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The relationship between balance and spatiotemporal gait factors with quality of life in below-knee amputees

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Abstract

Background: Losing a limb can negatively impact balance and gait, leading to reduced quality of life.

Aim: This study aimed to examine correlations between spatiotemporal gait and balance with scores of the Quality of Life questionnaire.

Materials and Methods: 30 veterans with unilateral below-knee amputations underwent gait analysis to measure step length, stride length, stance time, cadence, velocity, and walking symmetry index by step length. Static balance was assessed via the center of pressure path length by Wii Balance Board during standing. The Timed Up and Go test evaluated dynamic balance. The QoL scores were recorded using the Quality of Life questionnaire for amputees, Trinity Amputation, and Prosthesis Experience Scales (TAPES). Pearson's correlation coefficients were calculated between spatiotemporal of gait, balance scores, and TAPES domain outcomes.

Results: Stride length (r=0.660), prosthetic step length (r=0.648) and intact step length (r=0.618) showed significant moderate positive correlations with psychosocial adjustment, while amputation limb stance time (r=-0.409) correlated weakly. Activity limitations negatively correlated with step/stride lengths (r range -0.781 to -0.784) and cadence (r=-0.538). Moreover, prosthesis satisfaction was associated with improved walking symmetry (r=0.445) and prosthetic stance time (r=0.388).

Conclusion: Optimizing gait and balance in below-knee amputation can improve quality of life. Biomechanical factors should be targeted in rehab programs to enhance well-being.

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1. Introduction

The prevalence of limb amputation ranges from 2.8 to 3.9 per 10,000 people [1]. Among these, approximately 85% are related to lower limb amputations [2]. Losing a body limb disrupts body weight distribution and consequently alters the static and dynamic balance [3]. This, in turn, causes compensatory mechanisms that disrupt spatiotemporal gait factors, including stride length, step length, velocity, cadence, stance time, and symmetry of the walking [4]. Reducing the quality of daily activities such as driving, walking, and working can decrease the quality of life [5].

Determining the relationship between these changes can enhance the level of rehabilitation programs for individuals with limb amputations [6]. The Trinity Amputation and Prosthesis Experience Scales (TAPES) questionnaire provides valuable information in three domains: psychosocial health, physical functioning, and satisfaction with the prosthesis for individuals with amputations. This questionnaire aims to identify factors related to enhancing the quality of life of amputees [7].

This questionnaire includes three sections: psychosocial adjustment, physical restriction, and satisfaction with the prosthesis, which measure an individual's overall adjustment to limb loss and prosthesis, individual movement restrictions in various domains due to amputation, and personal satisfaction with the aesthetic and functional aspects of the prosthesis. TAPES comprises three subscales and comprehensively assesses the quality of life of amputated individuals by considering physical, psychological, and social factors associated with prostheses and limb loss [7].

Research into the improvement of quality of life in individuals with limb amputation has been limited [8, 9, 10, 11, 12, 13]. Sinha et al. (2011) identified employment status, use of walking aids, and phantom limb pain as variables that related to quality of life scores on the SF-36 questionnaire for amputees [14]. In another study, Hando et al. (2023) correlated factors such as education level, age, duration of amputation, and diseases with quality of life scores on the SF-36 in 160 individuals with lower limb amputation [15]. Godlwana et al. (2020) demonstrated that eight weeks of strength and balance exercises improved strength, balance, and quality of life scores [16].

Most prior studies have focused on the effectiveness of factors like age, diseases, and physical exercises on the quality of life of these individuals. However, research examining the relationship between biomechanical factors, balance, and quality of life is limited. Therefore, there needs to be more comprehensive research examining the determinants of quality of life in individuals with lower limb amputations. While many studies have used the SF-36 questionnaire to assess the quality of life in individuals with lower limb amputations [14, 17, 18, 19, 20], the TAPES evaluates the specific aspects of quality of life for amputees. Utilizing the TAPES questionnaire in research may aid in gaining a deeper understanding of factors related to the quality of life for individuals with lower limb amputations.

This study addresses the gap in comprehension of biomechanical factors, balance, and quality of life for individuals with unilateral lower limb amputations. We used the TAPES scale in our study, a specialized questionnaire to evaluate the quality of life in this population. Our research is unique and valuable, as it provides new insights into the experiences of amputees and highlights the importance of using a specialized tool to assess their quality of life comprehensively. The result of this study can provide information for clinicians and prosthetists in developing targeted treatments designed to address the specific needs of below-knee amputees. The research highlights the connection between physical improvements, overall quality of life, and psychological well-being, emphasizing the importance of a holistic approach to amputee care.

