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REVIEW ARTICLE

Fitting transtibial and transfemoral prostheses in persons with a severe flexion contracture: problems and solutions – a systematic review

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ABSTRACT
Purpose: In persons with a hip or knee flexion contracture $\geq$25°, fitting a prosthesis is said to be difficult. This systematic review aims to assess the evidence for fitting of a prosthesis in persons with a severe contracture ($\geq$25°) after a lower limb amputation.
Method: PubMed, Embase, Scopus, CINAHL, and Orthotics & Prosthetics Virtual Library databases were searched from inception to December 2019, using database specific search terms related to amputation, prosthesis, and contracture. Reference lists of included studies were checked for relevant studies. Quality of the included studies was assessed using the critical appraisal checklist for case reports (Joanna Briggs Institute).
Results: In total, 13 case studies provided evidence for fitting of a prosthesis in more than 63 persons with a transtibial amputation and three with a transfemoral amputation, all of whom had a hip or knee flexion contracture $\geq$25°. Some studies found a reduction in contractures after prosthesis use.
Conclusions: Several techniques for fitting a prosthesis in case of a flexion contracture $\geq$25° were found. Contracture reduction occurred in some cases and was possibly related to prosthesis use. Fitting a transtibial or transfemoral prosthesis in persons with a lower limb amputation with a severe flexion contracture is possible.

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KEYWORDS
Hip flexion contracture; knee flexion contracture; prostheses; prosthesis fitting; guideline; artificial limbs

➤ IMPLICATIONS FOR REHABILITATION
- This study provides information on prosthesis prescriptions and adaptations for persons with a transfemoral and transtibial amputation with a flexion contracture $\geq$25°.
- The fitting of bent prostheses is not limited by prosthetic components and techniques.
- Parallel to the use of bent prostheses, it is also important to treat the contracture.

Introduction

A hip or knee flexion contracture may occur in persons with a lower limb amputation [1]. Approximately, 13% of persons with a transtibial (TT) amputation and 23% of persons with a transfemoral (TF) amputation develop a flexion contracture $\geq$25° [2]. A flexion contracture of hip or knee limits full extension and can be caused by several factors [3–6], including muscle imbalance [3,4]. For example, the more proximal the level of a transfemoral amputation, the more the hip extensor (gluteus maximus), and hip adductors (adductor longus and adductor magnus) are amputated [4]. The strongest hip flexor (iliopsoas) as well as the hip abductors (gluteus medius and minimus); however, remain intact [4]. Contractures can also be the result of prolonged immobilization or improper positioning [3,5]. The immobilization could induce the adhesion of synovial membrane fold contributing to contractures [7]. Lying supine with a pillow underneath the knee or side-lying with hips and knees flexed can lead to hip and knee flexion contractures [5,6]. These incorrect positions may be maintained due to unawareness of a contracture [8].

Strategies to prevent postoperative contractures include use of a prosthesis immediately post amputation [9,10], rigid dressings [11], silicone liners [12], pneumatic postoperative prostheses, proper positioning (lying prone to prevent hip flexion contractures), use of an extension board while sitting on a wheelchair, and active range of motion exercises [5]. Stretching is another common strategy, but the effect of stretching on contracture prevention or treatment is unclear [13]. Furthermore, in case of a proximal amputation, the lever is short. The success of contracture prevention also depends on a patient's compliance with the prevention methods [8]. Moreover, the effects of postoperative care are influenced by amputation level, skills of surgeons, surgical techniques [4], and the patient's age and comorbidities (diabetes, peripheral vascular disease, other infections) [14,15].

Hip or knee contractures influence walking biomechanics [16] and lead to gait deviations [17]. Contracture simulations in healthy individuals show that when the knee flexion contracture

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Supplemental data for this article can be accessed here.

is more than 15°, the maximum axial load on both knees (contracture and non-contracture knees) increases [18], and a knee flexion contracture of 30° changes trunk kinematics in all planes [19]. Therefore, a knee flexion contracture may be associated with an increase in severity of knee osteoarthritis, knee pain, and back pain [18,19]. Low back pain has been reported in a person with a transfemoral amputation and a hip flexion contracture [20].

Earlier receipt of a prosthesis improves mobility [10,11] and positively affects the emotional state and self-image of the prosthesis user [15]. One review considered the ability to walk with a prosthesis as the main factor for improving quality of life [21]. Moreover, not providing the prosthesis at all or delaying receipt of the prosthesis increases healthcare costs by approximately 25% [22]. Consequently, not receiving a prosthesis due to a severe flexion contracture may hinder a person's desire to ambulate, increase complications associated with prolonged periods of immobility, and lead to further limitations in activities of daily living.

The Atlas of Limb Prosthetics suggests that fitting a prosthesis is difficult when the flexion contracture angle of the knee or hip is more than 25° [23–25]. In contrast to this suggestion, many prostheses have been made for persons with a lower limb amputation and a flexion contracture [26]. These prostheses tend to be bulky, which affects their cosmetic appearance [24,25]. Given that cosmetic appearance is highly associated with prosthesis satisfaction and is particularly important for the body image of women [27], it is important to pay attention to this aspect in the fitting process.

There is a paucity of research on prosthesis fitting in persons with a severe hip or knee contracture [28–30], even though such research is beneficial for rehabilitation clinicians when prescribing a lower limb prosthesis. Therefore, this systematic review aims to contribute to the evidence base regarding prosthesis prescription in persons with a flexion contracture. The specific aims of this study were to 1) explore whether prosthesis fitting is possible in persons with a hip or knee flexion contracture ≥25°, 2) discuss designs of TT and TF prostheses, and 3) illustrate the possibilities and problems related to prosthesis fitting in persons with a severe flexion contracture.

