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What is the optimal femur length in a trans-femoral amputation? A mixed method study: Scoping review, expert opinions and biomechanical analysis

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A B S T R A C T

In the Netherlands, 34% of all major lower limb amputations are at the trans-femoral level. Information and consensus is lacking on the optimal length of the residual length of the femur following the amputation.

Hypothesis: We hypothesize that femur length should be kept as long as possible considering construction of the knee unit beneath the socket. Evaluation of the hypothesis: Providing a comprehensive overview of considerations involved in choosing the optimal femur length in a trans-femoral amputation. This explorative study includes a scoping review, interviews with surgeons and certified prosthetists (expert opinions), and a biomechanical analysis. The scoping review resulted in 396 articles reduced to 6 articles after reviewing. All articles, the outcomes of the interviews with the experts and the biomechanical analysis suggest that it is important to maximize the length of the residual femur.

Conclusion: A longer residual limb length is more beneficial for gait parameters, prevention of contractures, and providing lever arm. Furthermore, the femur should be transected sufficiently proximal to the medial knee joint in order to fit a prosthetic knee at the same height as the contralateral knee. However, it remains unclear what the minimum length of the residual limb should be. This will require further research.

Background

In the Netherlands 660 amputations at the trans-femoral level are performed annually [1,2]. There is, however, a lack of knowledge on the optimal residual limb length in persons with a trans-femoral amputation (TFA) pertaining to functional outcomes. With regard to the residual limb length, the Dutch evidence based guidelines for TFA are as follows: “The aim should be to maintain the maximum length possible. However, in order to install an external knee prosthesis and to maintain a thigh of equal length to the contralateral side, amputation should occur at least 10 cm proximal to the medial knee joint space” [1].This aim is based on expert knowledge.

The residual limb length can play a role in the development of atrophy of the muscles of the hip joint. When the residual limb is too short, the remaining muscles are likely to atrophy [3]. Less muscle volume leads to altered muscle forces and reduced control over the prosthesis [4,5]. A shorter residual limb also increases the risk of development of contractures. After a TFA, an abduction contracture may result due to atrophy or loss of insertion of the adductor magnus [3,6]. A flexion contracture of the hip is also commonly found in TFA patients [6,7]. Contractures can lead to a wide-based gait, which is more energy consuming. It is therefore important to preserve as much femoral length as possible.

There is, however, an absolute limit to the maximum residual limb length. A cosmetic goal of the prosthesis is to maintain an equal length between the residual limb and the contralateral limb. Sufficient distal space is necessary to fit all the components of the prosthesis and to provide good alignment [1].

Despite the information mentioned above, there is, at present, no comprehensive overview of considerations involved in choosing the optimal TFA level. Surgeons stress that such an overview is needed in order to guide them in their decision-making process and assist them to perform their amputations in an optimal manner.

Hypothesis

In case of an expected TFA one should consider to leave the femur length as long as possible although keeping in mind the possibility to have enough space to build in an external? prosthetic knee.

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Table 1
Search terms in the databases.

Database	Search terms
Embase	('Trans femoral amput*' OR 'Transfemoral amput*' OR 'above knee amput*' OR 'aboveknee amput*' OR 'upper leg amput*' OR 'upper-leg amput*'):ab, ti AND (Length OR size* OR 'adductor magnus muscle' OR biomechanic*):ab, ti
PEDro	'Transfemoral amputation'
PsycINFO	TX (("Trans femor*" OR "Transfemor*" OR "above knee" OR "upper leg") N4 amput*) AND TX (Length OR size* OR "adductor magnus muscle" OR biomechanic*)
PubMed	"(Trans femoral amput*[tiab] OR Trans-femoral amput* OR above knee amput*[tiab] OR above-knee amput* OR upper leg amput*[tiab] OR upper-leg amput*) AND (Length[tiab] OR size*[tiab] OR adductor magnus muscle[tiab] OR biomechanic*[tiab])".

Methods

This explorative study used a mixed-method design, including a scoping review, interviews with experts, and a biomechanical analysis.

