

TECHNICAL NOTE

Immediate Effect of a Powered Prosthetic Knee on Loading Asymmetry During Sit-to-Stand Tasks in Individuals With Unilateral Transfemoral Amputation

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ABSTRACT

Introduction: Sit-to-stand (STS) movement is one of the most demanding tasks for individuals with unilateral transfemoral amputation (uTFA). Despite the potential of a powered prosthetic knee (PPK) to improve loading asymmetry during STS tasks, empirical evidence supporting its effectiveness remains relatively limited. The aim of this study was to investigate vertical ground reaction force (vGRF) loading during the STS task and its asymmetry in individuals with uTFA using a recently developed PPK.

Materials and Methods: This study used a single-group, prospective, repeated-measures observational study using an A–B design. Eight individuals with uTFA performed the STS task using their daily-use prostheses immediately followed by the same task with the PPK. We extracted the peak vGRF during the ascending phase of the STS task in both the prosthetic and intact limbs and then calculated the degree of asymmetry.

Results: The peak vGRF of the prosthetic limb significantly increased when participants used the PPK. However, no significant differences were observed in the peak force in the intact limb between two prosthesis cases. Consequently, degree of asymmetry was significantly improved with the PPK (40.1%) compared to that with the daily-use prosthesis (52.8%).

Conclusions: These findings suggest that PPK technology can help individuals with above-knee amputation distribute their weight more evenly when standing, even immediately after switching from their usual prosthesis.

Clinical Relevance: The immediate improvement in loading symmetry during sit-to-stand tasks suggests that PPKs may enhance functional performance in individuals with transfemoral amputation. This technology has the potential to support more balanced rehabilitation strategies and reduce compensatory strain on the intact limb. (*J Prosthet Orthot.* 2026;38:e103–e107)

KEY INDEXING TERMS functional mobility, lower-limb amputation, microprocessor knee, vertical loading, kinetic asymmetry, ground reaction force

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The sit-to-stand (STS) movement is one of the most demanding tasks for individuals with unilateral transfemoral amputation (uTFA). Previous studies have demonstrated that the peak vertical ground reaction force (vGRF) is significantly greater in the intact limb than in the prosthetic limb during the STS task in individuals with uTFA.^{1,2} Asymmetric loading increases the risk of secondary degenerative disorders due to overloading the intact limb.^{3–5} Therefore, understanding and addressing the factors causing asymmetric loading during the STS movement are vital for

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Table 1. Participant's demographic characteristics

Participants	Age (year)	Height (m)	Mass (kg)	TSamp (year)	Sex	Current prosthesis use (year)	Residual limb length	Prosthetic knee	Prosthetic foot	Etiology
1	30	1.70	70.3	21	M	6.0	Short	3R106	Valiflex xc	Sarcoma
2	33	1.73	62.7	17	M	10.0	Long	3R80	Aviator	Trauma
3	35	1.76	96.7	2.5	M	2.0	Long	Genium X3	Triton	Trauma
4	61	1.61	44.7	16.5	F	1.0	Long	NI-C411	Side flex Pro-Flex LP	Cancer
5	73	1.64	52.0	23	M	10.0	Long	C-Leg 3	1C53 Taleo LP	Trauma
6	31	1.73	64.5	11	M	0.5	Middle	P-BASS	LP Variflex	Sarcoma
7	50	1.64	82.7	6	M	4.0	Middle	ALLUX	Proflex pivot	Trauma
8	29	1.65	70.1	7.7	M	11.0	Long	3R80	1C61 Triton	Trauma
Mean	42.8	1.68	68.0	13.1		5.6				
SD	16.7	0.05	16.4	7.4		4.3				

TSamp indicates the time since amputation for each individual. Residual limb length was classified as long ($\geq 2/3$), medium ($> 1/3$ and $< 2/3$), or short ($\leq 1/3$) based on the ratio of the residual femur length to the intact femoral length.

developing interventions to reduce secondary degenerative disorder risks in individuals with uTFA.