Methods

PubMed, Embase, Scopus, CINAHL databases were searched for studies on the fitting of lower limb prostheses in persons with severe hip or knee flexion contractures. The Orthotics & Prosthetics Virtual Library was also searched because it contains earlier issues of the Journal of Prosthetics & Orthotics that were published under the headings Newsletter: Prosthetics & Orthotics Clinic and Clinical Prosthetics & Orthotics. Search strategies included combinations of database specific search terms relating to amputation or prosthesis and contracture. The search term "prosthesis" was not used in the Orthotics & Prosthetic Virtual Library because all the articles in this database already concern either prostheses or orthoses (Appendix 1). No restrictions were applied for publication year, study type, or language. The last search was performed on 11 December 2019. (Supplementary Appendix 1, Figure 1).

Only primary research that concerned the fitting of lower limb prostheses in persons with a hip or knee flexion contracture was included. Titles and abstracts were assessed by two reviewers independently (JP, JHB). Inter observer-reliability was assessed using Cohen's kappa [31]. All titles and abstracts selected by at least one of the reviewers were included for full-text assessment. Papers written in another language than the reviewers were skilled in, were translated into English by persons who were able to read and write that language and English. Full-texts were assessed by two reviewers independently (JP, PUD), using the same criteria. In addition, the texts had to include severe hip or knee flexion contractures (≥25°). Any disagreement between the reviewers was discussed until consensus was reached. Next, included studies were assessed (JP, PUD) for quality using the critical appraisal checklist for case reports of the Joanna Briggs Institute [32]. This tool has eight criteria; each criterion was scored 0 if the article did not meet the criterion and 1 if it did. Disagreement in quality assessment between the reviewers was discussed until consensus was met. This manuscript follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guideline [33] (Supplementary Appendix 2).

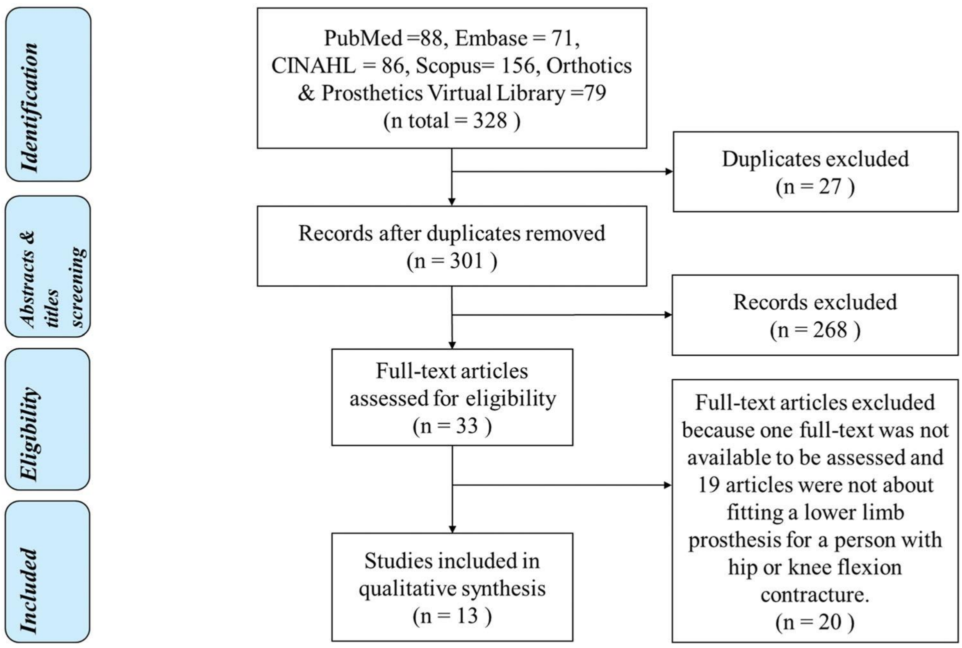

Figure 1. Flow diagram of study identification, inclusion and exclusion.

Table 1. Quality assessment results of 13 case reports based on the Joanna Briggs Institute critical appraisal checklist.

Authors, publication year (ref)	1.Were patient's demographic characteristics clearly described?	2.Was the patient's history clearly described and presented as a timeline?	3.Was the current clinical condition of the patient on presentation clearly described?	4.Were diagnostic tests or assessment methods and the results clearly described?	5.Was the intervention(s) or treatment procedure(s) clearly described?	6.Was the post-intervention clinical condition clearly described?	7.Were adverse events (harms) or unanticipated events identified and described?	8.Does the case report provide takeaway lessons?	Sum score
Trans tibial amputations:									
Beliakov 1958 [34]	0	0	0	0	1	0	1	1	3
Alexander et al., 1965 [35]	1	1	1	0	1	1	0	1	6
Ruskin et al., 1970 [36]	1	1	1	0	1	0	0	1	5
Pennell et al., 1973 [37]	1	1	1	0	1	1	1	1	7
Titner 1973 [38]	1	1	1	0	1	1	0	1	6
Gajsak 1977 [39]	0	0	0	0	1	0	0	1	2
Bannister 1978 [40]	0	0	0	0	1	0	0	1	2
Alexander 1980 [41]	1	1	1	0	1	0	0	1	5
Hays et al., 1992 [42]	1	1	1	0	1	1	1	1	7
Kim et al., 2017 [43]	1	1	1	1	1	1	0	1	7
Trans femoral amputations:									
Freed 1962 [44]	1	1	1	0	1	0	0	1	5
Lippmann 1967 [45]	1	1	1	0	1	1	1	1	7
Biedermann 1976 [46]	1	1	0	0	1	0	0	1	4

Ref: reference; TT: transtibial; TF: transfemoral; 0: study does not meet the criterion; 1: study meets the criterion.