Systematic review

A literature search was conducted in April 2018 using PubMed, Embase, PsycINFO, and PEDro. In the search, no Medical Subject Headings (MeSH) were used; the MeSHterm "Amputation" was not specific enough since this study concerns only TFAs. Multiple search terms were used instead. Table 1 provides an overview of the search terms.

Titles and abstracts of the retrieved articles were reviewed. No restrictions were made regarding publication year. Articles were included if they met the following criteria: 1) the full text was published in English, German, or Dutch and 2) the article addressed femoral length after TFA and its functional consequences. Articles were excluded if they were 1) animal studies, 2) case studies, 3) editorials, or 4) letters.

Next, the full text of the selected articles was assessed to decide whether the articles were eligible for inclusion. Abstracts and full texts were independently reviewed by two assessors (MdB and JG) for reasons of reliability. In addition, the reference lists of the included articles were searched for additional relevant studies.

Expert opinions

In order to collect relevant expert opinions, 4 surgeons who perform TFAs (all with more than 10 years of experience) and 2 certified prosthetists (both with more than 20 years of experience) were interviewed by one of the researchers (MdB). The interviews were voice recorded with permission of the experts.

The audio recordings were transcribed verbatim and coded using ATLAS.ti 6.2 (Scientific Software Development GmbH).

Biomechanical analysis

A biomechanical analysis was performed to determine the effects of femoral length on the biomechanical functions of the residual limb. A force analysis was made in the frontal plane of the residual limb with a prosthesis.

Results

Scoping review

The literature search resulted in 396 articles. Seven articles were selected for full text analysis (Cohen's kappa = 0.92). One article was excluded after full text analysis because it did not meet the inclusion criteria. Inter-rater agreement was excellent (Cohen's kappa = 1.0). No additional articles were included after a reference check, resulting in total of 6 included articles. Fig. 1 shows a flowchart of the inclusion process. Table 2 presents an overview of the included articles.

Considerations regarding TFA levels found in the articles were divided into 4 categories: abduction contracture, flexion contracture, lever arm, and gait.

Abduction contracture

Jaegers et al. found abduction contractures in persons with a TFA with residual limb lengths ranging from 10.5 to 27.5 cm.

An abduction contracture occurs when the abductor muscles provide a greater moment arm than the adduction muscles. Gottschalk and Still [8] stated that the adductor magnus is the best muscle to hold the femur in a neutral position because of the greater length of its lever arm. Furthermore, the large physiological cross-sectional area and volume of the adductor magnus allow for the development of a larger adduction moment [8].

Since the expanded base of the adductor magnus attaches to the femur, this muscle will be affected proportionally to a higher level of amputation. When the distal third of the femur is amputated, the adductor magnus loses 70% of its effective moment arm [6,7]. The abductor muscles will still keep their moment arm, however, and thus the remaining abduction moment will pull the femur into an abduction contracture against the decreased adduction moment [3,6–8].

Flexion contracture

The hip extensor muscles shrink in volume after TFA. The strongest hip extensor, the gluteus maximus, inserts into the iliotibial tract. When the iliotibial tract is not firmly reattached after TFA, the extension moment will decrease even further.

The iliopsoas, the strongest hip flexor muscle, stays intact after TFA. A lack of activity and immobilization, however, cause this muscle to atrophy. The degree of atrophy increases proportionally to a higher level of amputation. Consequently, the flexion moment of the iliopsoas will be greater than the extension moment of the antagonist hip extensor (hamstrings), resulting in a flexion contracture [3,7].

Lever arm

A longer femoral length implies a longer lever arm, which is beneficial for transferring forces to and from the prosthesis. Furthermore, a longer lever arm will provide more balance when the patient is sitting without wearing the prosthesis [6,8,11].

Gait

Baum et al. [9] studied the effect of the so-called limb ratio on several temporal-spatial parameters. The limb ratio is the percentage of residual femoral length relative to intact femoral length. The limb ratios of the persons with a TFA included in their study varied from 57% to 100%. A limb ratio of 100% indicates a knee disarticulation. No significant correlations were found between limb ratio and temporal-spatial parameters. As long as the residual femoral length is greater than 57% of the intact length, there is little impact on gait parameters [9].

