCT
Baumgartner 1979	Wrong study design - not an RCT
Campbell 1987	Wrong comparator - not above-knee amputation
Dustmann 1985	Wrong study design - not an RCT
Hagberg 1992	Wrong study design - not an RCT
Houghton 1989	Wrong study design - not an RCT
Jeans 2011	Wrong study design - not an RCT
Kahle 2016	Unable to locate full text

Study	Reason for exclusion
Knahr 1979	Wrong study design - not an RCT
NCT03900845	Wrong intervention - not through-knee amputation
NCT04023045	Wrong intervention - not through-knee amputation
NCT04120558	Wrong study design - not an RCT

RCT: randomised controlled trial

ADDITIONAL TABLES

Table 1. Example Summary of findings table

Through-knee amputation compared with above-knee amputation for vascular and non-vascular major lower limb amputations

Patient or population: participants with through-knee or above-knee amputation

Settings: all settings (surgical wards, rehabilitation centres, artificial limb units, community settings, etc.)

Intervention: through-knee amputation

Comparison: above-knee amputation

Outcomes	Anticipated absolute effects *		Relative effect (95% CI)	No. of participants (studies)	Certainty of evidence (GRADE)	Comments
	Risk with above-knee amputation	Risk with through-knee amputation				
Limb-fitted and not limb-fitted (follow-up: upon completion of prosthetic rehabilitation)	**Study population**		**OR [value]** ([value] to [value])	[value] ([value])	⊕⊖⊖⊖ **very low** ⊕⊕⊖⊖ **low** ⊕⊕⊕⊖ **moderate** ⊕⊕⊕⊕ **high**	
	[value] per 1000	**[value] per 1000** ([value] to [value])				
Uncomplicated primary wound healing (follow-up: within 30 days)	**Study population**		**OR [value]** ([value] to [value])	[value] ([value])	⊕⊖⊖⊖ **very low** ⊕⊕⊖⊖ **low** ⊕⊕⊕⊖ **moderate** ⊕⊕⊕⊕ **high**	
	[value] per 1000	**[value] per 1000** ([value] to [value])				
	Study population			[value] ([value])	⊕⊖⊖⊖ **very low**	

Table 1. Example Summary of findings table *(Continued)*

Time to achieve independent mobility (follow-up)	**[value] per 1000**	**[value] per 1000** ([value] to [value])	**HR [value]** ([value] to [value])		⊕⊕⊝⊝ **low** ⊕⊕⊕⊝ **moderate** ⊕⊕⊕⊕ **high**
Health-related QoL (any validated QoL outcome measure) (follow-up)	Mean [outcome] ranged across control groups from [value] [measure]	Mean [outcome] in the intervention groups was **[value] [lower/higher]** [(value to value lower/higher)]		[value] ([value])	⊕⊝⊝⊝ **very low** ⊕⊕⊝⊝ **low** ⊕⊕⊕⊝ **moderate** ⊕⊕⊕⊕ **high**
Walking speed (m/s) (follow-up: upon completion of prosthetic rehabilitation)	Mean [outcome] ranged across control groups from [value] [measure]	Mean [outcome] in the intervention groups was **[value] [lower/higher]** [(value to value lower/higher)]		[value] ([value])	⊕⊝⊝⊝ **very low** ⊕⊕⊝⊝ **low** ⊕⊕⊕⊝ **moderate** ⊕⊕⊕⊕ **high**
Pain (any validated pain measure) (follow-up)	Mean [outcome] ranged across control groups from [value] [measure]	Mean [outcome] in the intervention groups was **[value] [lower/higher]** [(value to value lower/higher)]		[value] ([value])	⊕⊝⊝⊝ **very low** ⊕⊕⊝⊝ **low** ⊕⊕⊕⊝ **moderate** ⊕⊕⊕⊕ **high**
Patient survival (follow-up: within 30 days)	**Study population**		**OR [value]** ([value] to [value])	[value] ([value])	⊕⊝⊝⊝ **very low** ⊕⊕⊝⊝ **low** ⊕⊕⊕⊝ **moderate** ⊕⊕⊕⊕ **high**
	[value] per 1000	**[value] per 1000** ([value] to [value])			

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: confidence interval;**HR:** hazard ratio; **OR**: odds ratio; **QoL:** quality of life.

GRADE Working Group grades of evidence.

