Turk J Phys Med Rehab 2026;72(1):63-72
DOI: 10.5606/tftrd.2026.15612
Available online at www.turkishjournalpmr.com

Original Article

The effect of microprocessor-controlled prostheses on walking pattern and energy consumption in above-the-knee amputees

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ABSTRACT

Objectives: The aim of this study was to investigate microprocessor-controlled (MIC) and non-microprocessor-controlled (non-MIC) prostheses in above-the-knee amputees in terms of energy consumption and gait pattern.

Patients and methods: Between June 2018 and February 2019, a total of 34 unilateral transfemoral male amputee patients (mean age: 40.6±13.2 years; range, 19 to 65 years) were included in this cross-sectional study. The patients were divided into two groups as Group 1 (n=17) using an MIC knee unit prosthesis and Group 2 (n=17) using a mechanical (n=5), pneumatic (n=8), or hydraulically (n=4) controlled knee unit prosthesis. Outcome measurements included three-dimensional gait analysis, Locomotor Capabilities Index-5 (LCI-5), exercise tolerance test, Satisfaction with Prosthesis Questionnaire (SAT-PRO), Short Form-36 (SF-36) Health Survey Questionnaire, and 6-min walk test (6MWT).

Results: In the MIC prosthesis group, amputated side walking speed (p=0.007), intact side walking speed (p=0.020), amputated side stride length (p=0.008), and amputated side single support phase duration (p=0.049) were significantly higher, while amputated side stride time (p=0.029) was significantly lower compared to the non-MIC prosthesis group. Energy consumption value was significantly lower in the MIC prosthesis group (p=0.005). The MIC prostheses were found to provide a significant improvement in physical health component compared to non-MIC prostheses (p<0.05). Satisfaction with the current prosthesis was significantly higher in the MIC prosthesis group (p=0.002). The gait capacity was found to be significantly higher in the MIC prosthesis group (p<0.001).

Conclusion: Our study results suggest that MIC prostheses should be used more widely in the rehabilitation process and daily lives of above-the-knee amputees.

Keywords: Above-the-knee amputee, energy consumption, gait analysis, microprocessor-controlled prosthesis.

Lower extremity amputation causes diminished quality of life (QoL) and reduced mobility. The main goal of prosthetic training for patients with lower extremity amputation is to provide standing and normal walking function.[1] The overall success rate in achieving functional ambulation in the patients with a lower limb amputation varies approximately from 36 to 70%.[2]

The main components of above-the-knee prostheses consist of socket, suspension system, knee unit, shank and foot unit. The purpose of the knee unit is to provide stability during the stance phase of walking, knee movement during the swing phase of walking, and knee flexion during sitting. Knee units are divided into two large groups as mechanically controlled and microprocessor-controlled (MIC) unit.[3] Mechanical control in the swing phase is provided by fixed-variable friction, hydraulic and pneumatic systems. Mechanical control in the stance phase is provided by manual locking, weight-activated brake, polycentric axle, or hydraulic systems.[2-4]

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Received: August 09, 2024 **Accepted:** June 12, 2025 **Published online:** December 19, 2025

Cite this article as: Baldug SG, Güzelküçük Ü, Adıgüzel E, Demir Y. The effect of microprocessor-controlled prostheses on walking pattern and energy consumption in above-the-knee amputees. Turk J Phys Med Rehab 2026;72(1):63-72. doi: 10.5606/tftrd.2026.15612.

In MIC prostheses, the flexion and extension resistance in the knee joint during swing and/or stance phase is controlled by the microprocessor.[3] The MIC knees allow walking at variable speeds through adaptive control of the swing phase and provide safer walking by adjusting to adaptive control of the stance phase, compared to mechanically controlled knees.[3] The MIC knees include sensors that monitor knee joint position during the swing phase, as well as pressure sensors that detect and evaluate ground related forces during the stance phase. Sensor systems can measure joint moments, pressure values, and angles.[4] This increases walking endurance and makes walking easier on uneven ground.[3] In addition, MIC prostheses are lighter than non-MIC prostheses,[3] and should be preferred in more active amputees.[3,4] However, there are certain disadvantages of high cost,[4] maintenance, and battery charging time.