Bell et al. [10] found that persons with a longer residual limb after a TFA had a significantly higher self-selected walking speed. The limb ratio in this group ranged from 57% to 77%, whereas the limb ratio in the group with shorter residual limbs varied from 21% to 56%. Furthermore, a shorter residual limb ratio resulted in increased pelvic motion and trunk excursion during walking. The femoral abduction angle had no influence on the temporal-spatial and kinematic

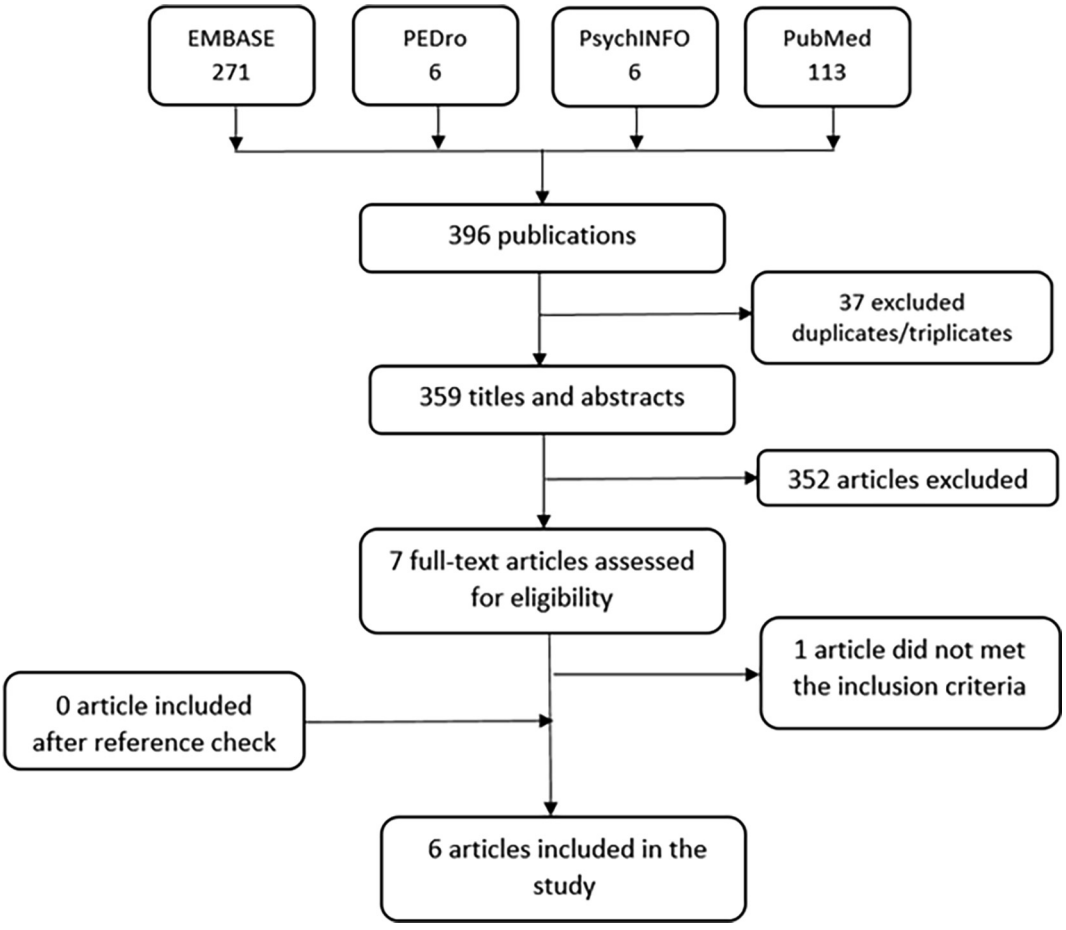

Fig. 1. Flowchart of the literature search.

parameters. On the other hand, a shorter residual limb was linked to more abduction of the femur [10].

Expert opinions

Four surgeons and two prosthetists were interviewed on their opinions on TFA. Characteristics of the experts are shown in Table 3.

