JOINT MOMENTS OF UNILATERAL TRANSFEMORAL AMPUTEES USING RUNNING-SPECIFIC PROSTHESIS DURING SPRINTING

Yuta Namiki[1,2] , Yoko Sano[1,2] , Atsushi Makimoto[1,2], Satoru Hashizume[1], Akihiko Murai[1],Yoshiyuki Kobayashi[1], Hiroshi Takemura[2], Hiroaki Hobara[1]

National Institute of AIST, Tokyo, Japan[1]
Tokyo University of Science, Chiba, Japan[2]

The aim of this study was to investigate the bilateral difference of the joint moments between an intact leg (INT) and a prosthetic leg (PST) in unilateral transfemoral amputees (TFAs) wearing running-specific prosthesis during sprinting. Eight sprinters with unilateral TFAs performed maximal sprinting on a 40-m runway with 7 force platforms located in between. Hip and knee joint extension and flexion moments during stance phase in INT were significantly greater than those of PST. However, ankle plantarflexion moment in PST was significantly greater than that of INT. Since kinetic asymmetry between legs is thought to be related with running-related injury, sprinter with unilateral TFAs may have a higher risk of musculoskeletal injury at hip and knee joints.

KEYWORDS: asymmetry, kinetics, prosthetic sprinting.

INTRODUCTION: Since sprint kinematics in transfemoral amputees (TFAs) are different from those in able-bodied sprinters and transtibial amputees, improving sprint performance of this population can be a very complex task (Buckley, 1999). Understanding the kinetics, especially joint moments, should provide insight into the motor adaptations that have been made by the individual to offset the structural asymmetry caused by amputation (Sanderson and Martin, 1996). Previous studies found that hip, knee and ankle joints in the intact leg (INT) had significantly greater peak extension moment than the prosthetic leg (PST) during running in transtibial amputees with conventional prosthetic leg (Czerniecki et al., 1991; Miller, 1987; Sanderson and Martin, 1996). According to previous studies, kinetic asymmetry between legs is thought to be linked to overuse injuries in running (Bredeweg et al., 2013; Zifchock et al., 2006). However, little is known about joint moments during sprinting in unilateral TFAs wearing running-specific prosthesis (RSP). Therefore, the aim of this study was to investigate the bilateral difference of the joint moments between INT and PST in unilateral TFAs wearing RSPs during sprinting.

METHODS: Eight sprinters with unilateral TFAs participated in this study (5 males and 3 females, age: 34.6±11.2 years, height: 1.62±0.08 m, mass: 57.4±8.4 kg, 100-m personal records: 16.4±1.9 s). All participants used the same design of prosthetic knee joint (3S80, Ottobock, Duderstadt, Germany) and RSP (1E90 Sprinter, category 2 or 3, Ottobock, Duderstadt, Germany). They performed maximum sprinting on a 40-m runway.
Prior to beginning the experiment, a total of 80 retro-reflective markers were attached to the bony landmarks including prosthetic knee joint and RSP. All the markers on the whole body except the prosthetic segments were placed based on Helen Hayes marker set. We collected ground reaction forces (GRFs) using seven force platforms (60 cm × 40 cm, P400600-10000PT, AMTI, Watertown, MA, USA; sampling at 2000 Hz) and three-dimensional marker positions using 20-camera motion capture system (Vicon, Centennial, USA; sampling at 200 Hz). The GRFs and three-dimensional marker positions were filtered using a fourth order, zero lag low pass Butterworth filter with a cut-off frequency of 75 Hz (Hunter et al., 2004) and 20 Hz (Kuitunen et al., 2002), respectively. Forward velocity during sprinting was calculated as the distance divided by the elapsed time that the sacral marker passed over the seven force platforms.
Previous studies investigating running with RSPs have estimated the PST “ankle” joint to be either at the same relative position as the INT ankle joint or the most acute point on the prosthesis curvature (Buckley, 1999; Buckley, 2000; Burkett et al., 2003). In this study, the center of PST “ankle” joint was defined by the markers on the most acute point on the

prosthesis curvature attached on the medial and lateral edges of RSP. The coordinate systems embedded to the prosthetic shank segment was defined by the four landmarks as follows: center of prosthetic knee joint (medial/lateral), center of prosthetic ankle joint (medial/lateral). And the coordinate systems embedded to the prosthetic foot was defined by the four landmarks as follows: center of prosthetic ankle joint (medial/lateral), toe (medial/lateral).

