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The effect of prosthetic alignment on lower limb kinetics in people with a transtibial bone-anchored prosthesis: An experimental within-subject study

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ABSTRACT

Background: The alignment of a bone-anchored prosthesis has consequences for the external moments around the residual joints and implant, and these external moments can lead to serious negative long-term effects. A clear understanding of the relationship between transtibial prosthetic alignment and external joint and implant moment for bone-anchored prosthetic users is still lacking.
Research question: What is the effect of systematic frontal plane prosthetic alignment changes on lower limb external joint moments in people with a transtibial bone-anchored prosthesis?
Methods: Participants underwent gait analysis on an instrumented dual belt treadmill. Between analyses, frontal-plane alignment adjustments were made, shifting the prosthetic foot 2, 4, and 6 mm medial and lateral in relation to the residual limb. The effect of alignment changes on frontal- and sagittal plane external joint moments during the stance phase of gait were assessed at the hip, knee, and implant level, using statistical parametric mapping regression analyses.
Results: Twenty-seven unilateral transtibial bone-anchored prosthesis users were included. Alignment changes had a significant effect on external frontal plane knee and implant moments on the prosthetic side, with the largest effect at the level of the implant. Incremental medial and lateral displacements resulted in a progressive increase or decrease of the external adduction moments, respectively. Alignment changes did not significantly affect external moments around the prosthetic hip, non-prosthetic joints in the frontal plane or in any of the evaluated joints or implant in the sagittal plane.
Significance: Mediolateral foot alignment changes have a considerable effect on the frontal plane external knee and implant moments at the prosthetic side of a transtibial bone-anchored prosthesis. The findings of this study can help prosthetists to anticipate and adjust alignment changes for transtibial BAP users to minimize joint moments before issues arise.

1. Introduction

An important determinant of prosthetic functioning is alignment, the process of positioning the prosthetic components relative to the residual limb. Incorrect prosthetic alignment is a common cause of abnormal gait patterns in people with a transtibial amputation, which may result in inefficient ambulation and potentially injurious/harmful compensatory patterns [1]. The alignment process of socket-suspended prostheses involves three phases: bench alignment, static alignment, and dynamic alignment [2]. While the first two phases use objective alignment equipment, the final phase relies on prosthetist's visual assessment and user feedback. A complicating factor in the assessment process is that an

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optimal gait pattern, in terms of energy and gait stability, is not expected to be symmetrical due to limitations such as impaired push-off power of the prosthetic limb [3].

Several studies have focused on the effect of socket-suspended prosthetic alignment changes on gait kinematics and kinetics, particularly on the external socket reaction moment. Systematic alignment changes do not alter spatiotemporal and kinematic parameters in a predictable manner [3], while small alignment changes affect external socket reaction moments in a consistent predictable manner, indicating their potential to guide prosthetic alignment [4] [5]. In that light, a study by Jonkergouw et al. [6] aimed to achieve a predefined mean frontal plane external socket reaction moment during the stance phase of gait, by altering the prosthetic alignment. While being successful in reducing inter-subject variance in external socket reaction moment, this alignment resulted in a high variability in frontal plane knee moments. This might compromise the load on this proximal joint. Therefore, it should be noted that the reported evidence on external socket reaction moments is not necessarily transferable to higher orientated joints within socket-suspended users. This implies that evaluation of external moments at both the socket base and higher-located joints are crucial for a comprehensive objectifiable alignment evaluation.

A socket-suspended prosthesis is not rigidly connected to the residual bone, consequently external moments acting on the socket would induce movement of the socket in respect to the residual limb. Up to sixty-three percent of individuals with lower-limb amputations suffer from socket-related skin problems, which significantly reduce their quality of life [7, 8]. For these individuals better functional outcomes, activity level, and health-related quality of life are observed with the use of a bone-anchored prosthesis (BAP) [9,10]. A BAP involves an osseointegrated implant which is anchored in the residual bone, directly connected to the prosthetic parts via a transcutaneous connector [11]. This direct connection poses new challenges compared to socket-suspended prostheses, notably shifting the focus from soft tissue loading towards joint and implant loading [9,12].

If the external joint moments are not prioritized during the prosthetic alignment process of BAP-users, substantial harmful long-term consequences may arise, such as knee or hip osteoarthritis [13]. As joint loading is an important factor in knee osteoarthritis degeneration [1], showing association between dynamic loading of the knee joint during gait and degeneration of the medial compartment [14]. While several studies have explored the functional outcomes of BAP and its effects on gait biomechanics, most biomechanical research tends to focus on the impact of prosthetic alignment on gait symmetry as well as kinetic rollover characteristics or implant loading [5],[11],[15]. While it is still unknown if systematic alignment changes would have predictable effect on external implant, knee, and hip joint moments.

