

# The Vertical Ground Reaction Force and Temporal-Spatial Parameters of Transfemoral Amputees Wearing Three Prosthetic Knee Joints Available in Thailand: a Pilot Study

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## ABSTRACT

**Objective:** To examine the temporal-spatial characteristics of transfemoral amputees using three prosthetic knees available in Thailand. In addition, the estimated vertical Ground Reaction Force (vGRF) was explored, in particular the graphical differences in the M-shape of the vGRF pattern amongst each of the knees and the sound limb.

**Methods:** Three transfemoral amputees were fitted with three different prosthetic knee joints (Chulalongkorn University (CU) Polycentric Knee Joint, Prosthesis Foundation Knee, Otto Bock 3R20) and performed walking trials while the vGRF and temporal-spatial parameters were collected for all participants.

**Results:** Similarities existed amongst GRF metrics across all prosthetic knees. Stance and swing time in the CU Polycentric Knee Joint was similar to that of the sound limb. Walking speeds were highest in the Otto Bock 3R20 and lowest in the Prosthesis Foundation Knee.

**Conclusion:** This preliminary pilot testing revealed similarities amongst all three prosthetic knees. Future research with more participants and additional analysis could further elucidate characteristics of these prosthetic knees.

**Keywords:** Prosthetic knee joint; transfemoral amputee gait; vertical ground reaction, temporal-spatial parameters (Siriraj Med J 2019; 71: 399-404)

## INTRODUCTION

Lower extremity amputations are occurring at an increasing rate in South East Asia.<sup>1</sup> The provision of functional lower limb prosthesis is common place throughout the world and the advancement of technologies has led to an improved quality of life for persons afflicted with transfemoral amputations.<sup>2,3</sup> Still, for the transfemoral amputee, the loss of the anatomical knee joint presents a plethora of problems.<sup>4</sup> The biggest being the inability to

provide anatomical flexion and extension of the prosthesis. The able-bodied person has an intact knee joint and therefore a greater control over placement of the foot during walking. The above knee amputee has increased metabolic cost and a disturbed sensory control because of the absence of normal joint and muscular functions. They must make muscle adaptations in their non-affected limb musculature to compensate for these residual limb issues.<sup>5</sup> Furthermore, there are lowered joint torques and

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Received 21 September 2017 Revised 17 May 2018 Accepted 27 May 2019

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<http://dx.doi.org/10.33192/Smj.2019.60>

mechanical energy requirements for the transfemoral prosthesis limb and an increased demand placed on the sound limb compared to able-bodied persons.<sup>6</sup> Fortunately, efforts have been made to reduce the inherent reduced swing phase duration that occurs with the prosthetic knee joint, through either mechanical or hydraulic knees.<sup>7</sup>

The prosthetist creating a transfemoral prosthesis has a number of suitable prosthetic knee options available to them. The single axis hinged knee joints that were commonly prescribed several decades ago are no longer a standard of care for the ambulating amputee. Modern knee joints have integrated hydraulic mechanisms for added functionality.<sup>19</sup> Prosthetic knees which take into consideration direction of the instantaneous center of rotation (ICR) while attempting to mimic the sliding motion of the anatomical knee joint, are more commonly provided to users.<sup>8</sup> A commonly used knee in Thailand is the Otto Bock 3R20 (Otto Bock, Duderstadt, Germany), which is a 4-bar linkage knee joint with a mechanical swing phase control. The kinematics of transfemoral amputees walking in this knee have been explored before.<sup>9</sup> The 3R20 knee has been shown to allow for decreased mean values of stride length and increased walking speed than its lower end model the 3R15.<sup>10,11</sup>

However, there has been an increased push by the United Nations for affordable locally developed rehabilitation technologies over recent years.<sup>12</sup> Thailand has answered the call by developing its own prosthetic knee joints. The CU Polycentric Knee Joint and the Prosthesis Foundation Knee were both designed and developed with a desire to provide locally made prosthetic technology to Thai amputees. The CU Polycentric Knee Joint is designed to closely mimic the motion of the anatomical knee joint through utilization of a unique sliding apparatus and the Prosthesis Foundation Knee is a 4-bar linkage polycentric knee joint. There is a dearth of objective data and scholarship for both of these knee joints as they are still relatively new to the market. Of unique interest to researchers and prosthetists are the performance features provided by each of the aforementioned knee joints.