Results

In total, 301 titles and abstracts were screened, and 33 full-texts were included for full-text selection (Inter observer agreement = 86%, kappa = 0.46). Besides not being a primary study and not including a human participant, 268 abstracts were excluded during screening because they concerned arthroplasties, endoprostheses, surgical techniques/experiences/options, postoperative care/treatments/complications, upper limb prostheses, and flexion angles <25° or mild contractures. After full-text selection, 13 studies published between 1958 and 2017 were included for methodological quality assessment (Inter observer agreement = 94%, kappa = 0.88) [34–46], and 20 studies were excluded [9,47–65]. Studies translated into English included three studies written in Russian [34,54,65], and 3 studies written in Dutch [51], Croatian [39], and Polish [56], respectively. The quality sum scores ranged from two to seven (Table 1). Studies concerning TT prostheses are presented first and in chronological order.

Transtibial prosthetic designs for persons with a severe knee flexion contracture

Ten studies reported on TT prostheses in persons with knee flexion contractures (Table 2). Prostheses designs allowed for the fitting of a prosthesis in persons with a knee contracture up to 90°. Body weight was transferred from the residual limb via a socket (Figure 2(A–C)) or a kneeling platform or bearer (Figure 3(A,B)) to the ground by means of a crutch (Figure 2(A)), sidebars with knee hinges (Figures 2(B) and 3(B)) or a shank and a foot (Figure 2(C)). Suspensions used were self-suspension by belts or Velcro straps (Figures 2(A) and 3 (A,B)), a thigh corset (Figure 2(B)), or a socket trimline above the femoral condyles (Figure 2(C)). Some designs enabled adjustment of socket angles once the contracture improved (Figure 2(A)).

For TT prostheses with sidebars (Figure 2(B)), the knee hinge joint was optional. If used, it can be locked or unlocked depending on the person's ability to control the knee joint [40]. An extra joint can be added for sitting [42].

Transfemoral prosthetic designs for persons with a severe hip flexion contracture

Five studies reported about the fitting of TF prostheses (Table 2). One case reported on a bilateral amputation (TT and TF) [35,41]. Similar to TT prostheses, TF prostheses consisted of a socket, knee, shank, and foot. In some cases, an extra joint was added underneath the socket to increase range of flexion during sitting [35,44] (Figure 4).

Aesthetic considerations regarding TT and TF prostheses for severe flexion contractures

When sitting, a bent prosthesis sticks out [35,42,44] (Figure 5(A–C)). An extra joint added underneath the concerned joints helps to increase range of motion and cosmesis [35,42,44] (Figure 5(D,E)). This extra knee joint, attached underneath the socket of a person with a bilateral TT with a 45° knee flexion contracture was illustrated recently [66]. In a person with a TF amputation who had a hip flexion contracture, a similar technique was used by adding an extra hinge connecting the socket and the knee joint or another prosthetic knee joint underneath the TF socket [35] (Figure 5(B)). The socket also sticks out when standing and walking. The extent to which the socket sticks out depends on the flexion contracture angle and the length of the residual limb

Table 2. Summary of prostheses designs and fitting results.