All surgeons unanimously stated that they follow the Dutch guidelines for TFA when determining the level of amputation [1]. This level depends on the specific situation of the patient. Nevertheless, all interviewed surgeons try to preserve as much length of the femur as possible.

"*I always try to make the stump as long as possible, and I think that this [the stump] can never be too long*" [S3]

The majority of the surgeons mentioned that the level of amputation is a compromise in terms of being able to cover the end of the femur with sufficient muscle tissue on the one hand and preserving sufficient femoral length on the other hand. This means the femur is shortened when there is less remaining muscle tissue.

Two surgeons, S1 and S3, mentioned a specific amputation level: Hunter's canal. At this level, the adductor magnus is not attached to the femur, which means that after the amputation the functioning of the proximal part of the adductor magnus is preserved. The surgeons concerned, believe this will help prevent abduction contractures.

"*The most ideal level to amputate is approximately at the level of Hunter's canal, encompassing about two-thirds of femoral length.*" [S1]

Abduction and flexion contractures were also mentioned by surgeon S4, who stated that a shorter residual limb can lead to contractures because the antagonist muscles can exert less force. The surgeon tries to find a balance in the way the muscles are attached to each other to compensate for this lack of force. Surgeon S4 also mentioned there is a minimum to the residual limb length. Hip disarticulation is preferable to a very short residual limb in a flexion and abduction position. The prosthetists also agreed that a neutral position of the residual limb is important. It is more difficult to provide a well-fitting prosthesis to a person with limb contractures.

An argument in favor of a longer residual limb is that it results in a longer lever arm, which provides better control over the prosthesis. In addition, there is also a better distribution of pressure over the surface of the residual limb. Lower pressure is preferable since high pressure can lead to blood circulation problems. Furthermore, prosthetist P2 mentioned that the residual limb should always be longer than it is wide; otherwise, the socket might rotate around the residual limb, which in that case has an almost spherical shape. This makes control over the prosthesis more difficult for the patient and may even result in an abnormal gait in terms of, for instance, trunk motion.

To produce a prosthesis for a person with a TFA, a prosthetist needs a liner, a socket, an adapter and a prosthetic knee. Prosthetist P1 said that the socket and liner require 2 cm of femoral length, the adapter 2 cm, and the prosthetic knee 7 cm. The prosthetic knee lengths are not dependent on the person's height and include some space for improving the cosmetic appearance of the prosthesis. Consequently, to ensure the prosthetic knee is fitted at the same height as the contralateral knee, the amputation level needs to be at least 11 cm proximal to the medial knee joint.

Table 2
Overview of the included studies.

Author and publication year	Conclusion article	Abduction contracture	Flexion contracture	Lever arm	Gait	Study design
Gottschalk and Stills [8]	Longer residual limb length is preferable.	1) The adductor magnus has a major mechanical advantage in holding the thigh in its normal anatomical position. 2) The physiological cross sectional area of the adductor magnus is three to four times bigger than the adductor longus and brevis. 3) The most medial part of the adductor magnus makes the greatest contribution to the adduction moment.		Loss of the distal third of the adductor magnus results in a 70% loss of the effective moment arm of the muscle.		Cadaver study
Jaegers et al. [3]	Longer residual limb length is preferable.	1) Decreasing residual limb length is related to the amount of atrophy of the hip muscles. 2) Persons with a short or medium residual limb length show an abduction contracture.	1) Decreasing residual limb length is related to the amount of atrophy of the hip muscles. 2) Flexion contracture occurs when the extension torque of the hamstrings and gluteus maximus decreases and flexion torque of the iliopsoas remains. Fixation of the iliotibial tract is important to remain extension torque of the gluteus maximus.			Cadaver study
Baum et al. [9]	Limb ratio should be minimal 57%.				1) No significant correlation between limb ratio and velocity, cadence, prosthetic limb step length, intact limb step length, prosthetic limb stance time, intact limb stance time and step width. 2) No significant correlation between limb ratio and affected peak hip power, unaffected peak hip power, affected peak ankle power and unaffected peak ankle power. 3) Femoral residual limb ratio's ranged from 57% to 100%. No effects found on gait parameters when the residual femoral limb length is greater than 57% of the intact limb.	Cohort study
Baumgartner [7]	Longer residual limb length is preferable.	Fixation of the muscles results in less abduction contracture. The m. gluteus medius and m. gluteus minimus pull the residual limb into abduction.	Fixation of the muscles results in less flexion contracture. The m. iliopsoas pulls the residual stump into flexion.	Amputation through the femur should be at the most distal level possible. It is important to make a resilient and long residual limb. A longer residual limb provides a better lever arm.		Expert opinion
Bell et al. [10]	Bigger limb ratio is preferable.				1) Significant difference in self-selected walking velocity between the residual limb ratio groups. The cohort with longer residual limbs walked faster. 2) No significant differences between the residual limb ratio or the femoral abduction angle groups in the other metabolic cost parameters.	Cohort study
Gottschalk [6]	Longer residual limb length is preferable.	Amputation of the distal third of the femur results in an abducted femur. This because there is a 70% loss of adduction power.		A longer residual limb provides a longer lever arm		Expert opinion