There are studies in the literature comparing non-MIC prostheses and MIC prostheses in terms of energy expenditure and QoL,[5] stride characteristics,[6] or mobility and satisfaction.[7] Although the use of MIC prostheses has become widespread in recent years, the number of studies on the effects of these prostheses on energy consumption and gait in transfemoral amputees is relatively small. In the present study, we hypothesized that there would be differences in walking patterns and energy consumption between amputees using MIC prostheses and those using non-MIC prostheses. We, therefore, aimed to investigate the effects of MIC prostheses on energy consumption and gait pattern and in above-the-knee amputees through comparisons with other prostheses.

PATIENTS AND METHODS

This single-center, cross-sectional study was conducted at University of Health Science, Gaziler Physical Terapy and Rehabilitation Research and Training Hospital, Department of Physical Medicine and Rehabilitation between June 2018 and February 2019. Patients aged between 18 and 65 years who achieved independent community ambulation and had a unilateral above-the-knee amputation were included. Exclusion criteria were unwillingness to take part in the study, having deformity, contracture or additional amputation, leg length discrepancy of ≥2 cm, less than six months have passed since the amputation, experience with the current prosthesis for less than eight weeks, comorbidity or neuromuscular disease that may preclude performance of the study, or being not cooperative. Since the patients using MIC prosthesis evaluated for the study were veterans, the sex of this group was all male. Considering that a sex difference between the two groups could affect the results of the study, only male patients were evaluated for both groups and those who were eligible were included in the study. Finally, of a total of 47 male patients who were considered eligible for the study, 34 (mean age: 40.6±13.2 years; range, 19 to 65 years) were recruited. The patients were divided into two groups as Group 1 (n=17) using an MIC knee unit prosthesis and Group 2 (n=17) using a mechanical (n=5), pneumatic (n=8), or hydraulically (n=4) controlled knee unit prosthesis. The study flowchart is shown in Figure 1. All patients were evaluated in terms of age, height, weight, body mass index (BMI), educational status, occupation, amputation etiology, amputation side and duration, types of prosthesis used according to knee and foot units, duration of prosthesis use, stump length, dominant side and comorbidities. Relevant data were recorded in the Case Report Form for each patient.

Written informed consent was obtained from each patient. The study protocol was approved by the Ankara Numune SUAM Clinical Research Ethics Committee (Date: 25.05.2018, No: E-18-1983). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Outcome measurements

The study evaluation criteria were determined as three-dimensional (3D) gait analysis, Satisfaction with Prosthesis Questionnaire (SAT-PRO), exercise tolerance test, Locomotor Capabilities Index (LCI-5), 6-minute walk test (6MWT), and Short Form-36 (SF-36) Health Survey Questionnaire.

The 3D gait analysis was performed in the movement analysis laboratory of University of Health Science, Gaziler Physical Terapy and Rehabilitation Research and Training Hospital. Gait analysis was performed by the same physician for each patient. In the 3D gait analysis, performed using the Vicon 512 (Oxford Metrics Co/USA) system, the temporospatial and kinematic gait characteristics were recorded. This system is video supported and consists of seven infrared cameras, two video cameras and two power platform systems connected to the main terminal. Fifteen infrared retroreflective markers with a diameter of

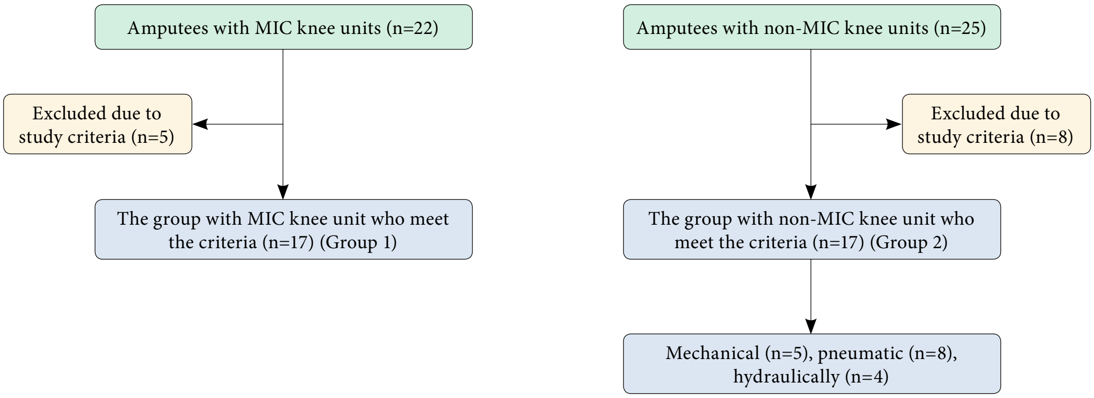

Figure 1. Study flowchart.