The aim of this study was to assess the effect of prosthetic alignment changes on the external moments around the knees, hips and implant during gait in individuals with an uni-lateral transtibial BAP. Previous studies underline the significant role of residual limb length in influencing heel strike force [16], as well as the effect of walking speed [17] and frontal plane hip-knee angle [18] on the external knee's adduction moment. Hence, we also assessed the effect of these covariables on the relation between alignment changes and external joint reaction moments. Our hypothesis was that a translation of the prosthetic foot would result in a higher external adduction- (medial shift) and lower (lateral shift) oriented adduction moments in the knee, hip and implant of the prosthetic limb. We had no hypotheses a priori regarding the effect of alignment changes on external moments in the non-prosthetic leg or in the sagittal plane nor of the effect of the effect of the covariables. The null hypothesis was that prosthetic foot translation would not significantly affect external moments in the knee, hip, or implant of the prosthetic limb.

2. Methods & procedures

Ethical approval was obtained from the CMO Oost-Nederland, the Netherlands (NL78861.091.22, ABR 78861). All participants provided written informed consent before measurements took place.

2.1. Participants

Adults with a transtibial BAP using a press-fit osseointegrated implant, provided by Orthodynamics GmbH (Lübeck, Germany), AQ Implants GmbH (Ahrensburg, Germany), or OTN Implants B.V. (Arnhem, the Netherlands), were eligible for inclusion. Convenience sampling was used to include users with at least two years of prosthetic use and those capable of unassisted treadmill walking. Exclusion criteria were: cognitive, communicative, physical (other than amputation of the lower leg) or visual impairment that would impair smooth and stable locomotion. This experimental within-subject study presents a sub analysis. The power calculation for this sub analysis is based on a different research question from the main study, detailed in the following ABR form (NL78861.091.22).

2.2. Protocol

Participant and residual limb demographics were obtained, including age, height, weight, adjusted BMI, cause of amputation, years since amputation and osseointegration implant surgery and residual limb length. Initially, weight bearing line alignment was achieved by mirroring the frontal plane hip-knee-ankle alignment of the non-prosthetic leg, obtained using radiography (Appendix A). Subsequently, the participant underwent a gait analysis with the achieved weight bearing line alignment, while wearing their daily shoes and a safety harness. This harness would have supported the participants in the event of a fall, but did not provide weight support while walking. A warm-up trial of approximately five minutes was started before the measurements were conducted. The gait analysis was conducted at a comfortable walking speed, as established using the method employed by Hak et al. [19].

After the baseline measurement with the weight bearing line alignment, systematic alignment changes of 2, 4, and 6 mm in medial and lateral directions were randomly performed with the use of an off-set adapter at implant level (Fig. 1). If the built-in height prevented the use of an adapter, a low-profile prosthetic foot matching the participant's weight, activity level, prosthetic side, and foot size was used (Proflex Low-Profile, Ossur). If the built-in height allowed for adapter accommodation, the participant's daily prosthetic foot was used for the measurements. After each alignment change, the gait analysis was repeated.

2.3. Equipment

Gait analysis was performed on an instrumented dual-belt treadmill (M-Gait, Motek, Houten, the Netherlands), measuring the ground reaction force at 2000 samples/seconds. Kinematics were recorded with 12 infrared cameras (Vicon MX, Oxford, United Kingdom), operating at 100 samples/seconds. A total of 53 reflective markers were placed on each participant (Appendix B).

2.4. Data analysis

External implant moment was defined as the moment around the distal point of the double cone adapter. The external joint and implant moments were calculated using inverse dynamics with a custom-made MATLAB algorithm (R2021b, The MathWorks Inc, US). The external moment is the inverse of the net moment generated by the body. For the inverse dynamics calculation, ground reaction forces and marker position data were used [20]. The kinematic data were filtered with a

Fig. 1. Prosthetic setup to enable alignment adjustments and calculations. A: The markers which are used to determine the implant position. These markers are employed to compute implant kinetics in both the frontal and sagittal planes. The point at which the external moment is calculated is positioned equidistant between these two markers and corresponds to the implant's location. B: The zero-line indicates the weight bearing line alignment. The dashes adjacent to the zero mark indicate lateral (indicated by "L") and medial (indicated by "M") displacements of 2, 4, and 6 millimeters, respectively.

zero-lag 4th order low pass Butterworth filter with a cutoff frequency of 10 Hz. We obtained the joint kinematics with direct kinematics. The estimated masses and moments of inertia of the body segments were based on calculations from Zatsiorsky [21]. The moment of inertia of the prosthesis was set to zero since rotational acceleration during the stance phase of a transtibial amputee is minimal resulting in a negligible effect on net joint moments [22].

During the data analysis, only strides involving correct ground reaction force data throughout the stance phase (initial contact to toe-off) were used. A step was considered correct when the foot was placed entirely on one force plate, without the contralateral foot touching that same force plate throughout this period. Data was considered inaccurate if a minimal force of 50 Newtons was registered on the contralateral force plate. Furthermore, the steps during which the participant touched the handrails were labelled incorrect. All incorrect steps were discarded from further analyses. Additionally, participants were required to have a minimum of 25 correct steps to be included in the study.