Table 3
Characteristics of the interviewees.

Expert	Gender	Age (years)	Function	Experience (years)
S1	Male	64	Vascular surgeon	31
S2	Male	42	Vascular surgeon	14
S3	Male	45	Trauma surgeon	17
S4	Male	49	Orthopaedic surgeon	13
P1	Male	58	Prosthetist	35
P2	Male	51	Prosthetist	28

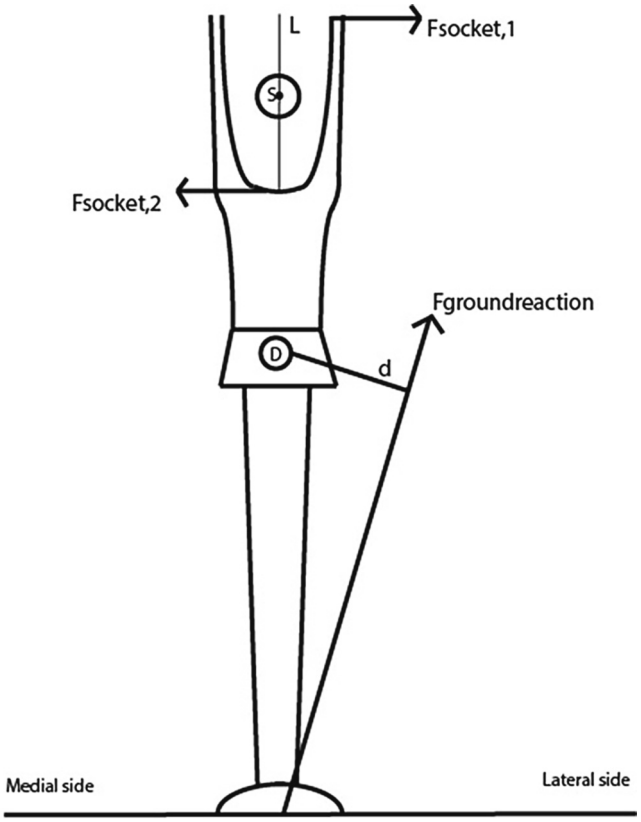

Fig. 2a. Longer residual limb length and smaller forces from residual limb onto prosthesis socket. $F_{groundreaction}$ = ground reaction force, F_{socket} = force from residual limb onto prosthesis socket, $F_{bodyweight}$ = force from the mass of the person, AB = residual limb length. AC = length of the residual limb and the prosthesis.

Biomechanical analysis

The literature has shown that a longer femoral length is beneficial for transferring forces to and from the prosthesis, since a longer length generally means there are more distal muscle attachments, which result in a longer lever arm [3,6–8]. The biomechanical analysis below explains why a longer lever arm is beneficial.

When a person with a TFA stands on a prosthesis, a force is exerted by the ground onto the prosthesis. This force, called the ground reaction force, is displayed in Fig. 2a as $F_{groundreaction.}$ A force can cause a rotation when the force vector does not pass through the center of rotation, but has a lever arm distance relative to that center. A lever arm is the perpendicular distance from the action line of the force to the rotation point. The product of lever arm and force magnitude is called moment. In Fig. 2a, the $F_{groundreaction}$ is counteracted by a force of the amputee, $F_{bodyweight}$ and a force of the residual limb, transferred through the socket.