MIC: Microprocessor-controlled; non-MIC: Non-microprocessor-controlled.

15 mm, which enable three-dimensional recording during walking, were placed on both spina iliaca anterior superior, on the midpoint of the line connecting both spina iliaca posterior superior, on the midpoints of the lateral thighs, on the lateral condyles in the knees, on the midpoints of the lateral legs, on the lateral malleoli in the ankles, on the posterior side of both calcaneus, and on the bilateral second metatarsal heads in the feet, according to the "plug-in-gait" marker placement definitions used by the software. After the markers were placed, static tests were performed on the patients before the dynamic test so that the infrared cameras could recognize the markers. The patients were asked to walk with their existing prostheses at normal gait in an area consisting of a 10-meter walking track and power platforms. The normal walking pattern of the patients was evaluated and walking was repeated until a minimum of four optimal walking trials were obtained for the dynamic test study. After obtaining the data records required for the analysis, the markers used in the static test recording were uploaded to the Vicon Workstation version 4.5 software (Vicon Motion Systems Ltd., Oxford, UK), which is the motion analysis software. The mathematical data of the walking phases recorded in a three-dimensional environment were, then, obtained. By transferring the mathematical data to the polygon program, data of the temporospatial and kinematic characteristics of gait were obtained. The temporospatial characteristics evaluated in the study were cadence, single support phase time, stride length, stride time and walking speed. The kinematic characteristics evaluated in the study were the angles of the hip, knee and ankle joints in the transverse and sagittal planes during stance and swing phases.

The energy consumption of the cases was calculated in the exercise tolerance laboratory of the same hospital. The energy consumption measurements of the patients were made using an open circuit indirect calorimeter (Vmax 29c, SensorMedics LLC, CA, USA) system and a mask. The subjects were rested by sitting on a chair in front of the treadmill until they reached resting heart rate values before the test. After an appropriate rest period with a face mask, the test was started at a treadmill rotation speed of 1.6 m/s. After warming up at this speed for 1 min, a speed increase of 0.2 m/s was made every 3 min. In the last minute, cooling down was applied with a speed of 1.6 m/s and the patients were walked for 11 min in total. The first and last 1-min segments, in which the steady state was reached, were not included in the calculation in the 11-min walking period. The energy consumption amounts of the cases were measured with computer calculations of the amount of oxygen consumed in calories.

The 6MWT was used to measure the walking capacity of the cases. It is a reliable measure of functional capacity in individuals with lower extremity amputation.[8] In this study, the patients were instructed to walk for 6 min at their most comfortable walking speed in a previously planned area under the supervision of the same physician, and the distance walked was calculated and recorded in meters.

The SF-36 Health Survey Questionnaire was used to evaluate the general health status and QoL of the cases. The scale consists of 36 items in two main scales, the physical component summary and the mental component summary, providing measurement of a total of eight subscales. The physical function, physical role, body pain, and general health subscales belong to the physical component scale, while the energy/vitality, social function, emotional role, and mental health subscales belong to the mental component scale.[9] The score for each item is coded and converted into points ranging from 0 (worst health status) to 100 (best health status). The Turkish validation of the SF-36 was conducted by Koçyiğit et al.[10]

The LCI, which was developed to evaluate the locomotor abilities of patients with lower extremity amputation,[11] was used in this study to assess the patients' ability to move with their current prosthesis. The LCI-5 consists of 14 items, each with five options, ranging from '0' indicating that the patient cannot perform the specified activity, to '4' indicating that the patient can perform it without assistance. The maximum score is 56,[12] with higher score indicating a higher locomotor capacity index and less need for assistance. The Turkish reliability of the LCI was conducted by Safaz et al.[13]

The satisfaction level of the patients with their current prostheses was evaluated with the SAT-PRO. This questionnaire consists of 15 questions, evaluated with a four-step ordinal scale, where '0' indicates dissatisfaction, and '3' full satisfaction. The scores of the sixth, 12^{th}, and 14^{th} questions, which are asked negatively, are reversed.[14] The maximum score a patient can receive is 45 points, with a higher total score representing greater prosthesis satisfaction. The scoring system was used in accordance with the original.[15] The Turkish validation of the SAT-PRO was conducted by Safaz et al.[16] All outcome measurements were performed and evaluated by the same physician.

