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Original Research

The Relationship Between Body Mass Index (BMI) And Walking Speed in Users of SACH Foot Designed Transtibial Prosthesis

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ABSTRACT

Background: Walking speed is an important indicator for assessing mobility in prosthesis users. One factor suspected to influence walking speed is Body Mass Index (BMI). This study aims to determine the relationship between BMI and walking speed in transtibial prosthesis users with a SACH (Solid Ankle Cushion Heel) foot design.
Methods: This observational study used a cross-sectional approach and was conducted at Klinik Bangkit Kaki Palsu from January to June 2025. A total of 15 subjects were purposively selected from a population of 40 patients who met the inclusion and exclusion criteria. BMI was calculated from body weight and height measurements, while walking speed was assessed using the 10-Meter Walk Test on a 14-meter walkway. Data normality was tested using the Shapiro-Wilk test, and the correlation analysis was performed using the Pearson product-moment test.
Results: The majority of subjects were aged 26–35 years (53.3%), male (66.7%), and had a normal BMI (80%). The average walking speed between male and female subjects did not differ significantly. Statistical analysis revealed a significant correlation between BMI and walking speed, with a correlation coefficient of 0.590 and a p-value of 0.020 ($p < 0.05$), indicating a moderate positive relationship.
Conclusion: This study found a significant relationship between BMI and walking speed among transtibial prosthesis users with a SACH foot design. These findings support the importance of considering BMI in prosthesis design and adjustment to enhance walking efficiency and user comfort.

INTRODUCTION

Mobility is a fundamental component of human life, enabling independence, social participation, and the performance of daily activities (World Health Organization [WHO], 2011). Loss of lower limb mobility, particularly due to transtibial amputation, has a profound impact on functional capacity, balance, gait efficiency, and self-confidence among individuals with disabilities worldwide. The World Health Organization estimates that approximately 30 million people globally require mobility assistive devices, including lower-limb prostheses; however, only about 10% have adequate access to these devices due to limitations in availability, cost, and rehabilitation services (WHO, 2011, 2017).

In Indonesia, the need for mobility aids continues to increase in parallel with the rising incidence of amputations caused by diabetes mellitus, traffic accidents, and chronic infections. Data from Riskesdas 2018 indicate that amputations related to chronic disease complications, particularly diabetes, affect approximately 3.5% of the adult population (Kementerian Kesehatan Republik Indonesia, 2018). Despite this growing demand, access to comprehensive rehabilitation services and appropriate prosthetic components remains uneven, especially in lower–middle socioeconomic populations and in regions outside major urban centers.

From a biomechanical perspective, gait performance in transtibial amputees is influenced not only by the presence of a prosthesis but also by individual characteristics and prosthetic component design. One key individual factor is Body Mass Index (BMI), which has been shown to affect gait biomechanics through alterations in joint loading, balance control, energy expenditure, and plantar pressure distribution (Browning & Kram, 2007; DeVita & Hortobagyi, 2003; Spyropoulos et al., 1991). International studies report that higher BMI is associated with reduced gait efficiency and increased mechanical stress during walking, while excessively low BMI may compromise stability and muscular endurance. In amputee populations, these effects may be amplified due to altered limb mechanics and reliance on prosthetic components.

Another important determinant of gait performance is the type of prosthetic foot used. Comparative studies have demonstrated that different prosthetic foot designs—such as SACH feet, single-axis feet, and dynamic-response feet—produce distinct biomechanical and functional outcomes, including variations in step length, symmetry, shock absorption, and walking efficiency (Hsu et al., 2006; Perry & Burnfield, 2010; Torburn et al., 1990). However, findings regarding the superiority of specific foot types remain inconsistent, particularly when user-related factors such as BMI are not adequately controlled or analyzed.

Walking speed is widely recognized as a clinically meaningful functional outcome measure in gait analysis (Bohannon, 1997; Middleton et al., 2015). Beyond serving as a general indicator of mobility, walking speed has been associated with balance confidence, fall risk, community participation, and overall rehabilitation outcomes in individuals with lower-limb amputation. Despite its importance, several previous studies have treated walking speed primarily as a descriptive parameter, without critically examining the factors that modulate it, including the interaction between BMI and prosthetic foot design.

In local clinical practice, particularly in regions such as Central Sulawesi, rehabilitation clinics and prosthetic fabrication centers increasingly rely on simpler and more economical prosthetic foot designs, most notably the Solid Ankle Cushion Heel (SACH) foot (Perry & Burnfield, 2010). The SACH foot is favored for its lightweight structure, durability, and shock-absorbing properties. Nevertheless, objective evaluations of its gait performance remain limited, especially studies that examine how user characteristics such as BMI influence functional outcomes like walking speed.