Authors, publication year (ref)	Cases described	Prostheses characteristics and contracture treatment	Fitting result
Transtibial amputation:			
Beliakov 1958 [34]	Forty- nine persons with a TT amputation with a knee flexion contracture ≤ 90°. Residual limb length ranged from 5 to 20 cm.	A TT leather socket was attached with a crutch via a hinge. The foot could be fitted to the end of the crutch (Figure 2(A)). At the back of the thigh part a belt attached the tibial part, holding the residual limb in the contracture angle. The belt length could be adjusted. A scale attached to the hinge showed the knee angle. The prosthesis should be used throughout the day with a break of 1 to 2 hours.	The best results were observed when fitting was combined with physiotherapy and other treatment methods such as therapeutic exercises, massage, a night splint. Users did not report pain. Range of motion after the prosthesis use was not reported.
Alexander et al., 1965 [35]	A 59-year-old male with a right TF and a left TT amputation, 60° hip flexion contracture on both sides and left 90°knee flexion contracture.	Prior to prosthesis fitting, manual stretching and pulleys failed to reduce the contracture. Release of the contracture by surgery was not chosen due to impaired local circulation. Temporary prostheses, made of a plaster of Paris socket and wooden shank, were given for training. A definitive TT socket was made of moulded leather with a thigh corset and fastened by Velcro straps. Metal sidebars with drop ring lock hinges were used to attach the TT socket with a shank and a conventional foot (Figure 2(B)). TF definitive socket was made out of wood and set at a 60° hip flexion. The sidebars with hinges locks attached the socket to the wooden distal thigh section. The locks could be manually unlocked when seated (Figure 4). Other prosthetic components included a Bock knee with friction lock, a pelvic band, and a single-axis foot. No details of other contracture treatments were given after prosthesis fitting.	After he was able to ambulate in parallel bars and a walker, definitive prostheses were made.
Ruskin et al., 1970 [36]	A 73-year-old male with a TT amputation, 30° hip and 60° knee flexion contractures.	After intensive physiotherapy (no details of the therapy), the hip flexion contracture was reduced to 10°, but the knee flexion contracture remained. A cushioned platform, made to carry the residual limb in 90° flexion, was attached to a crutch. The prosthesis was called a bent knee pylon (Figure 3(A)). A bent knee pylon has a pelvic belt and thigh strap for suspension. The definitive prosthesis consisted of a thigh corset and an open-end TT socket, metal sidebars with a knee lock, a shank, and a single axis foot. The open-end socket was used to avoid pressure on the residual limb. A fork strap was attached from the front of the shank to the thigh corset to aid knee extension.	He walked with a bent knee pylon using an axillary crutch. No details were reported on how long a bent knee pylon was used before the definitive prosthesis.
Pennell et al., 1973 [37]	Nine males with a TT, amputation, with a 15–40° knee flexion contracture.	Bent knee pylons were made for veterans in which a socket could not be used because of open wounds, scars, or split-thickness skin grafts over the residual limb and knee flexion contractures. The prosthesis consisted of a patellar platform connected to a crutch and suspended by a pelvic band (Figure 3(A)). Manual stretching and active range of motion exercises were mentioned parallel to the use of the bent knee pylons in some cases.	Six males gained both extension and flexion, and one gained flexion but extension was unchanged. In two males with knee joint injuries, knee range of motion decreased. A bent knee pylon was easy and cheap to make. The disadvantage is the cosmetic appearance. It is impossible to wear the bent knee pylon under clothing, and while sitting, it sticks out.
Titner 1973 [38]	A, 77-year-old male with TT amputation, 30° hip and 68° knee flexion contracture.	After 16 months of using a knee bearing crutch, the knee contracture had increased to 45°, a hip flexion contracture of 30° had developed, and hip abduction was limited to 20°. In December 1972, the knee range of motion had reduced to 0-68-73°. The prosthesis was constructed out of an ischial weight-bearing custom leather thigh corset, a patellar tendon bearing socket, and a SACH foot, with sidebars, similar to Figure 2(B) but with a knee extension aid.	He could walk with small and rapid steps with the prosthesis and knee range of motion increased 10° due to the prosthetic weight. At the time of the report, he had participated in gait training (no details of the training) for six weeks with good progress.
Gajsak 1977 [39]	An unknown number of persons with TT amputations with knee flexion contractures > 20°	The prostheses consisted of a thigh corset and a TT socket attached to metal sidebars that connect with a shank and a SACH foot (Figure 2(C)). Adjustments of the knee flexion angle could be made via the strap that attached the end of the socket with the front of the outer shank. No details of contracture treatments were given, other than prevention.	Use of the prosthesis could reduce contractures, but the authors suggested that the reduction depended on the individual's condition.
Bannister 1978 [40]	An unknown number persons with a TT amputation with knee flexion contracture ≤ 90°	Possibilities of fitting TT prostheses included a socket or a padded platform connected to a wooden stick (a peg leg) or a shank and suspended by a thigh corset, pelvic belt, or an extended peg strapped to the thigh. The knee hinge joint is optional (Figures 3 and 6). If the knee is kneeled on a platform, the prosthesis is called "a kneeling bearer" (Figure 3(B)). No details of other contracture treatments were given.	A problem of using a kneeling bearer with metal sidebars was skin damage where the corset attached to the thigh due to the incongruence between the single mechanical axis (the hinge) and the anatomical polycentric knee axis [25]. Another disadvantage of the kneeling bearer was that the person's knee always kneeled on the platform in 90°, and the available degree of the knee's range of

(*continued*)

Table 2. Continued.

