COMPARISON OF KINEMATIC PARAMETERS OF GAIT IN TRANSFEMORAL AMPUTEES WITH BIONIC AND HYDRAULIC KNEE – CASE STUDY

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The development of new technologies has led to further improvements in prosthetic knee joints. The aim of this study was to compare kinematics in knee and hip joints during the gait of transfemoral amputees and to determine the effect of the type of knee joint used (bionic, hydraulic) on their symmetry. One female with transfemoral amputation participated in the study. Symmetry of lower limb movement in the hip joint is better for all monitored parameters for bionic knee joints. Flexion at heel contact and maximum flexion in the swing phase in the knee joint are more symmetrical at hydraulic knee joints; for all other parameters the bionic knee joints achieves better symmetry. Kinematics parameters in bionic knee amputees approximate to the parameters of gait in people without pathology.

KEY WORDS: gait, amputation, bionic technology

INTRODUCTION: Transfemoral amputees must overcome the loss of two major joints and the less or partial loss of many of the lower limbs muscle groups. A prosthetic knee joint must “simulate” the movement of a human knee, provide stability in weight transfer during the stance phase, and allow for control of limb movement during the swing phase (Silver-Thorn & Glaister, 2009). The development of new technologies has led to further improvements in prosthetic knee joints. Many modern types of prosthetic knee joints use microprocessors to control the stance and swing phases, enabling amputees to walk with greater comfort. Bionic knee uses a magnetorheological actuator and dynamic learning matrix algorithm control system (Berry, 2006). One of the goals when developing prostheses and setting up their components is to reduce gait asymmetry between the intact limb and the affected limb. In cases when only one limb is amputated, symmetrical gait can prevent the excessive loading of the intact limb (Nolan et al., 2003). Gait asymmetry quantification in amputees in relation to nonamputees represents the first step trying to define the intensity of asymmetry which would be acceptable for prosthetic gait during rehabilitation (Dingwell, Davis, & Frazier, 1996). The aim of the study was to compare kinematic parameters and symmetry of gait in amputees using the bionic knee joint and hydraulic knee joint in relation to nonpathological gait.

METHODS: One female (age – 26, height – 1.64 m and weight – 50 kg) with transfemoral amputation participated in the study. The amputation was on the right side. The participant visited the laboratory on two occasions (first with mechanically passive knee joint and second with bionic knee joint) an interval of six months. Control subject was one able-bodied female (age – 26, height 1.63 m and weight 52 kg). Both participant performed 15 trials of gait. Calibration markers for determining kinematic parameters were positioned bilaterally on the lateral and medial malleolus, the lateral and medial femoral condyles, the greater trochanter of the femur, and the first and fifth metatarsal heads. Tracking markers were positioned to define the trunk (acromion), pelvis (iliac crest, posterior superior iliac spine, anterior superior iliac spine), thigh and shank (a cluster of four light-weight rigid plates on which were positioned four markers), and foot (three markers – posterior calcaneus, lateral calcaneus, proximal calcaneus). Before the trials, a standing calibration trial of the participants was carried out. For kinematic analysis we applied a set of seven infrared cameras (Qualisys, Oqus 100, Sweden). The recording frequency of the cameras was 247 Hz. For kinematic data measurement and saving, we employed the Qualysis Track Manager (QTM) software. In addition, the Visual3D v4 software (C-motion, Germantown, MD, USA) was used for model creation and data processing. The symmetry index (SI) was used to assess gait symmetry:

$$SI = ((X_{nonaffected} – X_{affected})/0{,}5(X_{nonaffected} + X_{affected})) \times 100\%.$$

SI values can range from -100% to +100%, where SI = 0 represents absolute symmetry. The effect size (ES) was used to assess practical significance. The ES values were: 0–0.2, trivial effect; 0.2–0.6, small effect; 0.61–1.2, medium effect; 1.21–2.0, large effect; 2.01–4.0, very large effect; ≥ 4.0, nearly perfect.