Statistical analysis

Study power analysis and sample size calculation were performed using the G*Power version 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Taking the study by Ladlow et al.[17] as reference with the recorded Group 1 treadmill mean predicting ambulatory energy expenditure (PAEE) Metamax value of 2.40±0.71 and Group 23.72±1.37, providing effect size 1.20, study power 80%, and type 1 error 0.05, taking a 20% rate of patient loss into consideration, it was planned to recruit a minimum of 24 patients, as 12 in each group.

Statistical analysis was performed using the SPSS for Windows version 22.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. The Kolmogorov-Smirnov test was used to determine whether continuous variables conformed to normal distribution. According to the results of the normality analysis, it was determined that the quantitative variables did not provide normality. Therefore, comparison analyses of the variables were examined with the Mann-Whitney U test which is one of the non-parametric testing techniques. The chi-square test was used to compare discrete parameters between the groups. A p value of <0.05 was considered statistically significant.

RESULTS

The demographic and etiological data for each group are detailed in Table 1. The MIC prosthesis users were significantly younger than non-MIC users (p<0.001), and all participants in both groups were male. There was a significant difference between the groups in terms of educational status (p=0.007) and etiology (p<0.001). No significant differences were observed between the groups in terms of height (p=0.205), weight (p=0.433) or BMI (p=0.062).

Considering the amputees in terms of the amputation side (p=0.300) and the dominant side (p=0.070), no significant difference was found between the groups. Prosthetic foot type showed a significant difference (p<0.001), as all MIC users used carbon feet (100%), while non-MIC users predominantly used single axis feet (52.9%), and 47.1% used carbon feet. There were no significant differences between MIC and non-MIC prosthesis users in terms of the time since amputation (p=0.106), duration of use of the current prosthesis (p=0.786), daily prosthesis wearing time (p=0.973), or stump length (p=0.563) (Table 2).

The MIC prosthesis users had significantly higher 6MWT performance (p<0.001) and SAT-PRO scores (p=0.002). The non-MIC users had significantly higher VO_2max (p=0.011), VCO_2max (p=0.003), and daily calorie consumption (p=0.005). No significant difference was observed in LCI scores (p=0.394) (Table 3).

According to the SF-36 results, the physical function (p<0.001) and general health (p=0.001)

TABLE 1
Demographic and etiological data distribution by groups

	MIC prosthesis users (n=17)			Non-MIC prosthesis users (n=17)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			31.1±7.4			50.1±10.7	**<0.001**
Height (cm)			174.9±5.6			172.8±7.2	0.205
Weight (kg)			75.8±9.1			80.4±16	0.433
Body mass index (kg/m²)			24.7±2.2			26.9±5	0.062
Sex							
Male	17	100		17	100		
Female	0	0		0	0		
Level of education							**0.007**
Primary school	0	0		6	35.3		
Secondary school	2	11.8		5	29.4		
High school	6	35.3		4	23.5		
University	9	52.9		2	11.8		
Etiology							**<0.001**
Peripheral vascular disease	0	0		2	11.8		
Gunshot wound/IED	14	82.4		1	5.9		
Work accident	0	0		5	29.4		
Traffic accident	2	11.8		8	47.1		
Malignancy	1	5.9		0	0		
Electric shock	0	0		1	5.9		

MIC: Microprocessor controlled; Non-MIC: Non-microprocessor controlled; SD: Standard deviation; IED: Improvised explosive device; p value is significant when p<0.05.

TABLE 2
Distribution of prosthetic foot type, amputation and prosthesis usage data by groups

	MIC prosthesis users (n=17)			Non-MIC prosthesis users (n=17)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Amputation side							**0.300**
Right	9	52.9		6	35.3		
Left	8	47.1		11	64.7		
Dominant side							0.070
Right	14	82.4		17	100		
Left	3	17.6		0	0		
Prosthetic foot type							**<0.001**
Carbon foot	17	100		8	47.1		
Single axis foot	0	0		9	52.9		
Time since amputation (mo)			102.41±101.71			176.5±140.1	0.106
Duration of use of current prosthesis (mo)			30.65±33.82			28.29±23.12	0.786
Daily prosthesis wearing time (h)			13.65±3.57			13.18±4.42	0.973
Stump length (cm)			34.82±10.48			37.18±6.62	0.563

MIC: Microprocessor controlled; Non-MIC: Non-microprocessor controlled; SD: Standard deviation; *p* value is significant when p<0.05.

values of the subscales were found to be significantly higher in the MIC prosthesis group, while no significant difference was obtained between the groups in the values of physical role limitation (p=0.150), emotional role limitation (p=0.865), energy/vitality (p=0.092), mental health (p=0.150), social function (p=0.140) and pain (p=0.865) components (Table 4).