Objectively measuring knee characteristics and stability can be performed through use of instrumented motion analysis exploring kinematic and kinetic parameters, although this procedure requires the use of resource demanding laboratory equipment and training. Exploring stability through alternative means such as plantar pressure distribution analysis is another viable option.<sup>20</sup> Pressure mat systems are useful for measuring pressure patterns occurring under the foot and to help understand temporal-spatial parameters such as stance and swing variability and cadence. By combining the

calculated simultaneous estimations of vertical ground reaction force (vGRF) and center of pressure (COP), the pressure mat system becomes a useful tool for identifying features of the aforementioned prosthetic knee joints.<sup>13</sup> The objective of this study was to examine the temporal-spatial characteristics of transfemoral amputees using three prosthetic knees available in Thailand. In addition, the estimated vGRF was explored, and in particular the graphical differences in the M-shape of the vGRF pattern amongst each of the knees and the sound limb.

## MATERIALS AND METHODS

This study protocol was approved by Siriraj Institutional review Board (Si 013/2014).

### Participants

All participants provided written informed consent prior to completing the Siriraj Hospital Faculty of Medicine Mahidol University SIRB protocol. Inclusion criteria were restricted to unilateral transfemoral amputees and patients of the Prosthetic and Orthotic clinic at Siriraj Hospital. Three eligible participants were recruited in this study. Each participant was 2-years post amputation, had a medium stump length, at least a grade 4 out of 5 on the manual muscle test (MMT) as determined by the study prosthetist. Participants' were previously familiar with walking with their transfemoral prostheses for at least one year. An Amputee Mobility Predictor (AMPro) activity level of either 3 or 4 (MFCL K Level) was required for all participants.<sup>14</sup>

### Prosthesis

Each participant performed walking trials in a newly provided prosthesis which received the Otto Bock 3R20, CU Polycentric Knee Joint or Prosthesis Foundation Knee (Fig 1). For the entirety of the study, all participants received a quadrilateral socket design with passive suction suspension and were then randomly assigned to receive either of the study knees, a solid-ankle cushion heel (SACH) foot which was appropriate for persons requiring stability and comfort during walking, and a 1 cm heel height shoe. Participants performed an hour walking accommodation period at their preferred walking speed along an indoor walkway prior to all data collection. Furthermore, each of the prosthesis was properly aligned by the study prosthetist according to manufacturer guidelines.

### Walking trials

All participants performed outcome measures in their prosthesis under each prosthetic knee configuration for



**Fig 1.** Image of three prosthetic knees tested: From left to right; Chulalongkorn University (CU) Polycentric Knee Joint, Prosthesis Foundation Knee, Otto Bock 3R20

a total of three trials. The Zebris Gait Mat System (zebris Medical GmbH, Germany) and FDM Software were used to collect and analyze temporal-spatial parameters as well as vGRF. Participants were instructed to walk along the designated walkway at their preferred walking speed.

### Data analysis

Data analysis from the Zebris Gait Mat System was performed using Microsoft Excel Analysis Toolpak (Microsoft, US). Key parameters of interest were walking velocity, percentages of stance and swing phases of both limbs, and step length. Moreover, with respects to vGRF, the visible differences between the sound side and prosthesis side first peak (weight acceptance), second peak (push-off) and valley of vGRF were analyzed. The GRF data was reported in Newton's (N) and was normalized to body weight with each step time being normalized to 100% of the gait cycle, where a complete cycle was defined as two consecutive heel contacts on a single foot.