The moment of inertial of prosthetic shank and foot segments were estimated using simply modeled prosthetic knee joint, adapter and RSP. Prosthetic knee joint, adapter and RSP were assumed as homogeneous solid cylinder and thin plate, respectively (Fugure 1-c). Mass of each piece was determined as the officially launched value.

Joint angles were calculated as the position and orientation of the coordinate systems embedded to the proximal segment relative to that embedded to the distal segment by using the Cardan sequence. Joint angular velocities were then calculated as the angular velocity vectors using the corresponding cardan angles. Joint moments were calculated by inverse dynamics approach on Visual3D (C-Motion, Germantown, MD, USA) software. Joint moments were normalized using the participant's body mass.

We performed Kolmogorov-Smirnov test to confirm the distribution of the data. If normality was observed, paired t-tests were conducted to compare the hip, knee and ankle peak moments between INT and PST. If normality was violated, Wilcoxon signed-rank test was conducted. SPSS for Windows Version 22 (SPSS Inc. Chicago, IL, USA) was used for all statistical analyses. Statistical significance was set at $p < 0.05$.

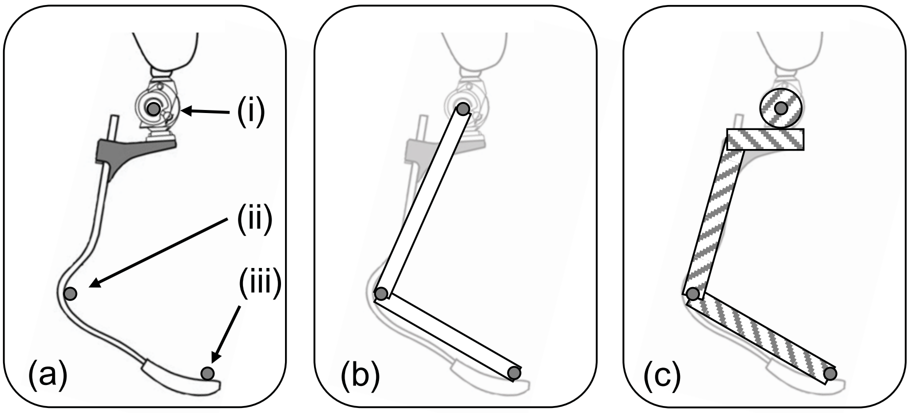

Figure 1: (a) Marker placements on PST with view of the sagittal plane: (i) center of prosthetic knee joint (ii) most acute point (iii) toe of RSPs. (b) A definition of ankle joint composed of shank and foot segments. (c) A model to calculate the inertia properties of each prosthetic components.

RESULTS: The average velocity of all subjects was 5.96±0.60 m/s. Figure 2 shows average joint moments pattern in INT and PST during stance phase. Time-course profiles of hip and knee moments were different between legs. However, ankle joint in both INT and PST produced plantarflexion moment throughout the stance phase. As shown in Table 1, except for plantarflexion moment, all the peak moments in INT were significantly greater than those of PST. However, plantarflexion moment in INT was significantly smaller than PST.