This transferred force is divided into 2 force components and is exerted onto the pressure points of the socket in the medial distal and lateral proximal parts of the residual limb. The two components of the force are displayed in Fig. 2a as $F_{socket,1}$ and $F_{socket,2.}$

The sum of forces is equal to zero. Since the socket forces have no vertical component and $F_{bodyweight}$ has no horizontal component the equilibriums are as following:

$$F_{groundreaction,y} + F_{bodyweight,y} = 0 \text{ and thus } F_{groundreaction,y} = -F_{bodyweight,y}$$

$$F_{groundreaction,x} + F_{bodyweight,x} + F_{socket1,x} + F_{socket2,x} = 0$$

The magnitude of the forces are unknown. The magnitude of $F_{groundreaction,x}$ and $F_{bodyweight,x}$ are dependent of the weight of the patient. The magnitude of the socket forces can be determined with the Sum of Moments in Equilibrium principle. Sum of torques around any arbitrary axis is equal to zero:

Point A is chosen as origin

$$M_{groundreaction,x} + M_{socket1,x} + M_{socket2,x} = 0$$

$$(F_{groundreaction,x} \cdot CA) + (F_{socket1,x} \cdot 0) + (F_{socket2,x} \cdot AB) = 0$$

$$\text{Fsocket2, x} = \frac{-(\text{Fgroundreaction, x} \bullet |CA|)}{|AB|}$$

Since the sum of all forces is equal to zero, $F_{socket1,x}$ can also be determined:

$$F_{socket1,x} = -F_{socket2,x} - F_{groundreaction,x} - F_{bodyweight,x}$$

$$\text{Fsocket1, x} = -\frac{-(\text{Fgroundreaction, x} \bullet |CA|)}{|AB|} - \text{Fgroundreaction, x} - 0$$

$$\text{Fsocket1, x} = \text{Fgroundreaction, x}\left(\frac{|CA|}{|AB|} - 1\right)$$

Any number can be filled in into the equations to show the magnitude of $F_{socket,1}$ and $F_{socket,2.}$

The Magnitude of $F_{groundreaction}$ is a constant value. However, residual limb length may vary in the model:

Long stump: CA = 1, CB = 0.8 and AB = 0.2 → $F_{socket1,x} = 4$ and F socket2,x = 5

Short stump: CA = 1, CB = 0.9 and AB = 0.1 → $F_{socket1,x} = 9$ and $F_{socket2,x} = 10$

The equations show a relation between the magnitude of socket forces and the residual limb length. When the residual limb length decreases, the magnitude of the forces increases. Fig. 2b displays the same situation as Fig. 2a, but with a smaller length L. Hence, $F_{socket\ ,1}$ and $F_{socket,2}$ are larger compared to Fig. 2a.

In conclusion, the forces from the residual limb onto the socket increase as the residual limb length decreases. These forces exert more pressure on the soft tissue, thereby reducing blood flow in this tissue.

Discussion

The aim of this study was to evaluate our hypothesis that the femur length in case of an trans-femoral amputation should be kept as long as possible. We tried to evaluate this by providing a comprehensive overview of considerations involved in choosing the optimal TFA level. The literature demonstrated that a longer residual limb is more beneficial for the prevention of abduction and flexion contractures. An abduction contracture results from an imbalance between the abduction and adduction moment. This imbalance is caused by the partial loss of the adductor magnus after the amputation. At present, there is no consensus on the level of amputation that might lead to this imbalance.

The dissection of the muscles leads to atrophy, but intact muscles can atrophy as well due to decreased innervation. A higher amputation level leads to more muscle atrophy. A longer residual limb can still result in poor functional outcomes, however, when the muscles are not stabilized and firmly attached to the femur. Good fixation is imperative, otherwise the muscles will atrophy more and can produce less force.

