BIONIC KNEES ALLOW OF SYMMETRICAL TEMPORAL-SPATIAL PARAMETERS OF GAIT COMPARED TO MECHANICALLY PASSIVE KNEE DESIGNS

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The purpose of this study was to compare the basic temporal-spatial parameters of gait and gait symmetry in transfemoral amputees with a bionic knee joint with those in patients using a mechanically passive joint in relation to non-pathological gait. Seven subjects with a transfemoral amputation participated in this study. The amputee subjects performed fifteen attempts to walk across two Kistler force plates embedded in the floor. Objective gait measurements were acquired with a computerized video motion analysis system utilizing seven infrared cameras (Qualisys). Gait with a bionic knee joint showed greater symmetry than gait with a mechanically passive joint. When using a bionic knee joint, the stance and swing times approximated those in people without pathology.

KEY WORDS: gait, amputees, prosthesis, kinematic analysis, bionic.

INTRODUCTION: Walking is the body´s natural means of moving from one location to another (Perry, 1992). Loss of a lower limb, an amputation, causes inability to walk without using a prosthetic aid. The use of a prosthesis results not only in improvement in the patient's functional state, but also in their psyche (Kishner, 2010). Prosthetic knee joints must substitute the function of a human knee joint, primarily to provide a stable weight transition in the stance phase, and controlled movement in the swing phase. The development of new technologies also results in improvements in prosthetic knee joints. New types of prosthetic knees utilize a microprocessor which controls the stance and swing phase. Intelligent prosthetic knee joints use bionic technology. The cardinal objective of bionics in prosthetics is to substitute the natural functions of the lost limb and as well as to restore normal sensory and locomotor driving functions in an individual after an amputation. Artificial intelligence transmits a constant flux of output signals into accurately manufactured high-performance prosthetic parts, and thus controls the performance of the required optimal function. Bionic technology uses both magnetorheological fluid and electromechanic drives which replace concentric muscle activity (Bionika-Ossur, 2012). Gait represents the only locomotor activity for most transfemoral amputees. In order to enable the transition from walking to running, it is necessary to be able to walk at excellent level and it is the new technologies of prosthetic knees which could be of assistance in this case. Temporal-spatial parameters and gait symmetry can be considered the basic characteristics of gait. Prosthetics endeavour to design a prosthesis so that the amputee's gait is as symmetrical as possible and their gait pattern approximates the pattern seen in non-pathological gait. Berry (2006) supposes that gait with a processor-controlled knee is more natural and symmetric than gait with other prosthetic designs. Thus the purpose of this study was to compare the basic temporal and spatial parameters of gait and gait symmetry in transfemoral amputees with a bionic knee joint with those in patients using a mechanically passive knee joint in the relation to non-pathological gait.

METHODS: Seven subjects with a transfemoral amputation participated in this study. The amputee participants consisted of 3 females and 4 males aged 39.2 ± 10.1 years, height 171.3 ± 9.5 cm and weight 68.5 ± 14.0 kg. All subjects had an amputation of their right lower limb. Three subjects were fitted with a bionic knee joint, while the others used a knee joint based on a mechanically passive principle. All patients had been using a prosthetic knee joint for more than two years. A control group was comprised of 10 subjects without pathology. Their natural walking speed corresponded to the walking speed of the amputees. The control group participants were chosen from 50 individuals on the basis of prior gait speed testing.

Each tested individual visited the *Human Motion Diagnostics Centre* two times on two different days. At each meeting the subjects performed fifteen attempts to walk across two Kistler force plates embedded in the floor so that met the conditions for the optimal step cycle. After initial training, the participants performed 15 trials of gait across the 16-m walkway over the force plates. The video recording was made by seven infrared Qualisys cameras. Only trials in which the footsteps fell entirely on the force plates and were performed at speeds ranging from 1.09–1.21 m/s were considered as valid. This speed was set as it represents the speed at which transfemoral amputees move. The speed was controlled on-line by wireless photocells.

The calibration markers were specifically placed bilaterally on the lateral and medial malleolus, medial and lateral femoral condyles, greater trochanter of femur, on the first and fifth metatarsal heads. The tracking markers were securely positioned to define the trunk (acromion), pelvis (iliac crests, posterior superior iliac spines, anterior superior iliac spines), thighs and shanks (four light-weight rigid plates holding a quaternion of markers) and feet (triad of markers on the heel over the calcaneus). Using Visual3D (C-motion, Rockvile, MD, USA), all lower extremity segments were modelled as frustra of right circular cones (Figure 1). The local coordinate system of the thigh, leg and foot was derived from the standing calibration trial. For dynamic parameters measurements we used two force plates (Kistler 9286AA a 9286BA) with an integrated amplifier**,** connected to a compatible computer. For kinematic analysis we applied a set of seven Qualisys Oqus 100 cameras (Qualisys, Sweden) connected to an AD converter, and synchronized them with the force plates. The recording frequency of the cameras was 247 Hz.