A review of the existing literature reveals a clear research gap. While previous studies have independently examined the effects of BMI on gait or compared different prosthetic foot designs, there is a lack of integrative research that specifically analyzes the relationship between BMI and walking speed in transtibial amputees using SACH feet, particularly within the Indonesian context. Moreover, limited engagement with international findings has constrained the generalizability and comparative relevance of local studies.

Therefore, this study aims to investigate the relationship between Body Mass Index (BMI) and walking speed in users of transtibial prostheses equipped with SACH feet at the Bangkit Kaki Palsu Clinic. By integrating biomechanical considerations with functional outcome measures, this study seeks to clarify the role of BMI in gait performance and to provide evidence-based insights for prosthetic component selection and rehabilitation planning. The findings are expected to contribute not only to improved local prosthetic services but also to the broader body of knowledge in orthotic and prosthetic rehabilitation.

METHODS

This study employed an analytical observational design with a cross-sectional approach conducted at the Bangkit Kaki Palsu Clinic, Boyolali, Central Java, from January to June 2025. The study population consisted of transtibial amputee patients using prostheses equipped with a Solid Ankle Cushion Heel (SACH) foot. A total of 15 participants were recruited using purposive sampling from a population of 40 individuals who met the inclusion criteria. Inclusion criteria comprised unilateral transtibial prosthesis users with SACH foot design, the ability to walk independently for at least three months post-fitting, age between 17 and 65 years, absence of cardiovascular disease, and willingness to participate in the study. Exclusion criteria included bilateral prosthesis users and individuals with musculoskeletal or neurological disorders.

Body weight was measured using a calibrated digital weighing scale (Omron HN-289, Omron Healthcare Co., Japan) with an accuracy of 0.1 kg, while height was measured using a portable stadiometer (Seca 213, Seca GmbH & Co. KG, Germany) with an accuracy of 0.1 cm. All measurement instruments were calibrated prior to data collection according to the manufacturer's guidelines. Measurements were conducted with participants barefoot and wearing light clothing, standing upright with the head positioned in the Frankfurt plane, in accordance with standardized anthropometric measurement procedures (World Health Organization [WHO], 2020).

Body Mass Index (BMI) was calculated as body weight in kilograms divided by height in meters squared (kg/m^2) and classified according to the World Health Organization (WHO) BMI classification (WHO, 2020). BMI is widely used as an indicator of body composition and has been shown to influence gait biomechanics, balance, and walking efficiency in individuals with lower-limb amputation (Browning et al., 2006; Spyropoulos et al., 1991).

Walking speed was assessed using the 10-Meter Walk Test (10MWT), a valid and reliable functional outcome measure for individuals with lower-limb amputation (Resnik & Borgia, 2011). Time measurement was performed using a digital stopwatch (Casio HS-80TW-1EF, Casio Computer Co., Ltd., Japan). Participants were instructed to walk at a comfortable self-selected speed along a 14-meter walkway, consisting of a 2-meter acceleration phase, a 10-meter timed section, and a 2-meter deceleration phase. Each participant completed two trials, and the mean walking speed was used for analysis to improve measurement reliability, as recommended in previous studies (Resnik & Borgia, 2011).

Data collection was carried out through direct observation and systematic recording using standardized research worksheets. Statistical analysis began with the Shapiro–Wilk test to assess data normality, followed by Pearson Product–Moment correlation analysis to examine the relationship between BMI and walking speed. Pearson correlation analysis is appropriate for assessing linear associations between continuous variables when normality assumptions are met (Field, 2018). The results are presented as frequency distribution tables, mean values, and graphical representations illustrating the relationship between the studied variables.

This study was approved by the Health Research Ethics Committee of Dr. Moewardi General Hospital (RSUD Dr. Moewardi), Surakarta, Indonesia (Approval No: 1.386/VI/HREC/2025). All procedures were conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to data collection after they received a clear explanation regarding the study objectives, procedures, potential risks, and their right to withdraw at any time without any consequences.

RESULTS

This study involved 15 samples of unilateral transtibial prosthesis users using a SACH foot design.

Table 1. Participant Characteristics

Variable	Category	n	%
Age (years)	26–35	8	53.3
	36–45	6	40.0
	46–55	1	6.7
Gender	Male	10	66.7
	Female	5	33.3

Table 1 presents the demographic characteristics of the participants included in this study. A total of 15 unilateral transtibial prosthesis users were analyzed. The majority of participants were male (66.7%), while females accounted for 33.3% of the sample. In terms of age distribution, most participants were within the 26–35 years age group (53.3%), followed by those aged 36–45 years (40.0%), and a smaller proportion aged 46–55 years (6.7%). Overall, the participants were predominantly within the productive age range, which may reflect the functional demands associated with prosthesis use in daily activities.