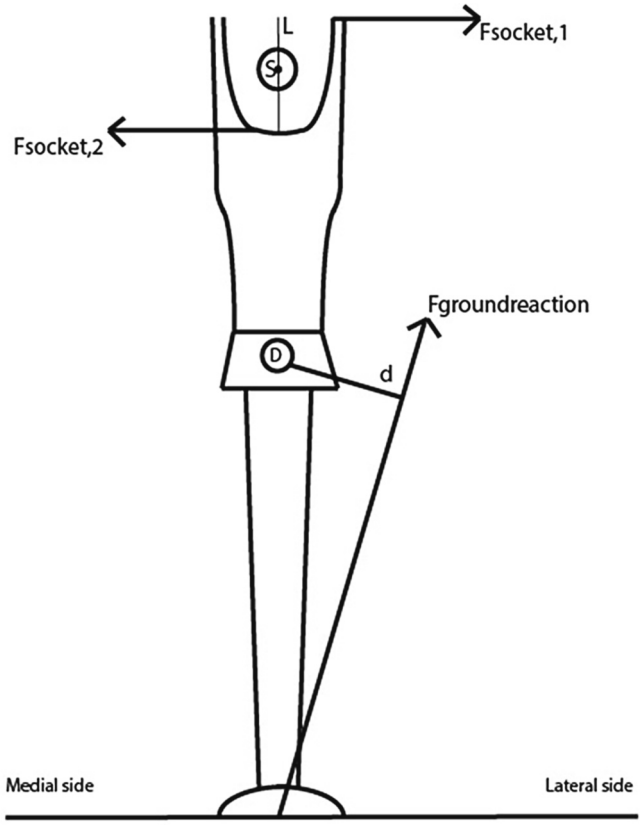

Fig. 2b. Smaller residual limb length and bigger forces from residual limb onto prosthesis socket. $F_{groundreaction}$ = ground reaction force, F_{socket} = force from residual limb onto prosthesis socket, $F_{bodyweight}$ = force from the mass of the person, AB = residual limb length. AC = length of the residual limb and the prosthesis.

Resulting from the expert opinions, the surgeons also reported a preference for a longer residual limb. Two surgeons specifically mentioned Hunter's canal (hiatus adductorius) as the optimal amputation level. The prosthetists mentioned that a longer residual limb makes it easier to fit and align the prosthesis. As a result, patients have better control over the prosthesis. If the patient wants to have the prosthesis fitted at the same height as the contralateral knee, the amputation needs to be at least 11 cm proximal to the medial knee joint. This is close to Hunter's canal, which is situated approximately 15 cm above the knee joint.

These 11 cm, however, are based on a prosthetic knee that is 7 cm long. Prosthetic knees have lengths ranging from 3.5 to 11.7 cm. Consequently, the residual femoral length needed to fit a prosthesis will vary depending on the prosthetic components used. In Appendices 1 and 2, different types of prosthetic knees and their lengths are described. At present, the design of the prosthesis is often determined during the rehabilitation process. However, if the prosthetist, surgeon, and patient were to discuss suitable prosthetic options prior to the surgery, the amputation level could be adjusted to the length needed to install the prosthesis in advance.

The 11 cm does not depend on the height of the patients. Nevertheless, the loss of 11 cm of femoral length is likely to have more impact on a shorter person than on a longer person. In the studies of Baum et al. [9] and Bell et al. [10] limb ratios were used. The limb ratio is the percentage of the residual femoral length relative to the intact femoral length. The limb ratio may therefore be a better variable for defining the optimal residual limb length and for determining the optimal level of amputation.

We like to add one comment to the expert opinions (we do not fully agree to the statement: Surgeon S4 also mentioned there is a minimum to the residual limb length. Hip disarticulation is preferable to a very short residual limb in a flexion and abduction position. The prosthetists also agreed that a neutral position of the residual limb is important. It is more difficult to provide a well-fitting prosthesis to a person with limb contractures).

> "a hip disarticulation prosthesis does not require a socket, but rather a 'prosthesis basket' which is wrapped around the pelvic area. I am under the impression that if there is no prognosis of patients' being able to walk with a hip disarticulation, then the statement of the surgeon in question holds true. But, if the aim is to provide a functional prosthesis: then I would strongly suggest to emphasize the discomfort associated with wearing a 'basket' as compared to donning of a (very) short transfemoral socket."