2.5. Statistics

Demographic variables were assessed for normality using the Shapiro-Wilk test. Normally distributed variables were reported with mean and standard deviation, while non-normally distributed ones were summarized using median and Q1-Q3. To investigate the effect of alignment changes on external moments, specifically mediolateral translation (independent variable), on frontal plane net joint moments (dependent variable), we conducted one-dimensional statistical parametric mapping regression analyses using the SPM1D software package (M.0.4.10, www.spm1d.org) in MATLAB [23]. First, external moments were normalized for body weight and resampled to 0–100 % of the stance phase. As noted, our study utilized a within-subject design, yet implemented weight normalization to align outcomes with existing literature in this area. Separate regression analyses were performed per subject for each of the five external moments (knee and hip of the prosthetic and non-prosthetic limb and implant of the prosthetic limb) in frontal and sagittal planes based on the following formula:

$$Joint\ moment(pct_{stance}) = Intercept + \beta(pct_{stance}) * translation + \varepsilon$$

The regression models produced 27 β-trajectories for each dependent variable, corresponding to one trajectory per subject. These trajectories encompass 0–100 % of the stance phase (pct_{stance}). Lastly, a population-level SPM1D one-sample *t*-test using beta coefficients that represent the relationship between alignment changes and external joint moments was conducted. The null hypothesis was that there is no significant relationship (beta = 0) between these variables at the population level. SPM1D was used for this analysis, aiming to determine if the observed relationship in the study sample holds true for the investigated population [23]. Since we performed the statistical test at 5 interdependent joints simultaneously, we applied a Bonferroni correction so alpha was set at 0.01 ($\alpha = 0.05/5 = 0.01$) [24].

We utilized Pearson's correlation coefficients to assess if various covariates, i.e., comfortable walking speed, residual limb length, and frontal plane static hip-knee angle, derived from radiographic images, affect the relationship between alignment changes and external joint moments. This relationship was expressed as the value of the β-trajectories at midstance. Midstance is the phase of the gait cycle when the body's weight is directly over the supporting foot [25], and was defined as 50 % of the stance phase.[25]

3. Results

3.1. Participants

The study included 21 male and 6 female uni-lateral transtibial BAP users with a mean age of 57.4 years (SD 11.5) and adjusted BMI of 29.6 kg/m^2 (SD 3.4). Fifteen individuals (56 %) underwent right-sided amputation, 22 amputations (81 %) were trauma-related and the remaining reasons for amputation included one oncological, two vascular and two infectious origins. The median duration since amputation was 11 years (Q1; Q3, 9.5; 30.5), followed by the mean duration since osseointegration implant surgery of 4.9 years (SD 1.6). The residual limb demographics are reported in appendix C.

3.2. External joint moments

In total, 4725 gait cycles were analyzed across all conditions (27 participants × 25 steps × 7 conditions). Fig. 2 (frontal plane) and Appendix D (sagittal plane) show the effects of mediolateral alignment shifts on external joint moments during the stance phase of gait. Significant and systematic effects of alignment changes were found in the