2. Materials and Methods

This descriptive cross-sectional was conducted with 30 participants with unilateral below-knee amputations [21, 22] who visited the Kowsar Orthotics and Prosthetics Center in Tehran.

Initially, participants were acquainted with the research process and the evaluation methods in an informative session. The inclusion criteria for the study were as follows [23]:

1. Age between 50-70 years [24, 25]
2. At least one year since amputation [26]
3. Ability to walk independently without assistive devices such as a walker, cane, or wheelchair
4. No use of cardiac or neurological medications
5. No hearing or visual impairments such as amblyopia, vertigo
6. No respiratory or blood pressure issues after walking for 6 minutes.

Exclusion criteria were as follows [27]:

1. difficulties with fitting the prosthesis throughout the examination and gait analysis
2. Unwillingness to continue participation
3. Onset of pain or discomfort during testing.

The study was conducted under the ethical code IR.UT.SPORT.REC.1401.029. Participants were below-knee amputees who provided informed consent with the option to opt out at any stage. The data was anonymized to protect the identities of the participants. Individuals were enrolled in the study after signing informed consent forms. The spatiotemporal gait variables measured included prosthetic limb step length, intact limb step length, stride length, walking symmetry, velocity, cadence, and stance time duration of both the prosthetic and intact limbs. A Casio model EX-FX1 high-speed camera of 300 Hz was used to measure the spatiotemporal gait variables. Markers were attached to the heel area of participants, and they were instructed to walk back and forth along a 6 m path. The camera was positioned perpendicularly to the center of the path at a distance of 6 m from it and elevated 80 cm above the ground. The spatiotemporal gait variables were assessed using the Kinovea [2, 28] software version 0.9.5, which has a validity and reliability of 97% [28].

To assess static balance, the displacement of the center of pressure of the participants was measured using a Wii balance board with validity and reliability greater than 77% [29, 30]. This index represents the distance the center of pressure moves from a reference point during the measurement period. The overall displacement indicates the balance changes over the time of measurement. The total path of COP displacement was calculated using the following formula [31].

$$COP_{PathLength} = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

Participants stood on the balance board for three attempts, each lasting 30 se. The data from each individual was transferred to a computer via Bluetooth and processed using Excel software. Additionally, the Timed Up and Go (TUG) test was used to assess dynamic balance, with validity and reliability greater than 96% [32, 33]. In this test, the time it took for participants to rise from a standard armchair with a seat height of 45 cm, walk a distance of 3 m at their maximum safe speed, return, and sit down again was measured [34]. To examine walking symmetry, the following formula was used [35].

$$SI = \frac{x_p - x_i}{0.5(x_p + x_i)} * 100$$

where X_p was the step length of the amputation limb and X_i was the step length of the intact limb. The TAPES questionnaire was used to assess the quality of life of the individuals in the study, with a validity and reliability of 70% [7, 36]. This scale evaluates the psychosocial adjustment, physical restriction, and functional aspects of individuals. In this scale, higher scores in the psychosocial adjustment and satisfaction with prosthesis sections indicate better scores, while lower scores in the physical restriction section indicate better quality of movement [36].

Descriptive statistics determined the mean, standard deviation, and data dispersion indicators. The Shapiro-Wilk test was used to evaluate the normal distribution of the data. Pearson's correlation coefficient was also used to examine the relationships between variables [21, 37]. All data were analyzed using Excel and SPSS version 23.

3. Results

Table 1 represents the descriptive analysis of the characteristics of 30 participants. The average age of the individuals was 59 years, with an average height of 173 cm and weight of 83 kg. According to the values obtained from the results, the average dynamic balance in TUG test and static balance (path of the center of pressure displacement) using the Wii balance board was 11.26 sec and 82.62 cm, respectively. Furthermore, the average of the spatiotemporal gait factors included an amputation limb step length of 61.93 cm, an intact limb step length of 58.87 cm, a stride length of 120.43 cm, a walking cadence of 79.87 steps per min, a velocity of 0.79 m per sec, a walking symmetry of 4.9, a stance time duration in the intact limb of 0.81 sec, and the amputation limb of 0.75 sec.