A powered prosthetic knee (PPK), which provides additional torque to support the ascending movement, may promote task independence and reduce asymmetry in mechanical loading and muscle activation in individuals with uTFA.^{6,7} Despite the promising potential of PPKs in improving loading asymmetry during STS tasks, empirical evidence supporting their effectiveness remains relatively limited. In many cases, the evaluation of PPK involves extended training periods, prolonged accommodation, or device-specific alignment, making it unclear whether their biomechanical benefits can be realized immediately at the time of use. Furthermore, the immediate effects of PPK use on vertical loading asymmetry remain insufficiently characterized. Therefore, the aim of this study was to investigate vGRF loading during the STS task and its asymmetry in individuals with uTFA using a recently developed PPK.

METHODS

PARTICIPANTS

We recruited eight patients with uTFA. All participants could perform the STS movement independently without using any assistive devices during testing (Table 1). Based on interview responses and medical records, we confirmed that none of the participants had received systematic gait training or rehabilitation specific to the PPK used in this study, either in clinical settings (e.g., convalescent rehabilitation) or at home prior to data collection. The study was carried out according to the principles of the Declaration of Helsinki and was approved by the local Ethics Committee of the Tokyo University of Science (#23009). Subjects gave their written informed consent before any procedure.

DATA COLLECTION AND ANALYSIS

This study used a single-group, prospective, repeated-measures observational study using an A–B design. All participants were instructed to perform the STS task three times as naturally as possible without using their hands for assistance or counter-movements (Figure 1A). All participants performed the STS task using their daily-use prostheses (DUPs), in which four and four participants used microprocessor-controlled and nonmicroprocessor-controlled knees, respectively. Then, participants were asked to perform STS task three times by using the PPK (Bio Leg®, BionicM Inc., Tokyo, Japan). The Bio Leg is a single-axis, microprocessor-controlled prosthetic knee that is designed based on the concept of a variable transmission mechanism.⁸ The mechanism enables the Bio Leg to provide the appropriate knee extension torque for each functional task by contributing to a variable transmission ratio with knee angle. The Bio Leg is equipped with a built-in motor to provide the assistive torque, as well as built-in sensors to estimate the user's intentions. In the STS task, the control strategy is designed impedance-based, enabling the Bio Leg to adjust the output torque according to the user's movements and estimated intentions. On average, all participants had 2–3 days of experience (approximately 4 h per day) using the PPK prior to testing, except for two participants who had 10 days of experience. To account for differences in participant anthropometrics, we adjusted the chair height individually for each participant to ensure that the initial seated posture approximated 90° of both knee and ankle flexion. Subjects rested for as long as needed between repetitions to minimize the effects of fatigue.

The STS task was performed using two force plates (TF-40120-CL and TF-40120-CR; Tec Gihan, Kyoto, Japan). We extracted the peak vGRF from the time-series data during the ascending phase of the STS task in both the prosthetic and intact limbs (Figure 1B). From a previous study,¹ the degree of

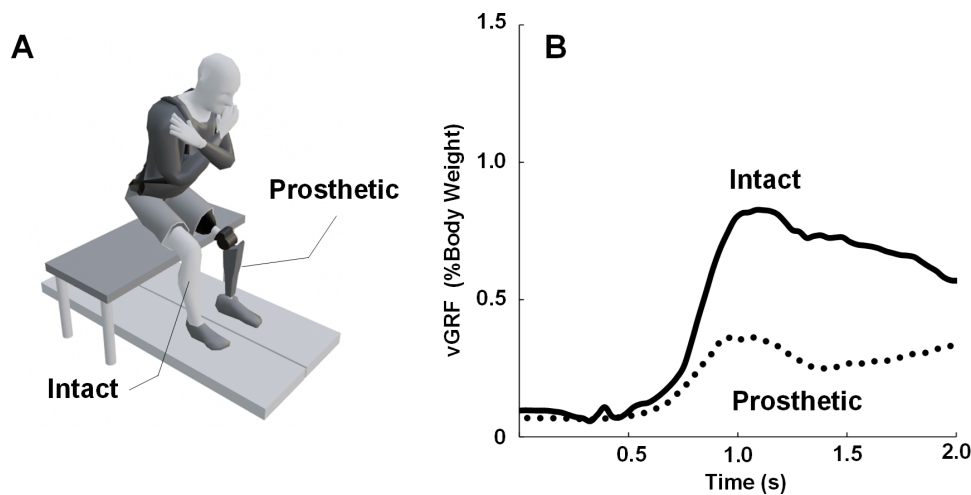


Figure 1. A, Illustration of the STS task in individuals with uTFA. All participants performed the STS task without using their hands for assistance or counter-movements. B, Representative time-course of vGRF in both the prosthetic limb (dotted line) and the intact limb (solid line) during the STS task recorded from a single participant using a nonmicroprocessor-controlled knee. We determined the peak vGRF during the ascending phase of the STS task. The data were recorded from one individual with uTFA using a nonmicroprocessor-controlled knee.