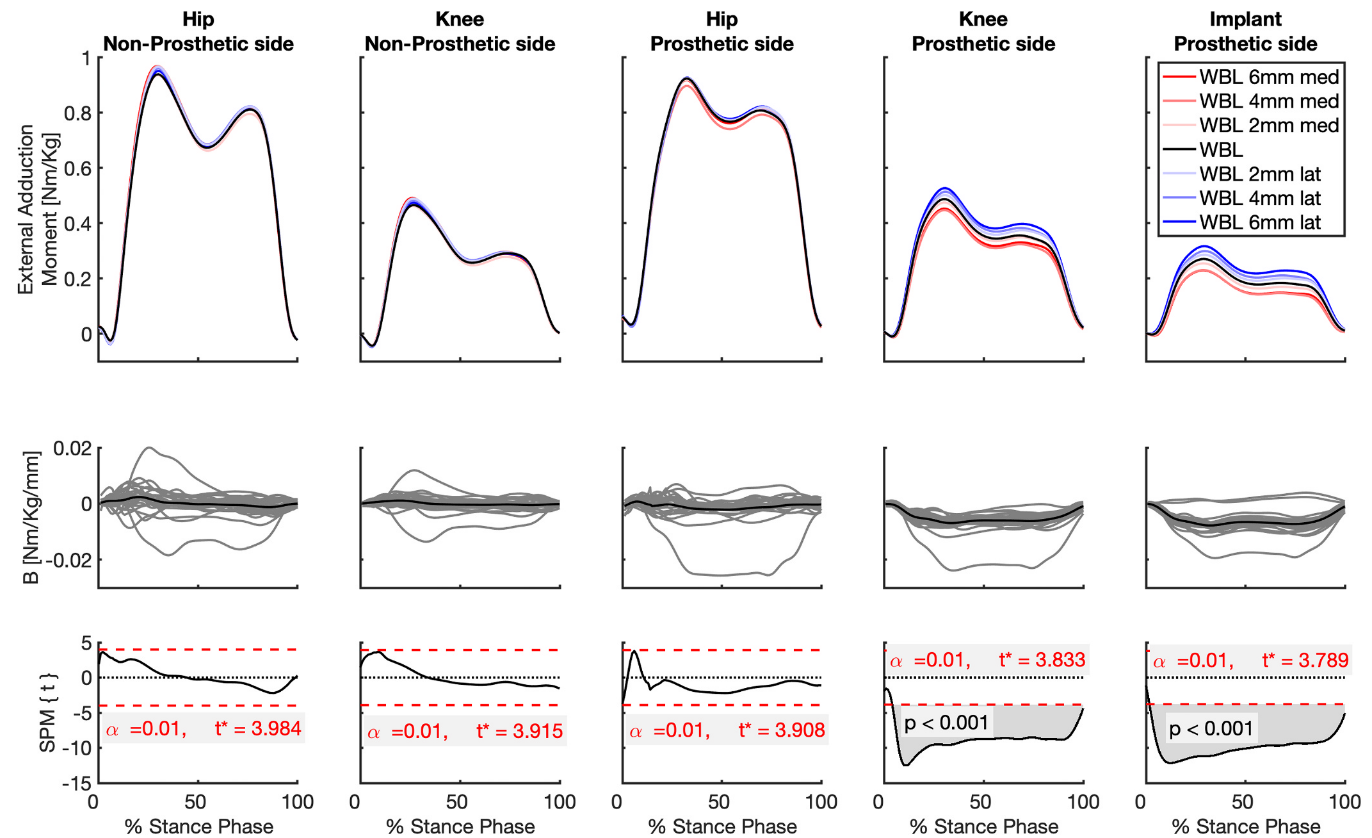

Fig. 2. The effect of alignment changes on frontal plane external moments. Upper panel: The mean external moments of the knee, hip, and implant of the prosthetic limb and knee and hip of the non-prosthetic limb in the frontal plane at different alignments. External adduction moment was defined as positive. Middle panel: The slopes (beta's) of the alignment-moment relationship calculated per person for all the aforementioned joints using the regression analysis, whereby the bold line represents the mean slope. Lower panel: The population level one sample *t*-test on the calculated beta's per included joint.

frontal plane of the prosthetic limb. This effect was present almost throughout the entire stance phase at the knee and implant. A shift of the foot in respect to the residual limb resulted in significant increases (medial shift) or decreases (lateral shift) of the external knee and implant adduction moments ($p < 0.001$). The mean β-value at mid-stance define the trend in which direction the moments will change when changing the translation. This indicated that each mm of shift changed the external adduction implant moment by 0.0068 Nm/kg (3.6 %) and the external knee adduction moment by 0.0055 Nm/kg (1.5 %). No significant effects were found at the hip of the prosthetic limb, the non-prosthetic limb or in any of the evaluated joints or implant in the sagittal plane.

3.3. Covariates

None of the confounders (comfortable walking speed, residual limb length, and frontal plane static hip-knee angle) showed a significant association with the relationship between alignment and external moments in the frontal and sagittal plane (Table 1).

Table 1
Effect of covariates on the relation between alignment changes and external moments.

Moment	Plane	Residual limb length		Speed		Knee Angle	
		R	p	R	p	R	p
NP Hip	Frontal	.03	.89	−.08	.70	−.03	.87
NP Knee	Sagittal	−.17	.41	−.24	.23	.14	.47
P Hip	Frontal	.09	.65	−.14	.50	.04	.83
P Knee	Sagittal	.13	.51	−.27	.18	−.11	.57
P Implant	Frontal	.09	.67	.22	.27	.28	.15
	Sagittal	.29	.15	.04	.85	.02	.91
	Frontal	.05	.80	.32	.10	.23	.24
	Sagittal	.18	.36	.16	.42	.24	.22
	Frontal	.19	.33	.30	.12	.22	.26
	Sagittal	−.11	.58	.17	.40	.30	.13

NP = Non-Prosthetic, P = Prosthetic, p = statistical significance of the correlation ($p < 0.05$), R = the strength and direction of a linear relationship ($R = 1$ is perfect positive, $R = -1$ is perfect negative, $R = 0$ is none).

4. Discussion

We investigated the effect of frontal plane systematic mediolateral alignment changes on external joint moments in both frontal and sagittal planes during gait in individuals with a transtibial BAP. Translation of the prosthetic foot resulted in an expected significant increase (medial shift) and decrease (lateral shift) in the external adduction moment at the implant and ipsilateral knee over the entire stance phase, with the largest effect at the implant-level, but unexpectedly no significant effect was observed at the ipsilateral hip. Introducing mediolateral shifts of 2, 4, and 6 millimeters resulted in incremental changes in external joint moment magnitudes at the implant and ipsilateral knee. Frontal-plane non-prosthetic limb and sagittal plane external joint moments of all of the evaluated joints were not significantly influenced by frontal plane alignment changes.