The comparisons of the temporospatial data of gait analysis of the groups are shown in Table 5. There was no significant difference in cadence for both the amputated (p=0.245) and intact limbs

TABLE 3
Comparison of 6MWT, LCI-5, SAT-PRO, VO_2max, VCO_2max and calorie consumption measurements by groups

	MIC prosthesis users (n=17)	Non-MIC prosthesis users (n=17)	
	Mean±SD	Mean±SD	*p*
6MWT (m)	391.83±63.66	301.18±52.46	**<0.001**
LCI	52.94±3.34	51.24±4.55	0.394
SAT-PRO	38.47±3.61	32.71±5.95	**0.002**
VO_2max (mL/kg/min)	18.8±5.85	24.31±6.4	**0.011**
VCO_2max (L/min)	0.76±0.25	1.07±0.32	**0.003**
Calorie consumption (kcal/day)	9036.53±2891.15	12768.53±4071.23	**0.005**

6MWT: Six-minute walk test; LCI: Locomotor Capabilities Index; SAT-PRO: Satisfaction with prosthesis questionnaire; VO_2max: Maximum value of consumed oxygen volume; VCO_2max: Maximum value of the volume of carbon dioxide produced; MIC: Microprocessor-controlled; Non-MIC: Non-microprocessor-controlled; SD: Standard deviation; *p* value is significant when $p<0.05$.

TABLE 4
Comparison of SF-36 subcomponent values by groups

	MIC prosthesis users (n=17)	Non-MIC prosthesis users (n=17)	
	Mean±SD	Mean±SD	*p*
Physical function	71.18±16.82	43.53±12.96	**<0.001**
Physical role limitation	82.35±27.62	63.24±37.62	0.1500
Emotional role limitation	82.35±33.59	78.43±37.16	0.865
Energy/Vitality	78.24±20.07	68.24±18.79	0.092
Mental health	78.12±16.26	71.29±12.35	0.150
Social function	89.71±16.67	80.88±16.61	0.140
Pain	80.15±18.88	81.91±13.79	0.865
General health	73.24±13.69	56.47±12.84	**0.001**

SF-36: Short form 36 health survey questionnaire; MIC: Microprocessor-controlled; Non-MIC: Non-microprocessor-controlled; SD: Standard deviation; *p* value is significant when $p<0.05$.

TABLE 5
Comparison of the temporospatial data of gait analysis by groups

	MIC prosthesis users (n=17)	Non-MIC prosthesis users (n=17)	
	Mean±SD	Mean±SD	*p*
Cadence (steps/min)			
Amputated	87.32±12.21	83.29±8.2	0.245
Intact	86.24±11.68	80.62±7.28	0.182
Single support phase (sec)			
Amputated	0.46±0.06	0.42±0.06	**0.049**
Intact	0.54±0.08	0.62±0.1	**0.024**
Stride length (m)			
Amputated	0.52±0.07	0.44±0.13	**0.008**
Intact	0.48±0.057	0.45±0.07	0.122
Stride time (sec)			
Amputated	0.74±0.10	0.8±0.14	**0.029**
Intact	0.66±0.09	0.65±0.07	0.760
Walking speed (m/sec)			
Amputated	0.76±0.18	0.59±0.15	**0.007**
Intact	0.74±0.17	0.61±0.11	**0.020**

MIC: Microprocessor-controlled; Non-MIC: Non-microprocessor-controlled; SD: Standard deviation; *p* value is significant when $p<0.05$.

(p=0.182) between MIC and non-MIC prosthesis users. Significant differences were observed in the single support phase for both amputated (p=0.049) and intact limbs (p=0.024), stride length for the amputated limb (p=0.008), stride time for the amputated limb (p=0.029), and walking speed for both amputated (p=0.007), and intact limbs (p=0.020), with MIC prosthesis users demonstrating better performance in these parameters.