Data normality was evaluated using the Shapiro-Wilk normality test. The data indicated a normal variable distribution (P<0.05). Furthermore, Pearson's correlation test was utilized to examine the relationship between the data (P<0.05).

According to the Pearson test results, the psychosocial adjustment domain of the TAPES questionnaire showed a significant positive correlation with step length (both limbs), stride length, and COP path length as the static balance. Additionally, a significant negative correlation between the stance time of the amputation limb and the psychosocial adjustment domain has been shown. Also, the data analysis found a positive correlation between the activity restriction component of TAPES and stance time (both limbs), there was a negative correlation between the step length (both limbs), stride length, cadence, velocity, and COP path length with activity restriction.

Results showed a negative correlation between satisfaction of the prosthetics with stance time on an intact limb and a positive correlation with walking symmetry index and dynamic balance scores (TUG) (Table 2) See the Appendix for the scatter plot illustrating the correlation between variables.

Table 1. Descriptive data of participants

Variables	mean±SD	Max	Min
Age (years)	59.33±8.32	69	50
Height (cm)	173.80±7.26	185	159
Weight (kg)	83.713±8.04	98	60
Prosthetic wearing time (hour)	8.6±0.60	15	3
Duration of amputation (years)	30.66±0.87	38	15
Step length (cm) intact limb	61.93±6.9	75	46
Step length (cm) amp. limb	58.87±6.2	72	45
Stride length (cm)	120.43± 13.9	148	90
Cadence (steps per min)	79.87±6.6	102	61
Speed of walking (m/s)	0.79±0.11	1.10	.61
Symmetry index	4.9±3.2	9.52	1.1
Stance time (s) amp. limb	0.75±0.07	0.92	0.62
Stance time (s) intact limb	0.81±0.01	0.98	0.64
TUG (s)	11.26±1.1	13.66	9.09
COP total path length (cm)	82.62±18.04	116.45	48.13
Psychosocial adjustment	26.80±4.40	37	20
Activity restriction	20.87±3.80	30	15
Satisfaction with the prosthetic	24.17±1.46	38	8

Table 2. Result of Pearson correlation between gait parameters, balance with quality of life

Variables	Psychosocial adjustment		Activity restriction		Prosthesis satisfaction	
	r	*P*	r	*P*	r	*P*
Amputation limb step length (cm)	0.648	0.0001	-0.800	0.0001	0.019	0.919
Intact limb step length (cm)	0.618	0.0001	-0.784	0.0001	0.130	0.494
Stride length (cm)	0.660	0.0001	-0.781	0.0001	0.097	0.611
Cadence (steps per min)	0.192	0.310	-0.538	0.002	0.339	0.067
Velocity (m/s)	0.171	0.367	-0.520	0.003	0.039	0.839
Symmetry index	0.258	0.168	-0.230	0.221	-0.445	0.011
Stance time (s) intact limb	-0.278	0.138	0.556	0.001	0.221	0.240
Stance time (s) amp. limb	-0.409	0.025	0.547	0.002	0.388	0.034
TUG (s)	-0.083	0.664	-0.356	0.054	0.468	0.009
COP total path length (cm)	-0.516	0.004	0.576	0.001	0.229	0.224

4. Discussion

The present study aimed to investigate the relationship between spatiotemporal gait variables (step length, stride length, velocity, cadence, walking symmetry index, stand time), static balance (COP path length), and dynamic balance (TUG) with different domains of TAPES questionnaire, which include psychosocial adjustment, physical restriction, and satisfaction with the prosthetic limb among individuals with unilateral below-knee amputations. The goal was to identify the factors associated with the quality of life in these individuals. The participant characteristics are presented in Table 1.

The spatiotemporal gait variables measured in this study, including step lengths, stride length, cadence, velocity, stance times, and symmetry index, were also within the ranges documented in prior investigations involving this population [38, 39, 40]. Moreover, the data of balance components such as TUG score and path length of center of pressure has a mean range of 11.26±1.1 (s), 82.62±18.04 (cm), were similar to values published in earlier work analyzing postural control in individuals with lower limb amputations [41, 42]. Furthermore, the data indicated a significant relationship between spatiotemporal gait and balance factors with the quality of life of individuals with unilateral below-knee amputations.