Within our study a significant correlation between alignment changes and external implant moment was detected. The absolute change of the external adduction moments at the implant level showed comparable magnitudes to studies that investigated the external moment changes at the base of the socket while executing systematic alignment changes [26,27]. Within our study, a 5 mm shift resulted in an estimated 0.039 Nm/kg change of the external implant moments at 30 % of the stance phase, which is of similar magnitude as the 0.044 Nm/kg reported by Boone et al. [26] and 0.043 by Kobayashi et al. [4] at that specific instance of the stance phase. However, it is important to emphasize that while the magnitude of external socket reaction moments may resemble the external implant moment following alignment changes, this does not necessarily imply that alignment changes in socket-suspended prostheses will cause similar changes in external knee and hip moments as in BAPs. As external socket reaction moments have been reported extensively, no data has been reported by the same group on the effect of such alignment changes on external knee or hip moments in socket suspended prosthesis users [3,4,28].

Blumentritt [29] explained that force transmission at the interface between the prosthesis and the residual limb is considerably different for TTA and TFA osseointegrated fixation and socket suspended prosthesis. Additionally, the fixation of a socket-suspended prosthesis could be considered a pseudo-joint [30]. Effectively suggesting that the residual bone is moving within a prosthetic socket, thereby potentially altering the direction of the ground reaction force as well as the relative orientation of the prosthesis to residual bone. Therefore, one should be cautious in extrapolating our findings to patients with socket-suspended prostheses. At the same time, our finding of significant changes in knee moments following alignment adjustments in the prosthesis or implant underscores the necessity for future research to report moments around adjacent joints.

Our results suggest that, on average, a shift of just one millimeter in the frontal plane leads to a change in external knee adduction moment by 1.5 %, and external implant adduction moment at midstance by 3.6 %. Given that dynamic alignments primarily rely on visual observations to assess gait kinematics and spatio-temporal parameters, alignment adjustments in clinical practice often require larger shifts, to obtain an observable change, typically exceeding one millimeter. These adjustments may be made not only to optimize gait parameters but also to address factors such as pain complaints. Nevertheless, our study demonstrated that smaller frontal alignment shifts already significantly affect the external joint moments. Consequently, our findings could serve as a warning to prosthetists regarding the consequences of changing the alignment of BAP on joint loading, emphasizing that a few millimeters of adjustment could potentially lead to substantial differences in the external moments of both the joints and the implant.

Studies showed that in patients with osteoarthritis significantly higher external adduction moments at the knee were detected compared to the healthy individuals [31,32]. These studies showed differences in the external adduction moments in the knee between healthy participants and osteoarthritis patients of 0.16Nm/kg [31], coinciding with the effect of an estimated 24 mm alignment adjustment within our study. We estimate such a translation results in a similar effect on net frontal plane knee moments as was observed between patients with knee osteoarthritis and healthy controls. In clinical practice, such a shift is quite large, hence it is important for future research to translate the magnitude of net knee moments to risk of injury to translate our findings towards a MCID.

The external moments in the non-prosthetic limb were not significantly affected by alignment changes. Moreover, the frontal alignment changes did not significantly affect the external sagittal plane moments, which corresponds to the study of Kobayashi et al. [33]. This highlights that a prosthetic alignment adjustment has a direct effect in the respective plane it has been executed in. Thus, prosthetists should keep in mind that it is not advisable to use these alignment changes to alter the non-prosthetic limbs gait kinetics.

None of the covariates showed a significant effect on the alignment-moment slope. Thereby, suggesting that there is no immediate need to consider the influence of residual limb length, walking speed, or knee angle on the external moments in the joints and the implant while fine-tuning the alignment of transtibial BAP-users.

For four participants, a different foot was required due to insufficient build-in height within the prosthesis. While this might have required an adjustment period, it didn't directly affect the differences in external moments within individuals across the conditions. The heterogeneity in prosthetic feet and shoes used could be considered a limitation. However, we feel that it contributes to the external validity of our results, enhancing their applicability to real-clinical scenarios. Nevertheless, clinicians should consider that prosthetic feet design, has an influence on ankle/foot stiffness and therefore may influence transtibial BAP-user implant loading [15]. Thereby, it does not alter the systematic effect of alignment changes on implant loading. However, it may primarily influence the baseline alignment. An additional limitation could be the use of a treadmill for gait analysis, which may slightly alter the gait pattern compared to overground walking [34]. However, this allowed recording more steps within a reduced amount of time, improving accuracy compared to traditional overground gait labs.