## RESULTS

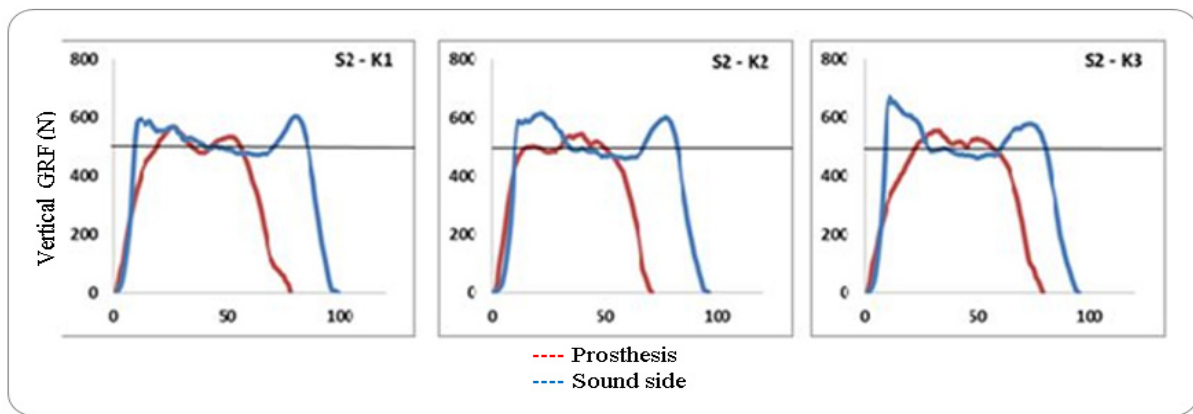
Participant demographics and activity classification are provided in Table 1. Slight differences were observed

for comparisons of the first peak and valley of the mean GRF for each of the study knees and sound limb (Fig 2). Similarities existed amongst GRF metrics across all prosthetic knees. Furthermore, across all prosthetic knees, the stance phase was shorter on the prosthetic side than on the sound side. When prosthetic and sound sides were compared, the curves were mostly dissimilar along the second peak and valley. The valley of vGRF of the sound limb were lowest and highest when participants wore the Prosthesis Foundation Knee (Fig 3). Stance and swing phase differences amongst prosthetic knees and the sound limb showed that the CU Polycentric Knee Joint exhibited stance (57%) and swing (43%) times closer to the sound limb (70%) and (30%) respectively (Figs 4 and 5). The preferred walking velocities showed a higher velocity when participants used the 3R20, and lowest velocity when using the Prosthesis Foundation Knee (Table 2). With respects to spatial parameters, the step lengths of participants using the CU Polycentric Knee Joint (68.33 cm) and Prosthesis Foundation Knee (68.33 cm) were closer in length to the sound side limb (51.88 cm), whereas the longest step length was observed when participants wore the 3R20 (72.33 cm).

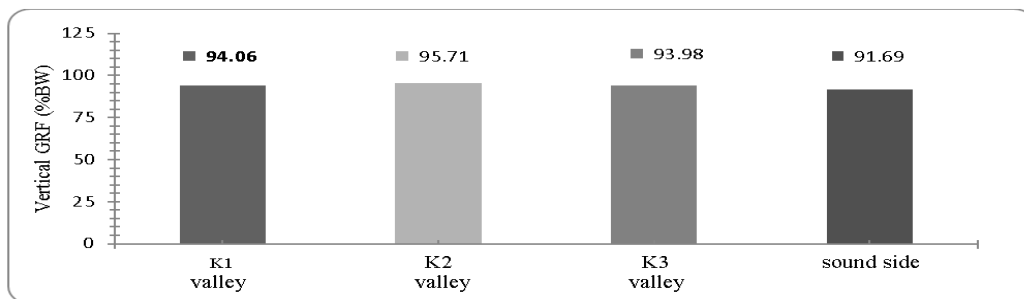
**TABLE 1.** Demographic data and MCFL classification for three study participants.