RESULTS: Patient with bionic knee joints achieved practically significantly greater maximum extension hip angles than the control subject in the stance phase, both on intact limbs (ES = 2.81) and affected limbs (ES = 1.51). At hip heel contact, patient with hydraulic knee joints achieved practically significantly lower angles than the control subject on intact limbs (ES = 1.20) and practically significantly greater angles than the control subject on affected limbs (ES = 2.12). Practically significant differences with large effect between the control subject and patient with hydraulic knee joints exist for maximum hip flexion on affected limbs during the swing phase (ES = 1.48) In comparison with the control subject, both prosthetic knees achieved lower knee maximum flexion during the loading phase on the affected limb. There is a difference with nearly perfect effect (ES = 4.52) for the maximum knee flexion in the swing phase on affected limbs among the patient with bionic knee joints. There is also a difference with large effect (ES = 1.32) for this parameter among the patient with hydraulic knee joints, but on the intact limb (Table 1).

Table 1 Comparison of selected angle parameters in the hip (H) and knee (K) joint during gait of patients with bionic knee joints (Bion), with hydraulic knee joints (Hydraulic) and the control subject (Control). ES Bion – difference between the bionic joint and the control parameters, ES Hydraulic – difference between the hydraulic joint and the control parameters.

Variable	Limb	Bion	Hydraulic	Control	ES Bion	ES Hydraulic
H_flex_heel_cont (°)	Intact	-25.49±4.62	-21.18±6.36	-26.14±4.10	0.16	**1.51**
	Affected	-28.93±4.45	-34.82±6.18		0.68	**2.12**
H_max_ext_stance (°)	Intact	16.39±5.67	24.53±4.08	8.56±3.14	**2.81**	**5.09**
	Affected	12.39±3.31	9.63±7.94		**1.20**	0.34
H_max_flex_swing (°)	Intact	-31.67±5.72	-30.25±5.53	-28.74±5.10	0.57	0.30
	Affected	-31.95±3.74	-36.30±6.48		0.63	**1.48**
H_max_add_stance (°)	Intact	-6.43±4.54	-4.15±6.37	-9.43±4.66	0.64	1.13
	Affected	-7.59±5.15	-10.72±4.75		0.39	0.28
H_max_abd_swing (°)	Intact	5.74±2.70	2.84±5.37	6.62±5.46	0.16	0.69
	Affected	6.86±3.35	3.78±3.62		0.04	0.50
K_flex_heel_cont (°)	Affected	0.15±1.47	3.74±6.68	1.54±3.40	0.41	0.65
	Intact	1.05±2.71	3.61±3.46		0.14	0.61
K_max_flex_load_ph (°)	Affected	2.89±1.77	1.96±1.31	17.60±4.21	**3.49**	**3.71**
	Intact	20.06±5.30	20.03±5.33		0.58	0.58
K_max_ext_stance (°)	Affected	3.93±1.62	1.67±2.32	4.77±3.77	0.22	0.82
	Intact	4.65±3.16	4.61±5.23		0.03	0.04
K_max_flex_swing (°)	Affected	48.52±8.17	61.28±9.80	64.96 ± 3.64	**4.52**	1.01
	Intact	66.14±5.05	60.14±2.00		0.32	**1.32**

Symmetry of lower limb movement in the hip joint is better for all monitored parameters in patient with bionic knee joints. The greatest asymmetry in hydraulic knee joint patient is in the maximum hip extension in the stance phase, the maximum hip adduction in the stance phase. Knee flexion at heel contact and maximum knee flexion in the swing phase are more symmetrical with hydraulic knee joints; for all other parameters the bionic knee joints achieves better symmetry. The greatest asymmetry at both type of prosthetic knees are for knee flexion during the loading phase (Table 2).

Table 2 Symmetry indexes for selected hip (H) and knee (K) joint angles for bionic knee joints (SI Bion), hydraulic knee joints (SI Hydraulic) and the control subject (SI Control). ES Bion – difference between the bionic joint and the control parameters, ES Hydraulic – difference between the hydraulic joint and the control parameters.