This study offers valuable insights regarding the effect of alignment on the external joint and implant moments in individuals with BAP. With limited previous research in this area, prosthetists have largely relied on clinical experience, based on socket prosthesis users. Our findings provide important information on the magnitude of external joint moment changes resulting from even minor off-set changes, contributing to existing knowledge. This knowledge is useful within clinical practice to inform more comprehensive decisions for maintaining joint health and could be used as input for modelling studies on safety and function of osseointegrated implants.

5. Conclusion

A medial frontal plane shift of the prosthetic foot in individuals with a transtibial BAP results in systematic increase of adduction moment at the implant and knee of the prosthetic leg, with the most pronounced effect at the implant. Even minor alignment changes can result in substantial alterations of external moments, underscoring the importance of precise adjustments. Notably, our study revealed that modifying alignment at the implant level significantly affects external moments not only at the implant but also at the knee joint, underscoring the importance for researchers and prosthetists to consider both the implant and higher-oriented joints during alignment adjustments.

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CRediT authorship contribution statement

Maarten R. Prins: Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Formal analysis, Conceptualization. **Ruud A. Leijendekkers:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Vera G.M. Kooiman:** Writing – review & editing, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation. **Han Houdijk:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Sjoerd M. Bruijn:** Writing – review & editing, Supervision, Software, Project administration, Methodology, Data curation. **Niels Jonkergouw:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Alyssa M.G. Groeneveld:** Writing –

original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Protocol weight-bearing line alignment

The baseline of all alignment changes was the weight-bearing line alignment. This alignment was achieved by performing the following steps; 1) A standing radiographic image was taken of the lower extremity (iliac crest to the ground) in initial alignment (Fig. 3A). The participant was positioned into a fixed stance (ensured with a 10 cm block between the knees) and both feet were placed in a five-degree exorotation (neutral alignment of the prosthesis foot); 2) On the standing X-ray, a line was drawn from the center of the hip to the center of distal end of the tibia on the unaffected side and the transition between the tube and the prosthetic foot on the affected side, which is called the weight-bearing line (vertical yellow lines); 3) The distance between the weight-bearing line and the medial condyle of the tibia on the un-affected side (purple) and affected side (green) was measured. The difference between the affected and the unaffected side was calculated; 4) The prosthesis was aligned to equalize the distance between the medial condyle of the tibia and the weight-bearing line on the prosthetic side compared to the non-prosthetic side (Fig. 3B). Our goal was to achieve symmetrical alignment while respecting the participant's anatomy. In Fig. 3A, the initial alignment of the prosthetic leg exhibits a greater distance between the weight-bearing line and the medial condyle of the tibia (highlighted in green) compared to the non-prosthetic leg (highlighted in purple). After the alignment change, Fig. 3B demonstrates that the weight-bearing line alignment results in equal-sized green and purple blocks, ensuring anatomical consistency in the alignment.

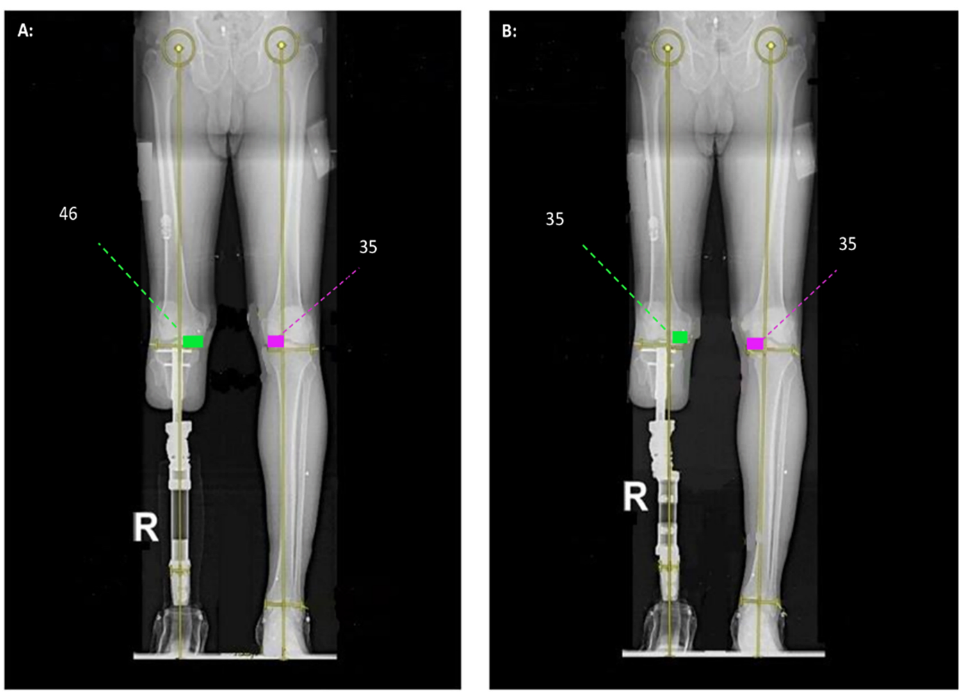

Fig. 3. Obtaining weight bearing line alignment. This figure presents the radiograph images obtained from one of the participants showing the lines used for the weight-bearing line (WBL) analysis. A: The initial alignment. B: The weight-bearing line alignment. The vertical yellow lines indicate the weight-bearing line. The purple (unaffected side) and green (affected side) numbers indicate the distance in millimeters from weight-bearing line to the medial condyle of the tibia measured on the radiograph in the initial condition (A) and WBL condition (B)