Authors, publication year (ref)	Cases described	Prostheses characteristics and contracture treatment	Fitting result
			motion was not used or trained. In persons with adequate knee muscular power, the author suggested that the socket should be used instead of the kneeling bearer [25].
Alexander 1980 [41]	A male with right TF and left TT amputation with reduced hip and knee flexion contracture (a follow up on previous study, Alexander et al. 1965 [35].	When the knee flexion contracture reduced after two years of a TT and TF prosthesis use, a conventional patellar tendon bearing and Quadrilateral socket could be made. The contractures reduced despite the lack of active stretching which was intentionally minimized because contractures were believe to be irreversible.	NA
Hays et al., 1992 [42]	A 62-year-old male with TT amputation, with a 50° knee flexion contracture and residual limb length of 3 cm.	He was fitted with an endoskeletal TT prosthesis with a patellar tendon bearing socket design and a foot (Figure 2(C)). Padding made of polyurethane foam (PPT®) was added to the inner socket over the entire anterior tibial area to protect the skin breakdown. A manual locking knee joint was added underneath the socket for close-quartered sitting after a month of prosthesis use. Prior to prosthetic fitting, a percutaneous hamstring release, intensive stretching and night splint was given, which reduced the contracture (70°) with 20°. After the prosthesis was fitted, no details of physiotherapy were reported. Using the prosthesis was described as therapeutic for the contracture.	Weight-bearing was dispersed over the entire anterior portion of the residual limb, and a thigh corset. He donned and doffed the prosthesis without the need to tailor his trousers since the residual limb length was very short. After 17 months, another similar prosthesis was made due to 10° reduction in a knee flexion contracture. At the time of reporting, he had used the prosthesis for two years. He ambulated independently without other assistive devices.
Kim et al., 2017 [43]	A 53-year-old male with a TT amputation, knee flexion contracture of (44°).	The prosthesis was total contact patellar tendon-bearing socket, pylon, Iceross liner (Comfort®; Össur, United Kingdom), pin lock suspension (BK, Republic of Korea), and a hydraulic ankle-foot (Echelon®; Endolite, United Kingdom). The sockets and pylon lengths were changed when the residual limb volume changed. Alignments had been adjusted four times during the four-months study period to accommodate the changes in flexion contracture. A prosthetist also adjusted the ankle module stiffness and damping according to his feedback when the prosthetic alignment changes. Adaptive training sessions were given to a person with a TT by a physical therapist five days per week for four months to strengthen the thigh muscles, improving standing balance, walking, and movement.	After four months of adaptive training, the 30° passive range of knee extension increased (knee range = 166°. Gait speed, cadence, stride length, and single limb support of the prosthetic limb increased, and gait asymmetries between sound and prosthetic side reduced. Functional level increased from being unable to walk safely on his own to being able to walk with varying speed independently.
Trans femoral amputations:			
Freed 1962 [44]	A 43-year-old male with a TF amputation, with 25° hip flexion and 15° abduction contracture, and residual limb length of 18 cm.	The TF prosthesis consisted of Silesian bandage suspension, an Otto Bock knee, and a foot. With this prosthesis, he could not bend enough for prolonged sitting, driving an automobile, working, or participating in most recreational activities. Hinges with locks were attached between socket and thigh sections similarly to Figure 4. The lock was released by pulling a cable connected to the lock before sitting. No details of other interventions for contracture reduction were reported.	These hinges allow more flexion range of the prosthesis when seated.
Lippmann 1967 [45]	A 72-year-old male with a TF amputation, 40° hip flexion contracture. Other male is the same as reported by Alexander et al., 1965 [35].	After the transfemoral amputation, the contracture developed despite physical therapy (no details provided). The person was fitted with a TF prosthesis similar to Figure 4. No details of other contracture interventions after fitting a prosthesis were reported. The second male is described above (Alexander et al. 1965, 1980) [35,41].	At the time of discharge, he walked with Lofstrand crutches and could perform daily activities without reporting any problems. Due to a decrease in flexion contractures after approximately two years of using the prostheses, a patellar tendon bearing socket for the TT prosthesis and quadrilateral socket for the TF prosthesis could be made [41,45].
Biedermann 1976 [46]	A 60-year-old male with a TF amputation, severe hip flexion, and abduction contracture (unknown degrees but based on illustrations very likely to be more than 25 °) and a very short residual limb with scarring and splinters inside.	For 30 years, he had never worn a prosthesis. Despite the contracture. He received a trial prosthesis first, consisting of a quadrilateral socket, pelvic belt suspension, Lang knee, and Greissinger foot. Due to the very short residual limb, the plastic TF socket had a high lateral and anterior trim line. The ischial seat was cushioned to counteract a sensitive tuberosity. He used the trial prosthesis in the unfinished state and had it adjusted several times before he received the definitive prosthesis. No details of other contracture interventions after the prosthesis was given were reported.	How long the temporary prosthesis was used and which degree of hip flexion contracture was reached and when a definitive prosthesis was made was not reported.

Ref: reference; TT: transtibial; TF: transfemoral; NA: not applicable.

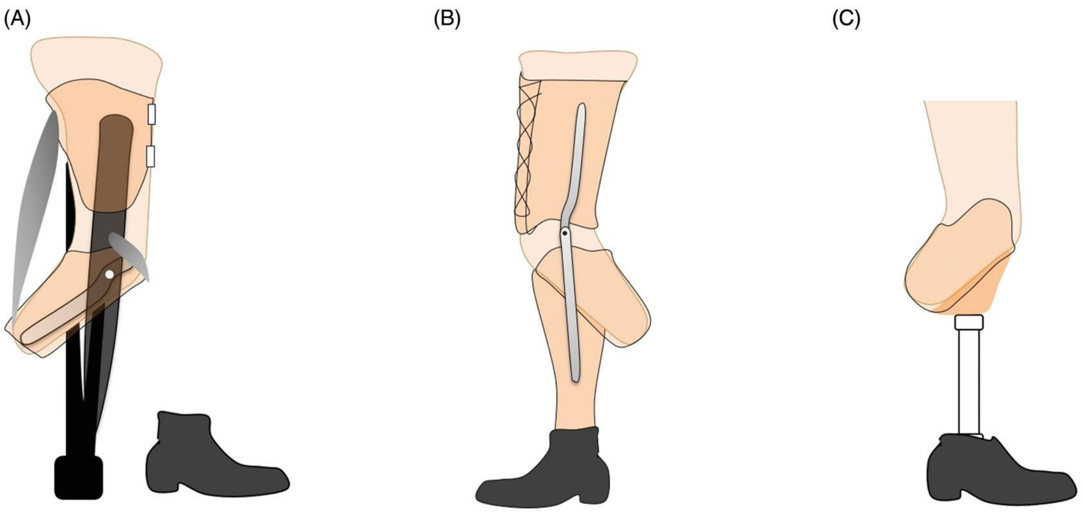

Figure 2. A shows a socket connected with a crutch; B shows a socket connected with a thigh corset, a shank, and foot by metal sidebars; C shows a transtibial socket connected with a shank and a foot.