The kinematic data obtained in the study showed that the maximum adduction angle in the stance phase of the intact side hip joint was significantly lower in the MIC prosthesis group (p=0.029) and the maximum flexion angle in the swing phase of the amputated knee joint was significantly lower in the non-MIC prosthesis group (p<0.001). There was no significant difference between the groups in other joint kinematic values (p>0.05).

DISCUSSION

In the present study, we investigated the effects of MIC prostheses on energy consumption and gait pattern and in above-the-knee amputees through comparisons with other prostheses. The results of this study demonstrated that MIC prostheses made a significant contribution to the temporospatial gait characteristics, energy consumption, physical health, prosthesis satisfaction and gait capacity of the amputees compared to non-MIC prostheses. However, no significant differences were obtained in the mental health and locomotor capacity among the groups.

In the current study, walking speed was found to be significantly faster on both the healthy and amputated sides of amputees using an MIC prosthesis. In the MIC prosthesis group, cadence values were found to be high in both the amputated and healthy sides, but not statistically significant. The stride length was found to be significantly higher on the amputated side in the MIC prosthesis group, and higher on the healthy side, but not at a statistically significant level. The single support phase duration of the amputated side was found to be significantly higher in MIC prostheses group. The stride time was found to be significantly short on the amputated side. These findings showed that MIC prostheses had significant positive effects on the temporospatial characteristics of gait.

In a study by Eberly et al.[6] to evaluate temporospatial characteristics, 10 unilateral lower functioning above-the-knee amputees were evaluated with non-MIC prostheses and then with MIC prostheses using 3D gait analysis. The study results showed that walking speed increased by approximately 20% walking with MIC prostheses compared to walking with other prostheses, and this was statistically significant. The single support phase duration of the amputated side during free walking, stride length and cadence were significantly higher when walking with MIC prostheses. In addition, Mohamed et al.[18] found that walking speed was significantly higher on both the amputee and the healthy side with the MIC prosthesis compared to the hydraulically controlled prosthesis at normal speed, and stride time was significantly higher with the hydraulically controlled prosthesis compared to control subjects at normal speed. The results of these studies support the findings of the current study.

Another factor which may affect gait biomechanics is prosthetic foot type, and the prosthetic foot type showed a significant difference among the groups in the current study. In a systematic review published by Hofstad et al.,[19] in which the effects of different prosthetic foot types were compared, 23 trials were evaluated. There was reported to be limited evidence to show the superiority of the Flex foot compared to the SACH foot during level walking in respect of gait efficiency in high activity transfemoral amputees. Therefore, it was thought that the significantly higher rate of use of carbon foot prosthesis in the MIC prosthesis group may have positively affected the temporospatial gait characteristics of the current study.

In this study, VO_2max (mL/min/kg), VCO_2max (L/min), and calorie consumption (Kcal/day) measurements were found to be statistically significantly lower in the MIC prosthesis group compared to the non-MIC prosthesis group. From the evaluation of the findings, it can be concluded that MIC prostheses reduce oxygen consumption and energy consumption, thereby contributing significantly to energy efficiency. However, the mean age of the current study patient group using MIC prosthesis was significantly lower than the patient group using non-MIC prosthesis. It can be considered that the significant difference in energy consumption may also have been due to the effect of this mean age difference between the groups.

There are different findings in the literature regarding the effect of prosthetic foot type on energy consumption. In a study published by Graham et al.,[20] six unilateral above-the-knee amputee patients were first walked with a conventional foot prosthesis and, then, with an energy-storing prosthetic foot on a treadmill at different speeds and their oxygen consumption was compared. The results showed that the oxygen consumption of the patients was significantly lower when they walked with an energy-storing foot prosthesis. However, in another study, Zelik et al.[21] evaluated five unilateral below-the-knee amputees and reported that when walking with controlled energy storage and return (CESR) foot prosthesis, amputee patients tended to expend more energy than walking with a conventional foot prosthesis. When these studies are evaluated, it can be speculated that the effect of prosthetic foot difference on energy consumption is not clear.