Appendix B. Figure of marker placement

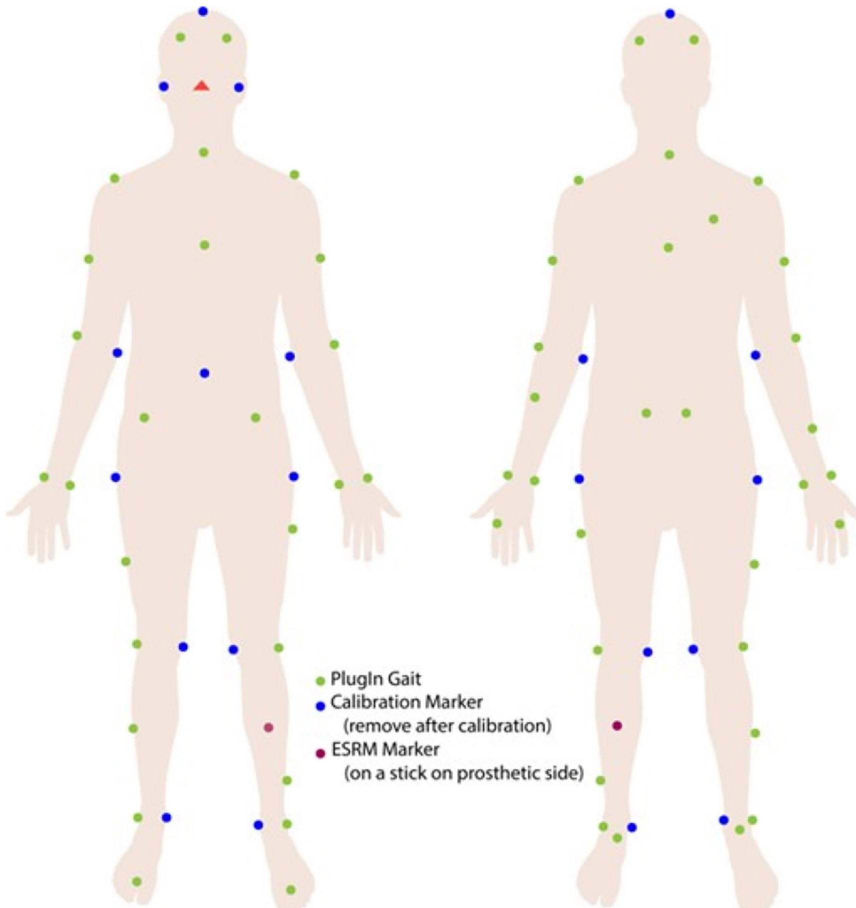

Fig. 4. Used marker models. Vicon plug-in full body markers (green), calibration markers (blue) and implant markers (purple) placement front (left) and back (right) view. The Vicon Plug-In Gait marker-setup (39 markers) with two additional markers was used to determine the implant location (the distal point of the double cone adapter) and 12 additional calibration markers to improve joint center estimations

Appendix C. Table 2: Residual limb demographics

Participant	Residual limb length (cm)*	Residual limb length (Percentage of Leg Length)	Prothesis connector	Prothesis foot	Type of prosthetic foot
1	52.0	58	Luci	Maverick Extreme AT	ESAR
2	46.0	53	Luci	Proflex XC (Ossur)	ESAR
3	50.5	57	OPL	Maverick extreme AT	ESAR
4	45.5	58	GV18	Proflex align (Ossur)	ESAR
5	46.0	54	OPL	Maverick AT	ESAR
6	40.5	53	OPL	Maverick	ESAR
7	49.0	59	OPL	Marverick Extreme AT	ESAR
8	49.0	56	OPL	Taleo (Otto Bock)	ESAR
9	56.0	66	OPL	Maverick Extreme	ESAR
10	56.5	60	OPL	Maverick AT	ESAR
11	25.3	53	OPL	Pro-Flex (Ossur)	ESAR
12	51.0	57	OPL	Maverick AT	ESAR
13	44.5	57	OPL	Maverick	ESAR
14	46.0	51	OPL	Taleo	ESAR
15	52.0	53	Nexus	Variflex Rotate XC	ESAR
16	50.0	52	Luci	Taleo	ESAR
17	50.0	60	OPL	Triton	ESAR
18	47.0	57	Nexus	Propiofoot	Computerized ESAR
19	56.0	63	GV20	Taleo	ESAR
20	47.5	52	OPL	Multiflex foot (Endolight)	ESAR
21	54.0	59	OPL	Vari-flex LP Align	ESAR
22	45.5	51	OPL	Maverick Extreme AT	ESAR
23	48.0	55	OPL	Maverick AT	ESAR
24	44.5	56	GV20	Pro-flex LP (Ossur)	ESAR
25	44.5	55	Luci	Taleo	ESAR
26	45.5	53	OPL	Triton	ESAR
27	47.0	54	GV20	Varifle EVO	ESAR

*Residual limb length is determined from groin to the distal end of the residual limb.
Abbreviations: cm = centimeter, ESAR = Energy Storing and Return Foot.