Variable	SI Bion (%)	SI Hydraulic (%)	SI Control (%)	ES Bion	ES Hydraulic
H_flex_heel_cont (°)	6.15 ± 4.6	21.38±6.26	2.55±1.07	0.96	**4.35**
	12.04 ± 5.25	50.72±7.26	3.12±1.36	**2.41**	**7.67**
H_max_ext_stance (°)	0.44 ± 2.28	7.21±4.05	1.03±0.45	0.36	**2.06**
	8.52 ± 3.12	45.12±9.87	2.10±0.55	**2.65**	**6.27**
H_max_flex_swing (°)	7.31 ± 2.91	9.92±5.22	1.68±0.66	**2.95**	**2.10**
	5.76 ± 4.52	2.19±2.05	1.11±0.76	**1.43**	0.70
H_max_add_stance (°)	77.56 ± 11.13	78.12±10.62	3.36±2.02	**9.00**	**9.88**
	8.46 ± 4.12	47.98±12.66	2.67±1.42	**1.80**	**4.28**
H_max_abd_swing (°)	15.91 ± 9.42	0.53±1.10	1.21±0.46	**2.19**	0.85

DISCUSSION: The aim of this study was to compare the kinematics of the hip and knee joint and gait symmetry in person with bionic knee joint and with hydraulic knee joint and to determine differences between kinematic parameters and the parameters of non-amputees control subject (Table 1). Gait asymmetry is considered to indicate pathology (Sadeghi et al., 2000). For unilateral amputees, a symmetrical gait is important to prevent excessive loading of the intact leg (Nolan et al., 2003). For the hip joint, the angles recorded in patient with bionic knee joints show greater symmetry in all monitored parameters (Table 2). Greater gait symmetry when using bionic knee joints is important due to its impact on energy expenditure. Energy expenditure is significantly lower when using bionic knee joints than when using hydraulic knee joints (Johansson et al., 2005). A high level of knee joint asymmetry occurs in both groups of amputees during flexion in the stance phase. This asymmetry is caused by the very low flexion of the affected limb knee joint in the stance phase. This low flexion in the stance phase is probably caused by patients' attempts to retain stability in the support phase in the affected limb. This conclusion is in accordance with other studies which described inadequate flexion in patients with various types of prosthetic knee joints (Johansson et al., 2005; Segal et al., 2006; Kaufman Frittoli, & Frigo, 2012). In use both prosthetic knee designs there is high maximum flexion of the hip joint during the stance phase for the intact limb. This flexion is practically significantly higher in hydraulic joint patient than in the control subject and in the bionic joint. This greater flexion is connected with the longer duration of the stance phase on the intact limb compared with the affected limb (Petersen, Comins, & Alkjære, 2010). The intact limb is a more stable source of support for patients than the affected limb. The step length, which is greater when starting from the intact limb, corresponds with the greater extent of movement in the hip joint. Use hydraulic joints show practically significantly lower flexion in the hip joint during heel contact with the intact limb, and they show practically significantly higher flexion during heel contact with the affected limb. These differences were also found in studies by Kaufman et al. (2012) and Johansson et al. (2005). This difference causes a high degree of asymmetry between the two sides in terms of the hip joint angle during heel contact. One reason may be the greater difficulty of controlling the hydraulic joint, leading in turn to worse coordination between the thigh and shank. From the perspective of hip and knee joint movement, the use of bionic knee joints in constructing lower limb prostheses appears to be a better solution than the use of hydraulic knee joints. However, it will be necessary for further studies to focus on the interaction among individual segments in order to gain a better understanding of gait strategies applied with different types of prosthetic knee joints. Conclusions from this study must be considered with the sample size in mind. This limitation reduces the wider application of these results.

CONCLUSION: Compared with a hydraulic knee joint, a bionic knee joint show greater symmetry. These differences are most prominent in the movement of the hip joint. Gait with bionic knee were similar to those non amputees. However, regardless of the type of prosthetic joint used, amputees show significantly lower knee joint flexion during the stance phase on the affected limb.

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