Table 2. Walking Performance Based on Gender (10-Meter Walk Test, seconds)

Gender	n	Minimum	Maximum	Mean	SD
Male	10	10.10	12.60	11.45	0.71
Female	5	10.90	12.50	11.90	0.64

Values are presented as mean ± standard deviation.
Lower values indicate faster walking performance.

Descriptive statistics for walking performance measured using the 10-Meter Walk Test (10MWT) are presented in Table 2. Male participants completed the test in a mean time of 11.45 ± 0.71 seconds, while female participants completed the test in a mean time of 11.90 ± 0.64 seconds. No formal subgroup comparison between sexes was conducted due to the limited sample size, particularly in the female subgroup.

Table 3. Body Mass Index (BMI) Classification

BMI Category	n	%
Normal	12	80.00
Obese	3	20.00
Total	15	100.00

As shown in Table 3, most participants were classified as having a normal Body Mass Index (BMI) (80%), while 20% were classified as obese.

Table 4. Shapiro Wilk Normality Test

Variable	p-value	α	Distribution
Body Mass Index	0.575	0.05	Normal
Walking Time	0.839	0.05	Normal

$p > 0.05$ indicates normal distribution.

The results of the Shapiro–Wilk normality test are summarized in Table 4. Both BMI ($p = 0.575$) and walking time ($p = 0.839$) were normally distributed ($p > 0.05$), supporting the use of parametric statistical analysis.

Table 5. Pearson Correlation Between BMI and Walking Time

Variable Pair	r	p-value	n
BMI – Walking Time (10MWT)	0.59	0.020	15

Pearson Product–Moment correlation analysis.
Walking performance is expressed as time (seconds); higher values indicate slower walking speed.

The relationship between BMI and walking speed was analyzed using the Pearson product-moment correlation test. As presented in Table 5, a statistically significant moderate positive correlation was observed between BMI and walking speed ($r = 0.590$, $p = 0.020$). This finding indicates that higher BMI values were associated with longer walking times, reflecting slower walking performance.

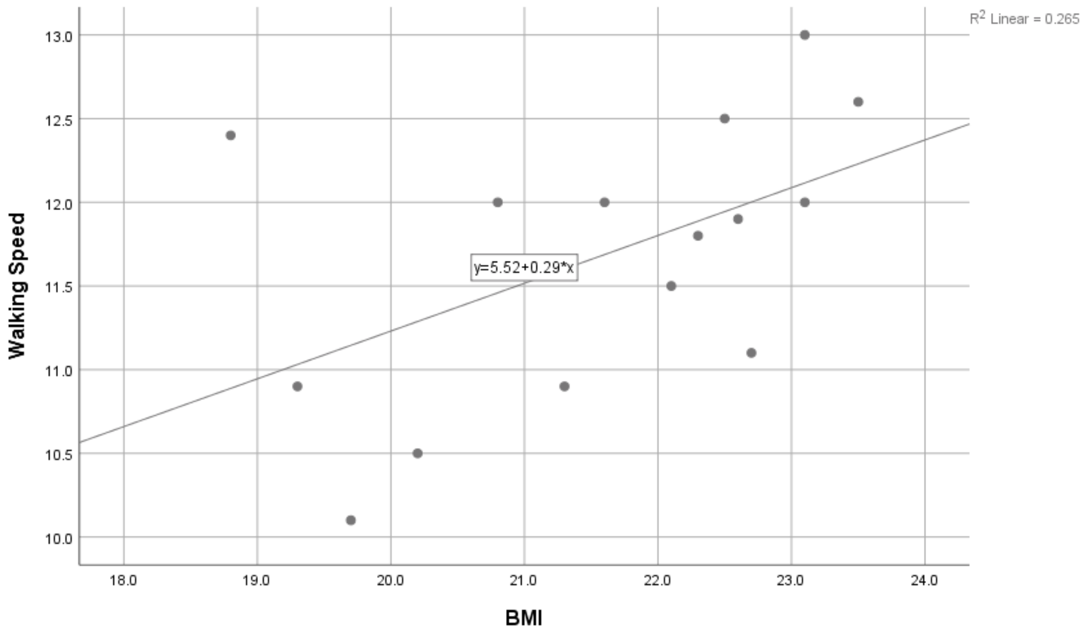

Figure1. Scatter Plot of BMI vs Walking Speed in Users of SACH Foot Prostheses

This relationship is further illustrated in Figure 1, which presents a scatter plot of BMI versus walking speed. The scatter plot demonstrates a positive linear trend, visually supporting the correlation analysis, with higher BMI values corresponding to increased walking time.