asymmetry (DoA, %) between the intact and prosthetic limbs was calculated by

$$\text{DoA} = \frac{\text{Intact} - \text{Prosthetic}}{\text{Intact} + \text{Prosthetic}} \times 100 \quad (1)$$

A positive DoA represents asymmetry with greater load on the intact limb, a negative DoA represents asymmetry with greater load on the prosthetic limb, and a DoA of zero represents perfect symmetry.⁹

STATISTICAL ANALYSIS

Data normality for each variable was assessed using the Shapiro-Wilk test. Since all variables met the assumption of normality, a dependent *t* test was used. Effect sizes (ESs) were calculated using Cohen's *d* for the *t* test. No missing data were present; thus, intention-to-treat analysis and data imputation were not required. Statistical significance was set at $P < 0.05$.

All analyses were conducted using SPSS software (IBM SPSS Statistics Version 26; IBM Corp., Armonk, NY, USA).

RESULTS

As shown in Figure 2A, the peak vGRF of the prosthetic limbs significantly increased when participants used the PPK compared with their DUPs ($t_{(7)} = -5.46$, $d = 1.93$, $P < 0.01$). We also found no significant differences in peak vGRF in the intact limb between the two conditions (Figure 2B; $t_{(7)} = 0.50$, $d = 0.18$, $P = 0.63$). Consequently, as shown in Figure 2C, DoA was significantly improved ($t_{(7)} = 4.55$, $d = 1.61$, $P < 0.01$) using the PPK (40.1%) compared with DUPs (52.8%).

DISCUSSION

Notably, immediate use of PPK increased the vGRF of the prosthetic limb during the STS task (Figure 2A). The

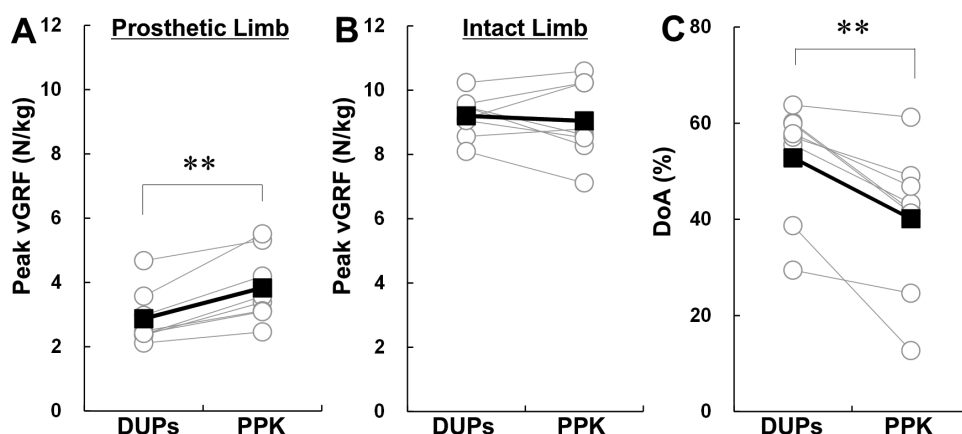


Figure 2. Comparisons of peak vGRF in (A) prosthetic and (B) intact limbs, and (C) the DoA for their DUPs and a PPK condition. White circles and black squares indicate individual and averaged values, respectively. An asterisk (*) indicates statistical significance at $P < 0.05$.

results agree with previous findings indicating that the prosthetic limb vGRF loading during the STS task in individuals with uTFA increased with the use of PPKs^{1,2} and Utah Bionic Leg.¹⁰ In this study, increased prosthetic limb vGRF loading was observed immediately after using the DUP trial. However, previous studies set no prosthetic adjustment for more than 90 days prior to data collection,¹ and 6 weeks of training users to transfer from a sitting to a standing position.² Thus, our results suggest that PPK can increase vGRF loading during STS tasks, even with immediate changes from their DUPs.