To our knowledge, this was the first study to perform a biomechanical analysis. The results indicate that the forces from the residual limb onto the socket increase as the residual limb length decreases. Because these forces exert pressure on the soft tissue, a longer limb length is preferable. There is also a very narrow margin between the placement of the 'anchor' under the socket and distance to the 'adaptor' of the knee-unit: slight displacement will either result in experienced instability or rigidity by patients/users at initial-contact and when initiating the transition from stance towards swing.

It remains unclear, however, what exactly constitutes the optimal residual limb length. More research is needed to determine what the optimal residual limb length or limb ratio is and how this correlates to negative consequences, such as the developsment of contractures. In the light of keeping the beneficial femur length more research should be focussed on the prosthetic knee as is also in the case for persons with a disarticulation of the knee.

Perhaps new developments in osseointegration with specially developed prosthetic knees can overcome the problem of the needed height of the knee [11]. The recently developed distal weight implant will be not a part of the solution: keeping femur length and allowing a appropriate prosthetic knee [12].

Conclusion

The results from the scoping review, interviews, and biomechanical analysis indicate that a longer residual limb length is most preferable. A longer residual limb is beneficial for gait parameters, prevention of contractures, and control over the prosthesis. In addition, the amputation level needs to be sufficiently proximal to the medial knee joint in order to fit a prosthetic knee at the same height as the contralateral knee. The exact level depends not only on the type of prosthetic knee that is used but also the method for fixating limb-socket. For example there considerable difference between the minimum needed height between the distal-socket and the knee unit when using either a) pen-lock, b) passive vacuum suspension, c) active vacuum suspension, and d) rope lock systems. Finally, it remains unclear what the minimum length of the residual limb should be and when the potential negative consequences outweigh the benefits of length preservation. These issues will require further research.

Declaration of Competing Interest

None.

Appendix 1

Knee lengths Ottobock

Type	Length
3R55	58 mm Measured with 4R41
3R106 = ST	65 mm Measured with 4R43
3R20	67 mm Measured with 4R41
3R36	67 mm Measured with 4R41
3R106pro = ST	68 mm Measured with 4R43
3R60-Pro = ST	69 mm Measured with 4R43
3R60 = ST	70 mm Measured with 4R43
3C88	74 mm Measured with 4R43
3R40	76 mm Measured with 4R41
3C86	77 mm Measured with 4R43
3R106	77 mm Measured with 4R41
3R60	78 mm Measured with 4R41
3R78	78 mm Measured with 4R41
3R60 = HD	79 mm Measured with 4R41
3R106 = HD	79 mm Measured with 4R41
Genium X3	82 mm Measured with 4R43
Genium X3 = ST	82 mm Measured with 4R43
3R106pro	82 mm Measured with 4R41
3R60-Pro = HD	82 mm Measured with 4R41
3R60-Pro	83 mm Measured with 4R41
3R15	84 mm Measured with 4R41
3R49	84 mm Measured with 4R41
3R95	84 mm Measured with 4R41
3R95 = 1	84 mm Measured with 4R41
3R90	84 mm Measured with 4R41
3R92	84 mm Measured with 4R41
3WR95	84 mm Measured with 4R41
3WR95 lock	84 mm Measured with 4R41
3C98	89 mm Measured with 4R41
3C96	92 mm Measured with 4R41
3R41	97 mm Measured with 4R41
3R93	98 mm Measured with 4R41
3R93 lock	98 mm Measured with 4R41
3R60 = KD	100 mm Measured with 4R41
3R80	116 mm Measured with 4R41
3R80 lock	116 mm Measured with 4R41
3R80 = ST	117 mm Measured with 4R41
3R80 = ST lock	117 mm Measured with 4R41

4R41 and 4R43 are adapters.

Appendix 2

Knee lengths Össur

Type	Length (mm)
Total knee	35
Balance knee	55
Mauch knee	68
Balance knee control	90
Rheo knee	90

Appendix 3. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2019.109238.

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