Seymour et al.[5] examined 13 unilateral above-the-knee amputees walking on a treadmill at two different speeds of normal and fast. According to the results of the study, statistically significant differences were found in oxygen consumption between prostheses at both speeds with MIC prostheses showing decreased values. In the study published by Datta et al.,[22] the oxygen cost values of the patients evaluated on a treadmill were found to be significantly higher at lower speeds for the pneumatic swing-phase control leg compared to the intelligent prosthesis. The results of these studies support the findings of the current study. In contrast to the current study, Orendurff et al.[23] reported that there was no statistically significant difference in oxygen cost between the two prosthesis groups.

When the SF-36 data obtained in the current study were evaluated, MIC prostheses had a significant positive effect on physical health compared to non-MIC prostheses, while no significant difference was observed between the groups in respect of mental health. Other possible reasons for this difference in physical health may that the patients using MIC prosthesis were more active in sports both in the pre-amputation and post-amputation periods, and the mean age was lower than that of the patient group using non-MIC prosthesis.

In a study published by Seelen et al.,[24] the SF-36 test was applied to 13 unilateral above-the-knee amputees using MIC prosthesis and 13 unilateral above-the-knee amputees using non-MIC prosthesis. This study showed that SF-36 subscale scores were higher in the MIC prosthesis group. In contrast to the current study, Lansade et al.[7] reported that MIC prostheses contributed significantly to mental health component compared to non-MIC prostheses, but there was no significant difference among the groups in the physical health component.

According to the LCI-5 data obtained in the current study, although MIC prostheses provided a slightly higher benefit than non-MIC prostheses, no statistically significant difference was observed between the groups. This was thought to be as a consequence of all the patients had similar mobility skills with their existing prostheses, and the time since amputation and the duration of prosthesis use were similar and long in both groups. Unlike the current study, Lansade et al.[7] evaluated above-the-knee amputees with both non-MIC and MIC prostheses and found that the LCI-5 result was statistically significantly higher with the MIC prostheses.

The SAT-PRO data of the current study demonstrated that MIC prostheses had a significant positive effect on the satisfaction of the patients. The MIC prostheses are comfortable to use and easy to move, particularly as they are light in weight. Not only were the patients satisfied with their external appearance, but they also thought that their prostheses were durable and felt safe compared to other prostheses. The results of the current study showed that MIC prostheses made a significant positive contribution to walking capacity compared to non-MIC prostheses.

In a study published by Fuenzalida Squella et al.,[25] 13 unilateral above-the-knee amputees were evaluated first with non-MIC prostheses and, then, with MIC prostheses after a certain practice and training period, and SAT-PRO and the 2-min walking test were applied to the patients. According to the results of the study, the SAT-PRO result was statistically significantly higher with the MIC prostheses, and this finding was compatible with the current study because of the positive contribution of MIC prostheses to patient satisfaction. The distance walked in 2 min was found to be statistically significantly higher with the MIC prostheses, compatible with the current study, as it was shown that MIC prostheses contribute positively to walking capacity and physical performance.

Nonetheless, this study has certain limitations. The first of these was the significant age difference between the groups. The MIC prosthesis users were significantly younger than the non-MIC users, and this significant age difference may have influenced the results. Additionally, activity level also showed a significant difference, as all MIC users had an activity level of K4 (100%), while 64.7% of non-MIC users had an activity level of K3 and 35.3% had an activity level of K4. This significant difference between the groups may have also affected the results of the study. Another limitation was the relatively small number of patients in the study. In addition, the prosthetic foot type showed a significant difference among the groups. Future studies with larger sample sizes including similar age groups, similar activity levels and similar foot prosthesis types are essential to provide more conclusive evidence.

However, the main strength of this study can be said to be that comparisons were made in the same study of the effects of different prostheses on gait kinematics and the temporospatial characteristics of amputees, energy consumption, satisfaction with the prosthesis, locomotor capability with the current prosthesis, gait capacities, and QoL.

In conclusion, our study results demonstrated that MIC prostheses provided significant improvements in gait pattern, energy consumption, physical health, prosthesis satisfaction and gait capacity compared to non-MIC prostheses. These results suggest that MIC prostheses should be used more widely in the rehabilitation process and daily lives of above-the-knee amputees. However, additional research is required to confirm these findings.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept, design and writing the article: S.G.B., Ü.G.; Control/supervision: Ü.G., S.G.B.; Data collection and processing: S.G.B., Y.D.; Analysis and interpretation: E.A., S.G.B.; Literature review: S.G.B.; Critical review: Ü.G.; References and materials: S.G.B., Ü.G., E.A., Y.D. All authors have read and approved the final version of the manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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