Effect size (ES) was used to compare gait characteristics. ES value is expressed as follows: 0 – 0.2 insignificant effect; 0.2 – 0.6 low effect; 0.6 – 1.2 mean effect; 1.2 – 2.0 high effect; 2.0 – 4.0 very high effect; 4.0 and more excellent effect (Hopkins, 2002). A Shapiro-Wilks test was applied to verify the normality of data distribution. Furthermore, the average relative error calculations were made according to Hopkins (2000). Statistical processing was performed using the IBM SPSS Statistics 19.0 programme.

RESULTS: Derived from the temporal parameters, the step time of the affected limb in subjects using the mechanically passive knee joint is longer by 0.055 s (ES=1.57) in comparison to the non-affected limb. A significant difference occurs especially in the swing phase when the swing time of the limb with a prosthesis is longer by 0.063 s (ES=1.75) (Table 1).

In comparison to the mechanically passive knee joint both the step and swing time of the amputated limb with a bionic knee joint were shorter by 0.03 s for step time (ES= 0.35) and 0.009 s for swing time (ES=0.39).

Table 1: Comparison of the temporal gait parameters of the left and right limb when using a bionic knee joint (Bion, ES1) and mechanically passive knee joint (Pasiv, ES 2) (n=15).

Variable	Bion Left	Bion Right	Pasiv Left	Pasiv Right	ES 1	ES 2
Step time (s)	0,600 ± 0,026	0,591 ± 0,047	0,577 ± 0,035	0,632 ± 0,031	0,35	**1,57**
Stance time (s)	0,742 ± 0,05	0,713 ± 0,036	0,772 ± 0,028	0,707 ± 0,043	0,58	0,53
Swing time (s)	0,457 ± 0,023	0,466 ± 0,027	0,433 ± 0,036	0,496 ± 0,035	0,39	**1,75**

In comparison to the control group, the swing time of the amputated limb in patients with a mechanically passive knee joint is longer by 0.042s with very high effect and also the stance phase of the non-affected limb is longer by 0.047s with high effect (Table 2). High effect was not observed when comparing the temporal parameters in a group using a bionic knee with those in the control group.

Table 2: Compares the temporal-spatial gait parameters in patients with a bionic knee joint (Bion) and in amputees with a mechanically passive knee joint (Pasiv) with those of the control group. ES Bion marks the difference in the parameters between the bionic knee joint patients and the control group, ES Pasiv represents the difference in the parameters between the mechanically passive knee joint amputees and the control group.

Variable	Limb	Bion	Pasiv	Control gr.	ES Bion	ES Pasiv
Step time (s)	Sound (left)	0.600 ± 0.026	0.577 ± 0.035	0.579±0.024	0.88	0.08
	Prosthetic (right)	0.591 ± 0.047	0.632 ± 0.031	0.594±0.036	0.08	**1.06**
Stance time (s)	Sound (left)	0.742 ± 0.05	0.772 ± 0.028	0.725±0.044	0.38	**1.07**
	Prosthetic (right)	0.713 ± 0.036	0.707 ± 0.043	0.705±0.031	0.26	0.06
Swing time (s)	Sound (left)	0.457 ± 0.023	0.433 ± 0.036	0.450±0.025	0.28	0.68
	Prosthetic (right)	0.466 ± 0.027	0.496 ± 0.035	0.454±0.020	0.60	**2.10**

DISCUSSION: The objective of this study was to assess the differences in temporal-spatial characteristics of gait in amputees with various types of prosthetic knee joints. From the results, it can be concluded that the difference in step time between the affected and non-affected limb is moderate in those using a bionic knee joint, which should result in higher gait symmetry than in amputees with a mechanically passive joint patients. Thorn & Glaister (2009) describe the variances in speed, cadence, step time, stance time and swing time in five subjects using two types of prosthetic knee joints. According to their findings, the stance time of the amputated limb is shorter, while the swing time is longer. The shorter stance time of the affected limb can be caused by lower stability of the prosthesis (Murray et al., 1980). It was determined that the stance time of the non-affected limb in mechanically passive knee joint amputees is longer than in the case of patients with bionic knee joints. It is believed this may indicate better stability of microprocessor-controlled knee joints. In addition, it is also evident from the measurements that the swing time of the affected limb in mechanically passive knee joint amputees is longer, which may signify greater energy expenditure when walking. Swing time is of a great importance for energy expenditure and it may represent up to one third of the total expenditure during gait cycle (Umberger & Rubenson, 2011). Johansson et al. (2005) report that the energy expenditure in patients with a microprocessor-controlled knee joint while walking is lower than in mechanically passive knee joint amputees. This is possibly caused by a shorter swing time of a bionic knee joint patients. As a result of the lower energy expenditure and the greater symmetry when walking, the run-walk transition may be easier in microprocessor-controlled knee joint patients than in mechanically passive joint patients.

CONCLUSION: Gait with a bionic knee joint indicated greater symmetry than that with a mechanically passive joint. The stance and swing times of a bionic knee joint gait approximated the gait parameters shown by people without pathology.

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