Participant	Amputation Cause	K-Level	Age	Height (kg)	Weight (cm)	BMI
Participant 1	Traumatic	3	17	168	52	18.42
Participant 2	Traumatic	3	46	173	68	22.72
Participant 3	Traumatic	3	53	164	55	20.44

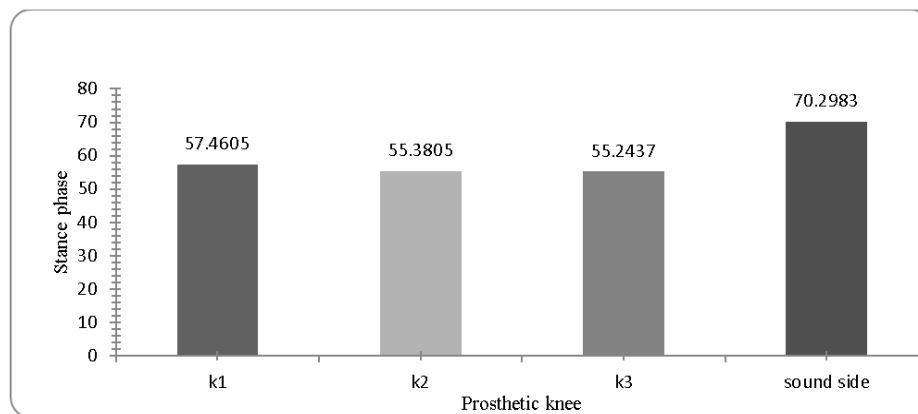
\*MCFL; Medicare Functional Classification Level, K-Level; MCFL, BMI = kg/m<sup>2</sup>



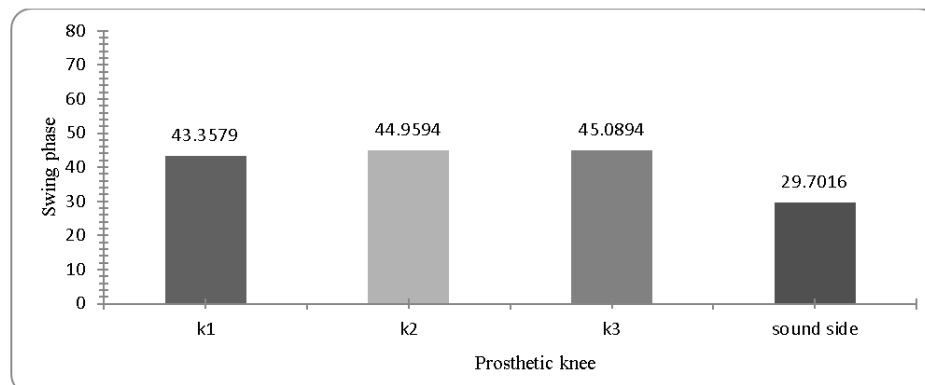
**Fig 2.** Example of one participant's vGRF curve comparisons of vertical ground reaction force for three prosthetic knees and sound side limb. (k1:CU Polycentric Knee Joint, k2:Prosthesis Foundation Knee, k3:Otto Bock 3R20)



**Fig 3.** Comparisons of vertical ground reaction force of three prosthetic knees and sound side limb at TVF (valley of the force in the vertical direction). Bars represent average vGRF for %BW (k1: CU Polycentric Knee Joint, k2: Prosthesis Foundation Knee, k3: Otto Bock 3R20)



**Fig 4.** Mean stance phase duration times for three prosthetic knees and sound side during a walking trial (k1: CU Polycentric Knee Joint, k2: Prosthesis Foundation Knee, k3: Otto Bock 3R20).



**Fig 5.** Mean swing phase duration times for three prosthetic knees and sound side during a walking trial (k1: CU Polycentric Knee Joint, k2: Prosthesis Foundation Knee, k3: Otto Bock 3R20).