Table 1. Example Summary of findings table *(Continued)*

High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

APPENDICES

Appendix 1. Sources searched and search strategies

Source	Search strategy	Hits retrieved
VASCULAR REGISTER IN CRSW	#1 Knee* AND INREGISTER #2 above-knee AND INREGISTER #3 Through-knee AND INREGISTER #4 #1 OR #2 OR #3 #5 Amput* AND INREGISTER #6 stump* AND INREGISTER #7 #5 OR #6 #8 #4 AND #7	Feb 2021: 116
CENTRAL via CRSW	#1 MESH DESCRIPTOR Knee EXPLODE ALL WITH QUALIFIER SU AND CENTRAL:TARGET #2 MESH DESCRIPTOR Knee Joint EXPLODE ALL WITH QUALIFIER SU AND CENTRAL:TARGET #3 Knee* AND CENTRAL:TARGET #4 "above-knee" AND CENTRAL:TARGET #5 "Through-knee" AND CENTRAL:TARGET #6 "trans femoral" AND CENTRAL:TARGET #7 #1 OR #2 OR #3 OR #4 OR #5 OR #6 #8 MESH DESCRIPTOR Amputation EXPLODE ALL AND CENTRAL:TARGET #9 MESH DESCRIPTOR Amputation Stumps EXPLODE ALL AND CENTRAL:TARGET #10 MESH DESCRIPTOR Amputees EXPLODE ALL AND CENTRAL:TARGET #11 "residua* limb*" AND CENTRAL:TARGET #12 (phantom adj6 limb*) AND CENTRAL:TARGET #13 amput* AND CENTRAL:TARGET	Feb 2021: 509

(Continued)

	#14 disarticulat* AND CENTRAL:TARGET #15 exarticulat* AND CENTRAL:TARGET #16 postamputation* AND CENTRAL:TARGET #17 post-amputation* AND CENTRAL:TARGET #18 stump* AND CENTRAL:TARGET #19 Gritti-Stokes AND CENTRAL:TARGET #20 Mazet AND CENTRAL:TARGET #21 Burgess AND CENTRAL:TARGET #22 #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 #23 #7 AND #22	
Clinicaltrials.gov	Amputation OR amputate OR amputee OR stump | Knee OR above-knee OR Through-knee	Feb 2021: 142
ICTRP search portal	Amputation OR amputate OR amputee OR stump | Knee OR above-knee OR Through-knee	Feb 2021: 0
MEDLINE (Ovid MEDLINE Epub Ahead of Print, In-Process & Other Non-Indexed Citations; Ovid MEDLINE Daily; and Ovid MEDLINE) 1946 to present	1 exp Knee/su [Surgery] 2 exp Knee Joint/su [Surgery] 3 Knee*.ti,ab. 4 "above-knee".ti,ab. 5 "Through-knee".ti,ab. 6 "trans femoral".ti,ab. 7 or/1-6 8 exp Amputation/ 9 exp Amputation Stumps/ 10 exp Amputees/ 11 "residua* limb*".ti,ab. 12 (phantom adj6 limb*).ti,ab. 13 amput*.ti,ab. 14 disarticulat*.ti,ab. 15 exarticulat*.ti,ab. 16 postamputation*.ti,ab. 17 post-amputation*.ti,ab. 18 stump*.ti,ab. 19 Gritti-Stokes.ti,ab. 20 Mazet.ti,ab.	Feb 2021: 942

(Continued)

	21 Burgess.ti,ab.	
	22 or/8-21	
	23 7 and 22	
	24 randomized controlled trial.pt.	
	25 controlled clinical trial.pt.	
	26 randomized.ab.	
	27 placebo.ab.	
	28 drug therapy.fs.	
	29 randomly.ab.	
	30 trial.ab.	
	31 groups.ab.	
	32 or/24-31	
	33 exp animals/ not humans.sh.	
	34 32 not 33	
	35 23 and 34	
Embase	1 exp knee/su [Surgery]	Feb 2021: 1377
	2 exp knee/su [Surgery]	
	3 Knee*.ti,ab.	
	4 "above-knee".ti,ab.	
	5 "Through-knee".ti,ab.	
	6 "trans femoral".ti,ab.	
	7 or/1-6	
	8 exp amputation/	
	9 exp amputation stump/	
	10 exp amputee/	
	11 "residua* limb*".ti,ab.	
	12 (phantom adj6 limb*).ti,ab.	
	13 amput*.ti,ab.	
	14 disarticulat*.ti,ab.	
	15 exarticulat*.ti,ab.	
	16 postamputation*.ti,ab.	
	17 post-amputation*.ti,ab.	
	18 stump*.ti,ab.	
	19 Gritti-Stokes.ti,ab.	