The vGRF loading of the intact limb did not vary even with the immediate use of the PPK. In this study, the intact-limb loading decreased in only five of the eight participants. However, it did not reach statistical significance (Figure 2B). Our results agree with those of previous studies showing that the PPK did not decrease vGRF loading of the intact limb during the STS task.^{1,10} However, Wolf et al² showed that the use of Power Knee™ could reduce the vGRF loading of the intact limb more than the C-Leg (Otto Bock Healthcare, GmbH, Duderstadt, Germany). Because humans routinely perform STS tasks 60 times per day,¹¹ a decrease in vGRF loading of the intact limb is vital to reduce degenerative secondary disorders. Further research should explore the factors influencing the effectiveness of PPKs in reducing the loading of intact limbs during STS tasks.

As shown in Figure 2C, vGRF loading asymmetry during the STS task significantly improved when the participants used the PPK. In this study, DoA of peak vGRF was 40.1% when the participants used the PPK. According to a previous study,¹ DoA of vGRF during STS tasks varied by prosthetic knee type, such as Power Knee™ (53%), C-Leg (65%), and Mauch SNS (69%). Although Wolf et al² did not calculate the DoA in their study, the estimated DoA would be 56% and 61% for Power Knee™ and C-Leg, respectively (calculated from Table 2 in their study). Furthermore, Hunt et al¹⁰ also showed the DoA of vGRF varied from 45% to 20% with increasing assistive torque of the prosthetic knee. Thus, the results of the present study suggest that 1) powered prosthetic technology is beneficial in reducing the vGRF loading asymmetry during the STS task in individuals with uTFA and 2) the PPK used in this study has comparable functions to other PPKs.

As expected, the increase in peak vGRF on the prosthetic limb significantly reduced loading asymmetry when the participants used the PPK (Figure 2A and C). Especially, the observed 40.1% loading asymmetry in the present study aligns with the clinical goal of minimizing excessive loading on the intact limb. From a developmental perspective, this finding supports the potential of PPK assistance to contribute to joint preservation and improved functional balance in daily activities. However, as shown in the individual plots in Figure 2A–C, the overall improvement in vGRF loading might be subject-specific. Thus, although the PPK demonstrates significant potential for improving loading asymmetry during the STS task, the variability observed among individuals

highlights the need for personalized approaches to prosthetic fitting and training. Furthermore, Simon et al¹² and Welker et al¹³ reported that the DoA of vertical loading during the STS task in a powered knee-ankle prosthesis were smaller (19%–26%) than those in a passive prosthesis (39%–57%). Thus, future research should identify the factors contributing to loading asymmetry when using PPKs during STS tasks to optimize design and functionality. Moreover, longitudinal studies should evaluate whether these improvements in symmetry translate into a reduced incidence of degenerative secondary disorders over time, ultimately enhancing the quality of life of individuals with uTFA.

This study has several limitations that should be acknowledged. First, the nonrandomized, nonblinded A–B study design introduces potential biases, including order effects and participant expectations, which may have influenced the observed outcomes. The absence of a washout period between conditions further limits the ability to distinguish immediate effects from short-term adaptation responses. Second, although the same prosthetic socket and suspension system were maintained across conditions to ensure consistency, the socket configuration was not specifically optimized for use with the PPK. In clinical settings, effective integration of PPKs often necessitates individualized prosthetic tuning to maximize torque transmission, ensure knee joint stability, and enhance user comfort and performance. The absence of such optimization in this study may have influenced the observed biomechanical outcomes during the STS task. Additionally, the type of prosthetic foot used—though held constant—may also impact STS biomechanics, as different foot designs can affect vGRF transmission and ankle stiffness during transitional movements. Moreover, participants did not receive structured gait or functional training with the PPK prior to data collection, which may have influenced their ability to fully utilize the device's capabilities. Third, because full-body motion capture was not performed in the present study, we were unable to determine whether compensatory pelvic movements or trunk motion were present in our participants, which may have influenced the observed loading patterns. Future studies should include comprehensive motion analysis to better understand how whole-body movement strategies contribute to loading asymmetry during STS task. Finally, the small sample size and short familiarization period limit the generalizability of the findings. While most participants underwent a three-day acclimatization period, two received 10 days based on their individual preferences and scheduling availability. Although this reflects real-world variability, the difference in exposure time may have influenced performance. Future studies should adopt standardized acclimatization protocols and randomized crossover designs with extended adaptation periods.