DISCUSSION

This study investigated the relationship between body mass index (BMI) and walking speed in users of transtibial prostheses with a Solid Ankle Cushion Heel (SACH) foot design. The primary finding was a statistically significant moderate positive correlation between BMI and walking time ($r = 0.590$, $p = 0.020$), indicating that individuals with higher BMI tended to demonstrate slower walking performance. As this study employed a cross-sectional design, the observed relationship should be interpreted as an association rather than a causal effect.

From a biomechanical perspective, the association between higher BMI and reduced walking speed can be explained by increased mechanical demands during gait. Excess body mass is associated with higher joint moments at the hip and knee, increased ground reaction forces, and greater muscular effort required to maintain forward progression and postural stability (Browning & Kram, 2007; DeVita & Hortobagyi, 2003). In individuals with transtibial amputation, these biomechanical challenges may be further amplified due to altered limb mechanics, asymmetric loading patterns, and reliance on prosthetic components for shock absorption and propulsion (Spyropoulos et al., 1991; Winter, 2009). Additionally, increased body mass may negatively affect center-of-mass control, thereby reducing gait stability and efficiency (Hof, 2008).

Higher BMI has also been consistently associated with increased metabolic cost during walking. Previous studies have reported that individuals with transtibial amputation expend approximately 10–40% more energy during ambulation compared to able-bodied individuals walking at similar speeds (Waters & Mulroy, 1999). When combined with elevated body mass, this increased energy requirement may contribute to earlier fatigue, reduced endurance, and slower self-selected walking speed, as observed in the present study (McDonald et al., 2018; Suh et al., 2019). These findings align with previous reports demonstrating that body composition plays an important role in functional gait outcomes among prosthesis users.

Although descriptive differences in walking performance between male and female participants were observed, no formal statistical comparison was conducted due to the limited sample size, particularly within the female subgroup. Therefore, any apparent sex-related differences should not be overinterpreted. Previous studies suggest that differences in gait performance between males and females are often mediated by body composition, muscle strength, and physical activity level rather than sex alone (Franchignoni et al., 2017; Sialino et al., 2021). In this context, BMI appears to be a more relevant functional factor influencing walking performance than gender per se.

Walking speed was selected as the primary functional outcome because it is widely recognized as a clinically meaningful indicator of mobility, balance confidence, and rehabilitation success in individuals with lower-limb amputation (Bohannon, 1997; Gonzales et al., 2021). Beyond serving as a descriptive parameter, walking speed reflects the integrated effects of neuromuscular control, prosthetic alignment, and biomechanical efficiency. The moderate association observed in this study suggests that BMI may contribute meaningfully to walking performance, although it should not be considered a sole or definitive predictor.

From a prosthetic perspective, all participants in this study used a SACH foot, which is designed to provide basic shock absorption and stability through a cushioned heel and rigid keel. Previous studies have shown that SACH feet offer acceptable gait performance and energy efficiency, particularly for users with low to moderate activity levels (Highsmith et al., 2016; Sushama et al., 2025). However, prosthetic foot characteristics such as stiffness, energy storage, and shock absorption have been shown to influence spatiotemporal gait parameters and loading patterns in transtibial amputees (Van der Linden et al., 2002; Sawers & Hafner, 2013). Because prosthetic foot type was not varied in this study, the findings cannot be generalized to users of dynamic-response or energy-storing feet.

Clinically, the findings of this study suggest that BMI should be considered as part of a comprehensive functional assessment in transtibial prosthesis users. Rather than directly informing prosthetic design decisions, BMI may assist clinicians in anticipating gait limitations, tailoring rehabilitation programs, and optimizing gait training strategies. Individuals with elevated BMI may benefit from integrated interventions focusing on weight management, muscle strengthening, and endurance training to improve walking efficiency and overall mobility.

Limitations

This study has several limitations. First, the small sample size (n = 15) limits statistical power and generalizability. Second, purposive sampling introduces potential selection bias, and the sample may not represent all transtibial prosthesis users. Third, potential confounding factors such as age, sex, duration of prosthesis use, physical activity level, and comorbidities were not controlled. Fourth, all participants used the SACH foot, so findings cannot be generalized to other prosthetic foot types. Finally, walking speed was assessed under controlled clinical conditions, which may not fully reflect real-world walking performance. Future studies with larger, more diverse samples and multivariate analyses are recommended.

CONCLUSION

This study found a moderate and statistically significant association between body mass index (BMI) and walking speed in transtibial prosthesis users wearing a Solid Ankle Cushion Heel (SACH) foot, with higher BMI values related to slower walking performance. These findings suggest that body composition may influence functional gait outcomes in this population. However, the interpretation of results is limited by the small sample size, non-representative sampling, lack of control for potential confounders, and the exclusive use of a single prosthetic foot type. Therefore, the results should be viewed as preliminary and not as evidence to guide prosthetic design. Future studies incorporating larger samples, multiple prosthetic components, and biomechanical gait analysis are needed to strengthen clinical applicability.

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