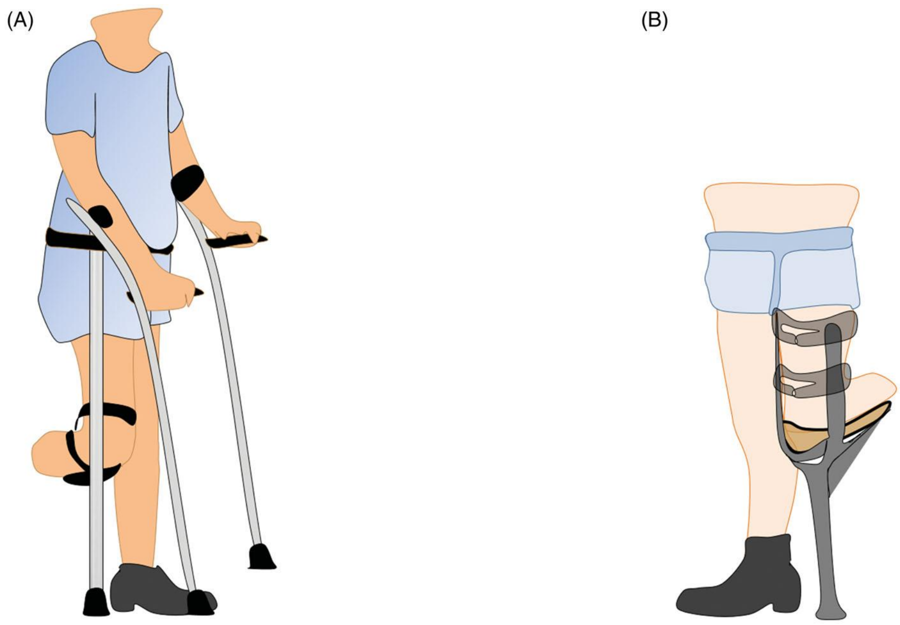

Figure 3. A shows a bent knee pylon; B shows a kneeling bearer connected with a peg leg.

(Figures 5(A–E) and 6(A–D)). A small flexion contracture can be accommodated more easily than a larger flexion contracture (Figures 6(A,B) and 7(A,B)). A short residual limb length can also be accommodated more easily and has better cosmesis than a longer residual limb (Figures 6(C,D) and 7(C,D)). This is in line with a case report on a person with a 50° knee flexion contracture and a residual limb length of 3 cm [42]. Conversely, persons with a long residual limb are more likely to have a bulky stump and may experience difficulties when getting dressed. However, a long residual limb may provide a larger lever arm for controlling a prosthesis.

Discussion

There are several possibilities for fitting a TT or TF prosthesis in persons with a severe flexion contracture of the knee, hip, or even both joints. The case reports included in this study date back to 1958. Despite the limited technology available at the time, prostheses could still be made and fitted. Generally, a TT prosthesis includes a socket, shank, and foot, which are connected to the residual limb by means of a suspension system. Similar designs were used in TF cases, but these designs employed a knee joint. Prosthetic knee joints and orthotic knee joints (sidebars and with knee hinges) are both used to connect the thigh part and the shank and to enable motion of the knee.

Alignment and biomechanics of a bent prosthesis in persons with a severe hip or knee flexion contracture

For persons with a severe flexion contracture, the socket is set to accommodate the angle of the knee or hip flexion contracture. An increase in socket flexion can create excessive pressure on the anterior proximal tibia, the patellar tendon, the patella of a TT residual limb, and the posterior aspect of a TF residual limb. For that reason, the knee and tibial crest area should be sufficiently supported within the socket, or a liner should be used to disperse the pressure over the residual limb and prevent skin breakdown [36,40,43,46]. Other solutions include using a thigh corset or quadrilateral brim in order to enable appropriate weight distribution between the tibia and thigh [36,38] or using a total contact socket [40,43].

During walking, a hip flexion contracture limits the hip extension required for walking stability. After heel strike, when the ground reaction force passes behind the knee, knee-buckling occurs, opposed by contraction of hip extensors, knee joint mechanics, and prosthesis alignment [67–69]. The voluntary control of the hip may not be possible in persons with a large hip flexion contracture [67,68], and they may compensate this by tilting the pelvis anteriorly and increasing lumbar lordosis [70]. However, none of the included case studies reported on this mechanism. In some persons, knee hinges with a locking mechanism were used to ensure knee stability [35].

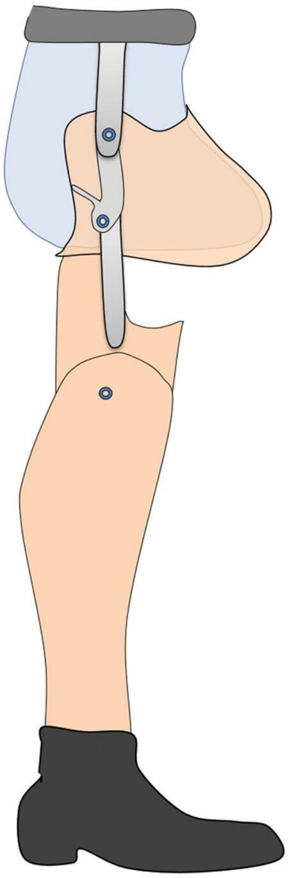

Figure 4. A bent transfemoral socket attached to the wooden shank via the sidebars with an extra joint allowing more flexion when seated.

Persons with both hip and knee flexion contractures may not be able to stabilize the knee sufficiently using the knee or hip muscles. In studies that included persons with both hip and knee contractures, knee extension aids were added to the prosthesis [36,38]. In persons with severe hip and knee flexion contractures, anterior trunk bending occurs if the person is standing and gait aids (crutches) need to be provided for support [38]. Anterior trunk bending may increase knee stability and the crutches enable weight sharing.

Persons with a transfemoral amputation but without a contracture demonstrated restrictions in hip motions, in which an amputated hip flexes and extends less [71,72]. This effect did not only limit their ability to control the prosthetic knee during early stance, but also reduced knee flexion during swing. The prosthesis could be shortened to facilitate toe clearance [71]. However, a study showed that a shorter prosthetic side (mean $=1.1$ cm (SD $=$ 0.5) increased postural and gait asymmetries, and it may be associated with impaired balance and back pain [71].