The results of the data showed a positive correlation between stride length, and step length (both limbs) and a negative correlation between stance time (amputation limb), and static balance (COP) with the psychosocial adjustment component of TAPES questionnaire ($P<0.05$). It is considered that a better balance is indicated by lower scores of TUG and COP path length. These findings are consistent with the research conducted by Miller et al. (2001), which investigated the relationship between psychological factors and gait abnormalities [43]. The relationship between these variables suggests that improvements in walking and static balance may contribute to the psychological well-being of individuals with lower limb amputations [44, 45]. An increase in stride and step length indicates enhanced movement efficiency and reduced physical limitations [46]. Conversely, reduced stance time on the prosthetic limb during walking and improvement in balance can decrease fatigue during activities such as walking [17]. All these factors can lead to an improvement in self-confidence in walking and quality of life in individuals with amputation [47, 48].

The activity restriction scores from the TAPES questionnaire demonstrated a negative correlation with step length (both limbs). The data also showed a positive correlation between the stance time of both limbs during walking and static balance (COP) ($P<0.05$). The results indicate that improvements in step length, stride length, cadence, gait velocity, and static balance may decrease mobility disorder in individuals with unilateral transtibial amputation. These findings align with previous studies by Gailey et al. (2008) [49], Kahle et al. (2016) [50], and Sansam et al. (2009) [23]. Restricted stride length and gait velocity can diminish motor function and increase energy expenditure during walking. Additionally, poor balance prone individuals to an elevated fall risk. These factors contribute to a reduction in confidence of individuals with lower limb amputation during daily movements and subsequently decrease the quality of physical activities including walking and running [51].

In addition, data analysis revealed a positive relationship between the walking symmetry index with the prosthesis satisfaction scores on the TAPES questionnaire ($P<0.05$). The findings indicate that enhancements in the symmetry index can increase an individual's satisfaction with their prosthesis. Improvement in gait symmetry could potentially reduce pressure on other body segments, and lead to fatigue reduction in individuals with limb amputations [52, 53].

According to the data, there was a positive correlation between TUG scores and satisfaction with the prosthesis ($P<0.05$). It is important to note that a lower TUG score indicates better balance. However, it seems that better balance is associated with less satisfaction with the prosthesis despite the positive correlation between them. Several complex reasons may explain the inverse connection between dynamic balance and prosthesis satisfaction in this study. Increased dynamic balance may lead to increased prosthetic device expectations, resulting in decreased satisfaction with prosthesis [17, 54]. Moreover, satisfaction with the present prosthesis can be influenced by the level of satisfaction with previous prosthetic devices; a factor that was not considered in this research. This aspect is missed in the analysis of user satisfaction, which constitutes a limitation.

Furthermore, although we examined the direct correlation between balance scores and satisfaction, it is important to consider that other substantial variables, including prosthesis fit and weight, have a critical impact on comfort, usability, and consequently the user's perceptions. Further research is required to identify and clarify other factors that may influence the satisfaction with prostheses.

The analysis further showed a positive correlation between the stance time on the amputation limb and the prosthesis satisfaction scores of the TAPES questionnaire (P<0.05). Greater prosthesis function may be indicated by a longer period of weight-bearing on the prosthetic side [55]. A prosthesis that fits well promotes sustained weight bearing, which increases reliance and utilization of the prosthetic limb for daily tasks [56, 57].

Additionally, a prolonged standing time for the amputated limb may suggest better balance and stability when using the prosthetic device [40]. Improved stability may lower the falling risk and lead to increased confidence in the ability of individuals to walk [58, 59]. All these factors contribute to an overall improvement in satisfaction with the prosthesis [57].

Although the present study presents new insights into the correlation between balance, spatiotemporal gait factors, and quality of life in patients with unilateral transtibial amputees, it is important to address several limitations. First, the small sample size and unique subjects make it difficult to apply the findings to all lower-limb amputees. Furthermore, the cross-sectional approach limits the investigation of changes across time by capturing data at a single moment in time. The study recruited participants from one clinic which may limit the diversity of the sample. Moreover, self-reported data obtained from questionnaires can be prone to bias. Correlations can discover associations between variables, but determining causes needs controlled experimental investigations that control the identified components.

5. Conclusions

Overall, the observed associations in this study between spatiotemporal gait parameters and quality of life aspects emphasize the relationship between physical and mental health in individuals with unilateral lower limb amputation. Therefore, a comprehensive approach targeting biomechanical and psychological factors in these individuals is necessary to enhance rehabilitation sessions.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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