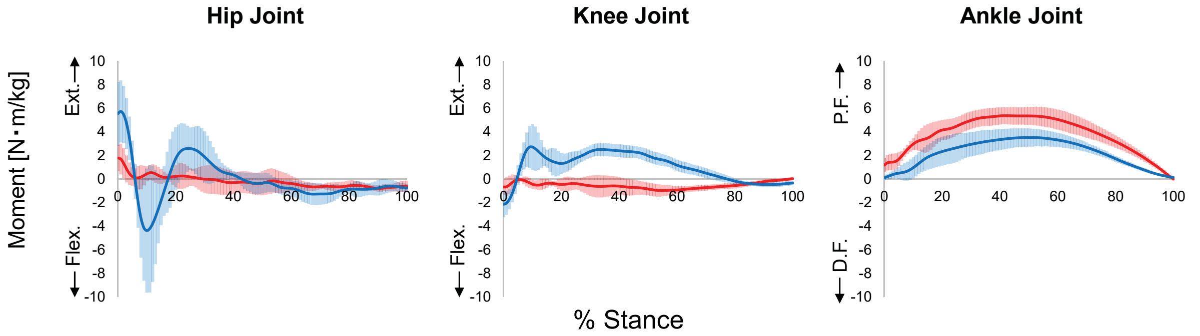

Figure 2: Averaged hip, knee, and ankle moments in INT (blue line) and PST (red line), respectively. All moments were normalized to body mass and to the stance time in each step. Solid lines and shaded area indicate mean values and standard deviations, respectively. Moments that tended to extend (Ext.) and flex (Flex.) a joint are shown as positive and negative, respectively. P.F. and D.F. represents plantarflexion and dorsiflexion for the ankle joints, respectively.

Table 1: Comparison of peak moments (N·m/kg) at each joint between INT and PST.

	Moments	INT	PST
Hip	Extension	7.43 (1.56)*	2.77 (1.08)
	Flexion	6.67 (1.84)*	2.01 (1.15)
Knee	Extension	3.77 (0.59)*	0.931 (0.709)
	Flexion	2.60 (0.69)*	1.69 (0.76)
Ankle	Plantarflexion	3.55 (0.83)*	5.71 (1.22)

S.D. are shown in brackets.
* Significant differences between the legs at $p < 0.05$.

DISCUSSION: The aim of this study was to investigate the difference of the joint moments between INT and PST in unilateral TFAs wearing RSPs during sprinting. As shown in Table 1, hip and knee joints in INT had significantly greater peak extension moment than PST. Our results agree with a previous finding which demonstrated that transtibial amputees wearing RSPs had greater hip and knee moments in INT than PST during flat ground running at three constant velocities (2.5 m/s, 3.0 m/s, and 3.5 m/s; Baum, 2012). The previous study suggested that individuals with lower extremity amputations relied on the INT more than the PST to run when wearing RSPs (Baum, 2012). Therefore, current results and the past finding suggests that hip and knee joints in INT would play a major role for compensatory straegies, due to the impairment of the muscles in PST. On the other hand, ankle joint in PST had significantly greater peak plantarflexion moment than in INT. This result contrasts with a previous study which demonstrated that two elite transtibial amputee sprinters wearing RSPs had greater plantarflexion moments in INT than PST during sprinting (Buckley, 2000). The cause of this discrepancy could involve methodological differences, especially, definition of shank segment. In the previous study (Buckley, 2000), proximal and distal markers of shank segment were at the center of residual knee joint, either at the same height as the lateral malleolus of the INT when standing on tip-toe (Flex Sprint, Össur, Iceland), or at the most acute point on the prosthesis curvature(Cheetah, Össur, Iceland), respectively. Additionally, GRFs data and kinematic data were collected by using a 2D, single camera protocol. In this study, proximal and distal of shank segment were at the center of prosthetic knee joint , the most acute point on the prosthesis curvature(1E90 Sprinter, Ottobock, Germany). Indeed, Baum (2012) and Brüggemann et al. (2009) stated that ankle plantarflexion moments were significantly affected by marker placement and modelling of the RSPs. Consequently, these factors might induce the difference in results of the previous study and current study.

Previous study reported that lower extremity kinetics asymmetry is thought to be related to developing running-related injury (Bredeweg et al., 2013; Zifchock et al., 2006). Because asymmetric hip and knee joints moments were observed, sprinter with unilateral TFAs wearing RSP may have a higher risk of running-related injury occurring at hip and knee joints.

CONCLUSION: The aim of this study was to investigate the difference of the joint moments between INT and PST in unilateral TFAs wearing RSPs during sprinting. Hip and knee joints extension and flexion moments in INT were significantly greater than in PST. However, ankle plantarflexion moment in PST was significantly greater than in INT. These results suggest that sprinter with unilateral TFAs wearing RSP may have a higher risk of running-related injury at hip and knee joints.

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