Contracture causes gait asymmetries [18,19,43,73], which are already higher in amputees compared with able-bodied persons (23% force asymmetry in persons with an unilateral lower limb amputation and 10% in able-bodied persons [17]). In the long term, greater force on the intact limb may lead to degeneration of weight-bearing joints and joint pain [17]. Lower loading on the amputated limb may lead to osteopenia and subsequently, osteoporosis [17]. A simulation study suggested that persons with a transtibial amputation with 10% loss of muscle strength require compensation from other muscles to minimize gait deviation, resulting in a higher metabolic cost [74]. For those reasons, persons with a severe hip or knee contracture will likely have an increase in gait deviations, require more energy to walk with the bent prosthesis, and have a higher risk of knee and/or back problems.

Therefore, it is essential to consider exercises, stretching, splinting, or other contracture treatments to relieve the knee flexion contracture in addition to the prosthesis use. In the reports about a bent knee pylon or kneeling bearer, the knee was held in 90° flexion during walking, but there was still a reduction in flexion contracture [37]. Although they are easy to fabricate and cost-effective [37], in some cases the knee flexion contracture increased after the use of a

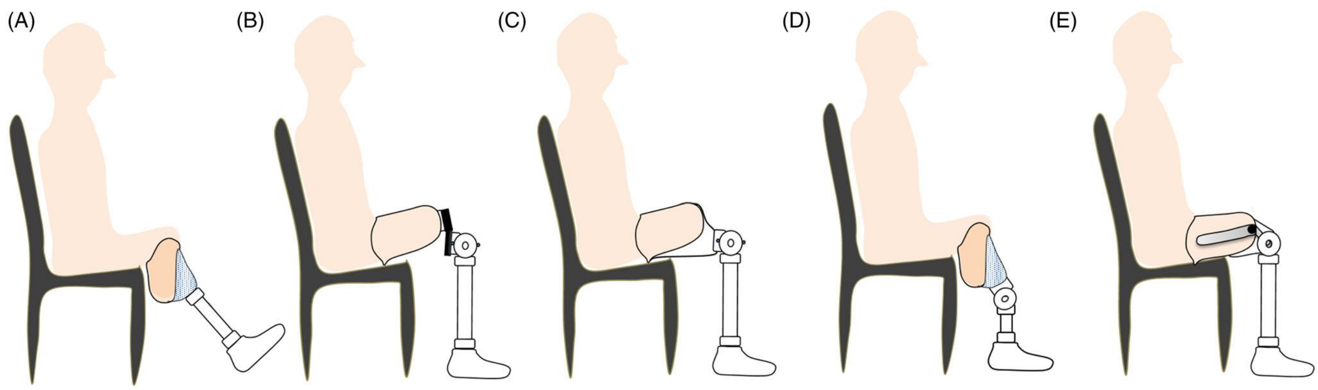

Figure 5. A shows a transtibial amputee sitting with a bent knee prosthesis without an extra joint; B shows a transfemoral amputee sitting with a bent hip prosthesis with a flexion contracture plate; C shows compensation material to offset the socket; D and E show transtibial and transfemoral amputees with an extra joint underneath the socket to increase the seating cosmetic.

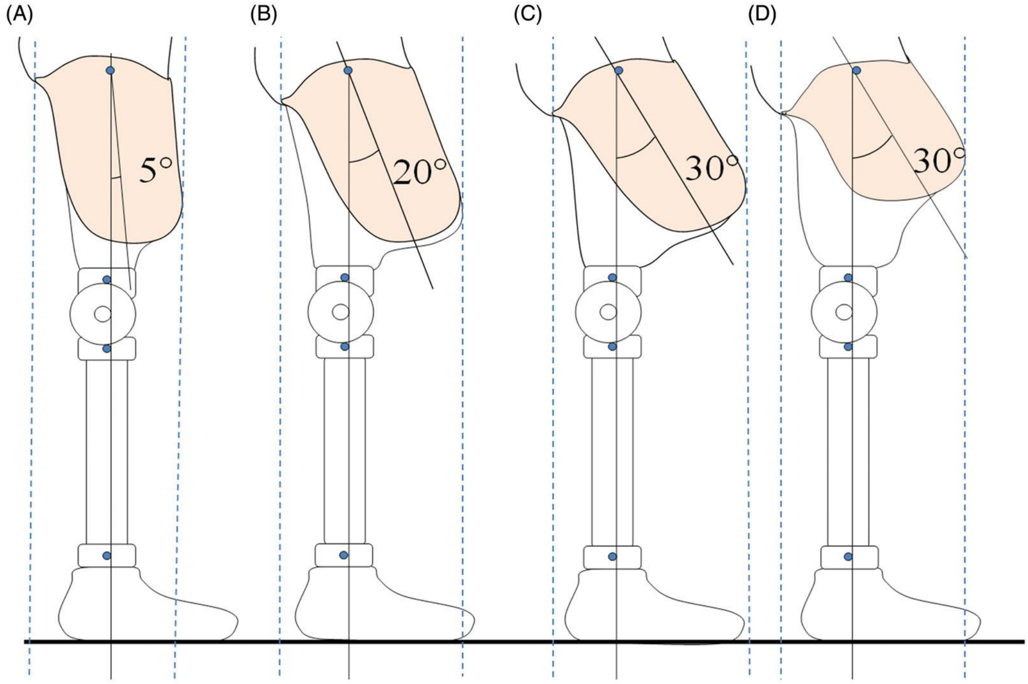

Figure 6. shows different degrees of transtibial socket flexion and path of the weight line dropping from mid socket and passing through the ankle. The distance between the 2 dotted lines shows the bulkiness of the socket in which the greatest distance is the bulkiest prosthesis. For the same residual limb length, the bulkiest is the most flexed socket (C > B > A), and for the same angle, it is the longer residual limb length (C > D).