(Continued)

	20 Mazet.ti,ab. 21 Burgess.ti,ab. 22 or/8-21 23 7 and 22 24 randomized controlled trial/ 25 controlled clinical trial/ 26 random$.ti,ab. 27 randomization/ 28 intermethod comparison/ 29 placebo.ti,ab. 30 (compare or compared or comparison).ti. 31 ((evaluated or evaluate or evaluating or assessed or assess) and (compare or compared or comparing or comparison)).ab. 32 (open adj label).ti,ab. 33 ((double or single or doubly or singly) adj (blind or blinded or blindly)).ti,ab. 34 double blind procedure/ 35 parallel group$1.ti,ab. 36 (crossover or cross over).ti,ab. 37 ((assign$ or match or matched or allocation) adj5 (alternate or group$1 or intervention$1 or patient$1 or subject$1 or participant$1)).ti,ab. 38 (assigned or allocated).ti,ab. 39 (controlled adj7 (study or design or trial)).ti,ab. 40 (volunteer or volunteers).ti,ab. 41 trial.ti. 42 or/24-41 43 23 and 42	
CINAHL	S38 MH "Random Assignment" S37 S22 AND S36 S36 S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 S35 MH "Random Assignment" S34 MH "Triple-Blind Studies" S33 MH "Double-Blind Studies" S32 MH "Single-Blind Studies" S31 MH "Crossover Design"	Feb 2021: 407

(Continued)

S30 MH "Factorial Design"	
S29 MH "Placebos"	
S28 MH "Clinical Trials"	
S27 TX "multi-centre study" OR "multi-center study" OR "multicentre study" OR "multicenter study" OR "multi-site study"	
S26 TX crossover OR "cross-over"	
S25 AB placebo*	
S24 TX random*	
S23 TX "latin square"	
S22 S6 AND S21	
S21 S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20	
S20 TX Burgess	
S19 TX Mazet	
S18 TX Gritti-Stokes	
S17 TX stump*	
S16 TX post-amputation*	
S15 TX postamputation*	
S14 TX exarticulat*	
S13 TX disarticulat*	
S12 TX amput*	
S11 TX phantom N6 limb*	
S10 TX "residua* limb*"	
S9 (MH "Amputees")	
S8 (MH "Amputation Stumps")	
S7 (MH "Amputation+")	
S6 S1 OR S2 OR S3 OR S4 OR S5	
S5 TX "trans femoral"	
S4 TX "Through-knee"	
S3 TX "above-knee"	
S2 TX Knee*	
S1 (MH "Knee Joint+/SU")	
TOTAL before de-duplication	3493
TOTAL after de-duplication	2520

HISTORY

Protocol first published: Issue 1, 2021

CONTRIBUTIONS OF AUTHORS

HC: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates, guarantor of the review.

GB: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates, guarantor of the review.

DC: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates.

NV: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates.

MT: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates.

GES: protocol drafting, acquisition of trial reports, trial selection, data extraction, data analysis, data interpretation, review drafting and future review updates.

DECLARATIONS OF INTEREST

HC: has declared that her institution received a research bursary of £2000 from the British Association of Chartered Physiotherapists in Amputee Rehabilitation (BACPAR). This was solely for participant costs for qualitative interviews conducted with through-knee and above-knee amputees for her PhD.

GB: has declared that her institution received £1000 from Help for Health solely to cover the costs of participant incentives and their travel costs when completing data collection for her PhD.

DC: has received consultancy fees from Medtronic related to venous treatment policy, and travel expenses from All Party Parliamentary Group on Vascular Disease, NICE, MHRA, to provide expert advice.

NV: has received payment for Editorial board membership (Associate Editor) for *Journal of Sports Sciences*. She is Chief Investigator on a study funded by the National Institute for Health Research (PB-PG-0816-20029). This study is conducted to assess the feasibility of conducting an RCT about the effectiveness and cost-effectiveness of a novel prosthesis for older patients with vascular-related below-the-knee amputations and multi-morbidities. It is not relevant to this review.

MT: none known.

GES: has in the past received consulting fees from BSN Medical for consulting on NICE technology appraisal application, speakers fees from BSN Medical and Bayer with regard to presenting research related to their products. GES reports that in the past, his institution has received unconditional funding from Diomed/Angiodynamics. This was used to help fund a research nurse to assist with objective assessments in the context of randomised controlled trials.

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Internal sources

- No sources of support provided

External sources

- Chief Scientist Office, Scottish Government Health Directorates, The Scottish Government, UK

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

None.

NOTES

Parts of the Methods section of the protocol are based on a standard template established by Cochrane Vascular.