CONCLUSIONS

Immediate use of a PPK increased prosthetic limb loading and reduced asymmetry during STS tasks in individuals with uTFA. These findings suggest that PPKs, on average, may

offer immediate biomechanical advantages in some prosthesis users, during functional tasks such as sit to stand, even in the absence of individualized prosthetic optimization or prior task-specific training.

REFERENCES

1. Highsmith MJ, Kahle JT, Carey SL, et al. Kinetic asymmetry in transfemoral amputees while performing sit to stand and stand to sit movements. *Gait Posture*. 2011;34(1):86–91. doi:10.1016/j.gaitpost.2011.03.018.
2. Wolf EJ, Everding VQ, Linberg AA, et al. Comparison of the Power Knee and C-Leg during step-up and sit-to-stand tasks. *Gait Posture*. 2013;38(3):397–402. doi:10.1016/j.gaitpost.2013.01.007.
3. Cutti AG, Verni G, Migliore GL, et al. Reference values for gait temporal and loading symmetry of lower-limb amputees can help in refocusing rehabilitation targets. *J Neuroeng Rehabil*. 2018;15(Suppl 1):61. doi:10.1186/s12984-018-0403-x.
4. Welke B, Jakubowitz E, Seehaus F, et al. The prevalence of osteoarthritis: higher risk after transfemoral amputation?—A database analysis with 1,569 amputees and matched controls. *PLoS One*. 2019;14(1):e0210868. doi:10.1371/journal.pone.0210868.
5. Farrokhi S, Mazzone B, Yoder A, et al. A narrative review of the prevalence and risk factors associated with development of knee osteoarthritis after traumatic unilateral lower limb amputation. *Mil Med*. 2016;181(S4):38–44. doi:10.7205/MILMED-D-15-00510.
6. Fanciullacci C, McKinney Z, Monaco V, et al. Survey of transfemoral amputee experience and priorities for the user-centered design of powered robotic transfemoral prostheses. *J Neuroeng Rehabil*. 2021;18(1):168. doi:10.1186/s12984-021-00944-x.
7. Jayaraman C, Hoppe-Ludwig S, Deems-Dluhy S, et al. Impact of powered knee-ankle prosthesis on low back muscle mechanics in transfemoral amputees: a case series. *Front Neurosci*. 2018;12:134. doi:10.3389/fnins.2018.00134.
8. Sun X, Sugai F, Okada K, Inaba M. Variable transmission series elastic actuator for robotic prosthesis. *IEEE International Conference on Robotics and Automation (ICRA)*, Brisbane, QLD, Australia, 2018; 2796–2803. doi: 10.1109/ICRA.2018.8460796.
9. Carey SL, Highsmith JM, Maitland ME, Dubey RV. Compensatory movements of transradial prosthesis users during common tasks. *Clin Biomech (Bristol, Avon)*. 2008;23(9):1128–1135. doi:10.1016/j.clinbiomech.2008.05.008.
10. Hunt GR, Hood S, Gabert L, Lenzi T. Effect of increasing assistance from a powered prosthesis on weight-bearing symmetry, effort, and speed during stand-up in individuals with above-knee amputation. *IEEE Trans Neural Syst Rehabil Eng*. 2023;31:11–21. doi:10.1109/TNSRE.2022.3214806.
11. Dall PM, Kerr A. Frequency of the sit to stand task: an observational study of free-living adults. *Appl Ergon*. 2010;41(1):58–61. doi:10.1016/j.apergo.2009.04.005.
12. Simon AM, Fey NP, Ingraham KA, et al. Improved weight-bearing symmetry for transfemoral amputees during standing up and sitting down with a powered knee-ankle prosthesis. *Arch Phys Med Rehabil*. 2016;97(7):1100–1106. doi:10.1016/j.apmr.2015.11.006.
13. Welker CG, Best TK, Gregg RD. Improving sit/stand loading symmetry and timing through unified variable impedance control of a powered knee-ankle prosthesis. *IEEE Trans Neural Syst Rehabil Eng*. 2023;31:4146–4155. doi:10.1109/TNSRE.2023.3320692.