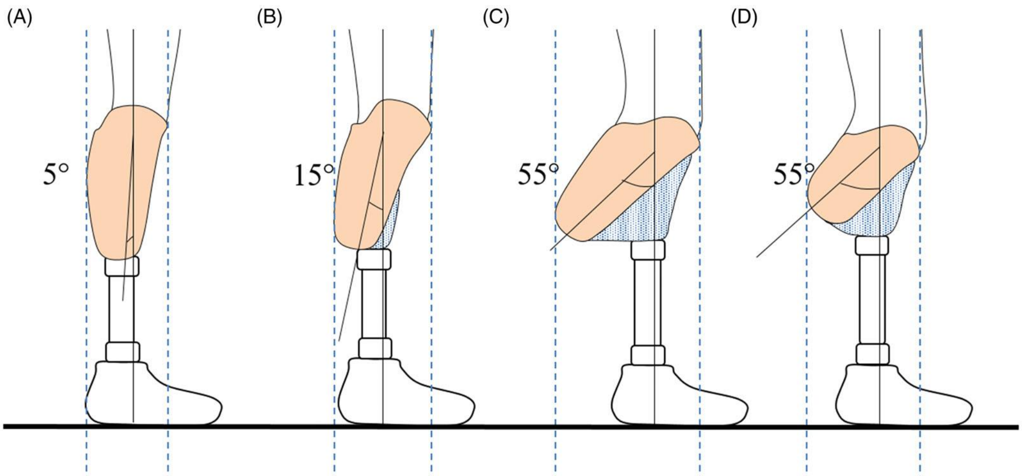

Figure 7. shows different degrees of transfemoral socket flexion and path of the weight line dropping from trochanter, falling in front of the knee and passing through the ankle. The distance between the two dotted lines shows the bulkiness of the socket in which the greatest distance is the bulkiest prosthesis. For the same residual limb length, most bulkiness occurs in the most flexed socket (C > B > A) and, for the same angle, it occurs in the longer residual limb (C > D).

bent knee pylon [37,38]. Hence, no matter what type of prosthetic device is fitted, the receivers should be trained in stretching and exercising their limbs. For example, adaptive training sessions were given to a person with a TT amputation with a knee flexion contracture [43]. After four months of training, improvements were found in the knee's range of motion, the level of functioning, and the person's quality of life [43].

When flexion contracture changes, the prosthesis should be realigned [43]. Before dynamic alignment, which takes place during walking, a prosthesis is set on the bench first (bench alignment). For stability, prosthetic components are set in such a way that a vertical reference line falls from mid socket to anterior of the ankle centre of a SACH foot [75]. Likewise, in a TF prosthesis, the weight line dropping from trochanter should fall in front of the knee and pass through the ankle [67–69] (Figures 6 and 7). Determining appropriate weight bearing from the bent socket to a foot can be challenging.

In some cases, a temporary or trial prosthesis was fitted first; once the contracture was reduced or gait improved, the definitive prosthesis was made [41,45]. Some prosthetic components such as socket or foot connectors/adaptors allow some degree of alignment adjustment [43]. Moreover, the fabrication technique can be facilitated by using a socket connector with a preset flexion angle and offset length to reduce the time and labour needed for fabrication [76]. Different offset lengths and preset flexion angles are available, depending on the manufacturer [76–78]. If the flexion plate is designed for fabricating a TF prosthesis with a hip flexion contracture (Figure 5(B)), the plate can be flipped and used for the TT prosthesis fabrication as well [78].

Although it is possible to fit a prosthesis in persons with a severe flexion contracture, prevention of contractures is important. When occurred, contractures should be treated prior to, parallel to, and after prosthesis fitting since a flexion contracture is a predictor of unsuccessful rehabilitation [79].

Limitations of the study

Most case studies used were published before the year 2000, which means the prosthetic materials used may not represent current technologies. Although case reports report on novelties and offer educational value, their generalizability is limited [80]. Reporting bias may be present because cases may have been selectively reported based on successful fitting results [80]. Due to the study design, combining the results of studies was not possible. Three studies [34,39,40] had very low quality scores; they only met two or three out of the eight checklist criteria. Outcomes were generally described as "a stable gait" or "able to participate in activities" and details of the gait characteristics in each walking phase were not provided. Many studies did not report on adverse effects of the use of bent prostheses. Only one study reported on how the alignment of the bent TT prosthesis affected kinematics and kinetics of walking [43]. In some of the cases described, a decrease in the flexion contracture was found, probably due to the prosthesis fit, exercise training and, most importantly, the person's compliance. However, only one study reported in detail about the types of therapy provided together with the use of prosthesis [43]. Lastly, the protocol of this review study was not registered prior to the study.

Conclusions

Fitting a prosthesis in a person with a flexion contracture $\geq 25^\circ$ can be challenging, but it is certainly possible, as this study has illustrated. Even in case of severe contractures and highly complex cases, fitting a prosthesis remains possible. However, the level of evidence to support certain choices regarding prosthetic adaptations remains low.

In their decision-making process, clinicians should consider the person's motivation to walk as a more important determining factor than a flexion contracture $\geq 25^\circ$. A strong motivation to walk or participate in activities has helped prosthesis users overcome esthetic issues and gait deviations. Because a severe hip or knee contracture can hinder walking and lead to other subsequent problems, interventions to reduce the contracture should be employed along with the use of bent prostheses.

Disclosure statement

The authors report no conflicts of interest.

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