**TABLE 2.** Temporal-spatial parameters for three prosthetic knees.

Prosthetic knee	Velocity (m/s)	Step length (cm)
CU Polycentric Knee Joint	0.814	68.33
Prosthesis Foundation Knee	0.792	68.33
Otto Bock 3R20	0.892	72.33
Sound Limb	N/A	51.88

## DISCUSSION

The purpose of this pilot study was to explore GRF and temporal-spatial characteristics of three prosthetic knees available to the Thai transfemoral amputee. Overall, the investigation revealed small differences in valley vGRF curve magnitudes between prosthetic knees and the sound limb. The CU Polycentric Knee Joint was capable of stance and swing times that were closer to that of the sound limb and increased preferred walking speed was seen in participants wearing the 3R20. Able bodied gait is characterized by roughly 60% of gait spent in stance and 40% of time spent in swing.<sup>18</sup> Previous investigations have observed the mechanical swing phase control 3R20 to be favorable by users because of a greater sense of stability over a pneumatic swing phase control knee.<sup>21</sup>

The CU Polycentric Knee Joint's ability to provide a more identical swing and stance time is an interesting finding which might be as a result of its lowered Instant Centre of Rotation (ICR) than the two 4-bar linkage knees. The CU Polycentric Knee Joint and Prosthesis Foundation Knee had step lengths that more closely resembled sound limb step lengths. The increased walking speed and larger step length seen in the 3R20 might be a result of a decreased dependence on compensatory mechanisms of the participants,<sup>15</sup> although our data does not allow us to determine that entirely. The lower limb amputee lowers walking speed to reduce the Rate of Metabolic Energy Expenditure (RMEE) ( $V_{O_2}$ , mL/kg per min).<sup>16,17</sup> Walking speed and RMEE could be explored to determine the relationship between speed of walking and metabolic cost when fitted with these knees.

This preliminary investigation was not without its limitations. The small participant sample of three transfemoral prosthesis users makes generalizing the results of this study difficult. Our decision to analyze data from three trials might have resulted in variance in amputee walking performance. Although we noticed no marked differences amongst trial metrics, an increase in walking

trials over several days could reveal the chance of trial-to-trial and day-to-day differences. Future investigations which recruit a larger sample size and able bodied matched control group should be pursued. Also these knee joints should be compared with others commonly used in prosthetic practice. We used a pressure measurement system, which is capable of quantifying center of pressure, but unable to directly measure a force vector applied. Other investigations have utilized coefficients collected from calibration trials to delineate gait phase and in doing so correct GRF and COP data collected from pressure mats. This in turn allows for a better estimation of forces in each foot during the double limb support period.<sup>13</sup> This study focused on vGRF and temporal-spatial parameters, so a more robust description of walking with these knees including kinematic, electromyography and energy consumption should be conducted. There are a number of additional GRF measurements that were not explored in this current study that should be in future work, such as weight acceptance and push-off as well as impulses and joint kinematics as well.<sup>18</sup> Ultimately, the lower limb prosthesis user, especially those living in resource limited environments, will be required to walk and traverse in a variety of terrain. Therefore, research exploring the performances of amputees using these and other new prosthetic technologies during free-living activity should be explored.

## CONCLUSION

This study presents a preliminary investigation on the gait characteristics of transfemoral prosthesis wearers using three prosthetic knees available to the Thai amputee. Special importance was given to the parameters that indicate walking ability. The CU Polycentric Knee Joint should be recognized for its ability to promote a more symmetrical gait and the 3R20, for its potential to increase walking speeds.

## ACKNOWLEDGMENTS

The authors would like to express the gratitude to Ms. Cathy McConnell for her valuable suggestion and support for this research work as well as the Sirindhorn School of Prosthetics & Orthotics (SSPO) for the research funding and thank Assistant Professor Dr. Pairat Tangpornprasert and Assistant Professor Dr. Chanyaphan Virulsri, Department of Mechanical Engineering, Chulalongkorn University for providing the CU Polycentric knee joints in the study as well as for the valuable suggestions and support.

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