Appendix D. : Fig. 5: The effect of alignment changes on sagittal plane external moment

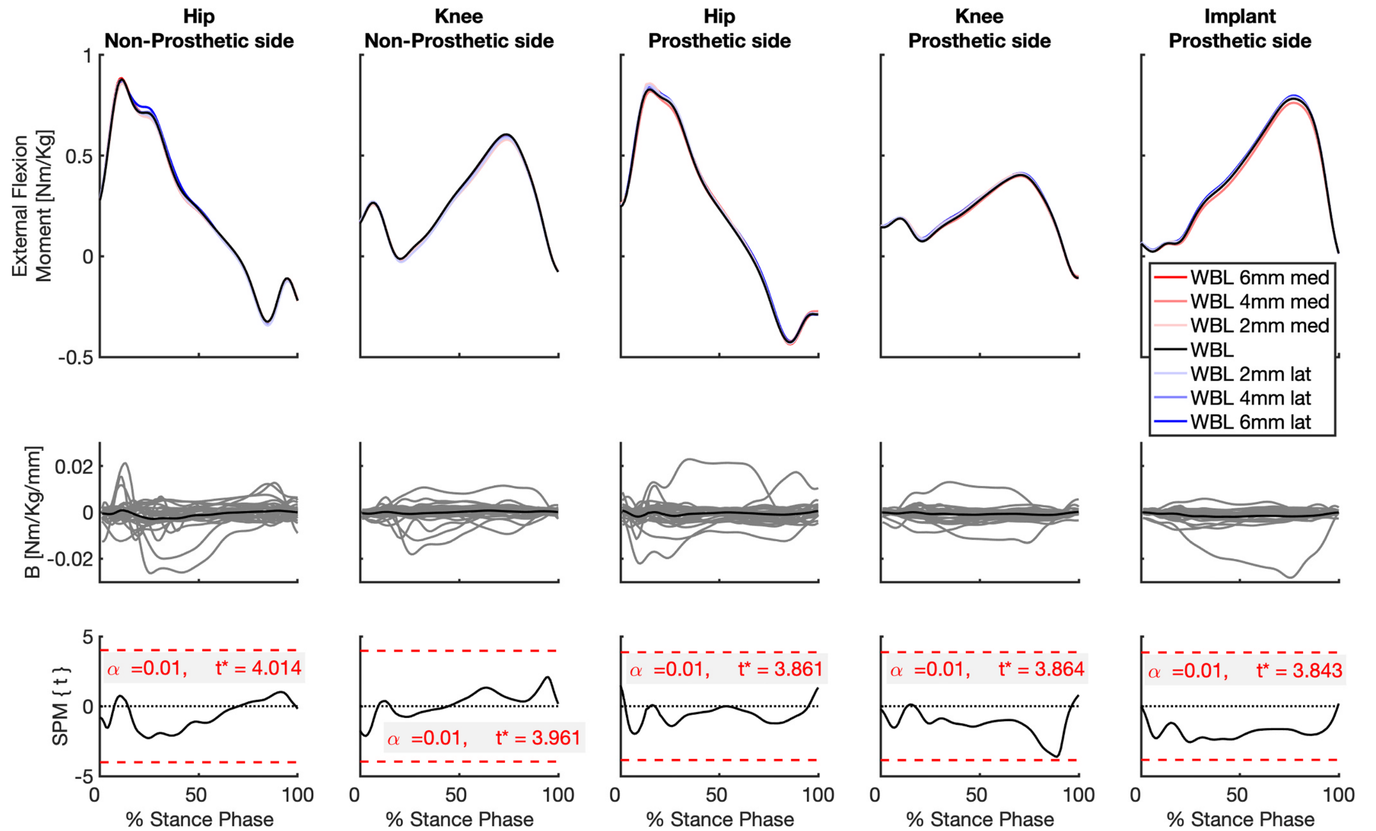

Fig. 5. The effect of alignment changes on sagittal plane external moments

Upper panel: The mean external moments of the knee, hip, and implant of the prosthetic limb and knee and hip of the non-prosthetic limb in the sagittal plane at different alignments. External extension moment was defined as positive. Middle panel: The slopes (beta's) of the alignment-moment relationship calculated per person for all the aforementioned joints using the regression analysis, whereby the bold line represents the mean slope. Lower panel: The population level one sample *t*-test on the calculated beta's per included joint.

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