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Original scientific paper

Spatial, Temporal and Kinematic Characteristics of Traumatic Transtibial Amputees' Gait

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ABSTRACT

Presented study gives findings of temporal-spatial kinematic gait analysis in 12 male adults, war trauma transtibial (TT) amputees fitted with prosthesis compared to 12 able-bodied persons. Results disclose asymmetries between the amputated, prosthetic and healthy legs of amputees, as well as between TT amputees and non-disabled persons. Amputees in comparison with able-bodied persons, generally, showed significantly increased swing-time (ms) ($p<0.01$). Prosthetic, right legs of amputees showed decreased stance-phase (ms and % GC) ($p<0.01$) and increased swing-time (ms) ($p<0.05$), compared with right legs of able-bodied persons while statistical significance was reached ($p<0.01$) for decreased stance-time (% stride and ms), increased swing-time (% stride and ms), decreased swing velocity (m/s), increased anterior step length and decreased stride length ($p<0.05$), compared with contra lateral, left legs of amputees. Our conclusion is that instrumented kinematic gait analysis study is able to provide assessment about the way prosthetic TT amputees walk.

Key words: *biomechanics, kinematic gait analysis, locomotion, traumatic transtibial amputation*

Introduction

Kinematic procedures are aimed at measuring spatial motion of the body and limb segments during representative walking strides. Temporal and spatial kinematic gait parameters, specifically, provide fundamental timing and position information about a person's gait. During stationary walking, gait cycle (stride) is a cyclic pattern of movement that is repeated. The stance is comprised of 5 gait phases (i.e., initial contact, loading response, mid stance, terminal stance and preswing). It is further subdivided into 3 segments, including initial double stance, single limb stance and terminal double limb stance. Each double stance period accounts for 10% of the GC, while single stance typically represents 40%, about 60% total (all percentage are approximate values). Swing phase is the period of single support during the gait cycle, presented during remaining 40% of the GC. The duration of a stride is the interval between sequential initial floor contacts by the same limb. A step is recognized as the interval between sequential floor contacts (heel strike) by ipsi-lateral and contra-lateral limbs. Two steps make up each gait stride, which is roughly symmetric in normal individuals. Cadence is a number steps/strides *per* unit of time. Step length is the projected distance from one to the next single support phase of left and right feet, while stride length is the projected distance between two positions (from one single support phase to the next single support phase) of the same foot along an anterior-posterior line drawn in the direction of ambulation. Healthy persons walk with almost symmetrical parameters for right and left leg[1–4].

Amputees with war trauma related amputation, represent a very specific group of patients, first of all because of their age, mostly young adults. During the war in Croatia (1991–1995) in the Institute for Rehabilitation and Orthopedic Devices University Hospital Center Zagreb, 864 amputated casualties were rehabilitated and prosthetically equipped[5].

Although they have great potential for good ambulating with effective prosthesis, after appropriate rehabilitation, very often they adapt a unique way of walking which differs from able-bodied persons. Amputee sub-

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jects, prosthesis users typically demonstrate gait patterns that are different from those of able-bodied individuals. The more distal the amputation, the better control the amputee has of his prosthesis, the more efficient the gait, and the more closely their pattern of walking resembles that of able-bodied persons[6–12].

This paper is aimed at presenting and analyzing spatio-temporal kinematic characteristics of gait in traumatic transtibial amputees, in comparison to able-bodied persons. It is a part of a broader systematic biomechanical studies of human walking, undertaken in The Biomechanics Laboratory Faculty of Kinesiology University of Zagreb, in values of projects: »Automated motion capture and expert evaluation in the study of locomotion« and »Real-life data measurements and characterization«, realized with the support of The Ministry of Science, Education and Sports, Republic of Croatia. The following theses report details of the findings attained[13,14].

Material and Methods

Kinematics characteristics of the body and limb segments were assessed by optoelectronic system Elite Biomech (BTS Bioengineering, Milano) with eight-camera (100 Hz), high-speed video system (2 camera 30 Hz) and control PC unit, including adequate software. Markers were placed, according to Davis protocol, over predefined body landmarks on the trunk, pelvis and legs; examining 3 joints each in 2 limbs in sagittal, frontal and transverse plane[15] (Figure 1). As the patient walks through the lab, the three-dimensional location of each marker is detected by multiple infrared cameras. They were used to track the 3-dimensional locations of individual body segments throughout a gait cycle. A biomechanical model is applied to the marker series to calculate the three-dimensional motion of each body segment. Simultaneously, kinetic measurements and dynamic electromyography (EMG) were performed. After a period of adaptation to the laboratory conditions and the equipment used and after informing about the purpose of study, the subject was asked to walk at free cadence[16,17]. The experimental sessions were carried out in the Biomechanics Laboratory at the Faculty of Kinesiology in Zagreb (Figure 2 and 3). Prosthetic rehabilitation of all TT amputees was performed in Institute for Rehabilitation and Orthopedic Devices University Hospital Center Zagreb in Zagreb.

Study population consisted of twelve (12) males with right trans-tibial traumatic amputation in mean age 40.25+6 years (31–52) volunteered to participate in this study (Table 1). They were all war victims, mostly injured by means of land mines, in the period 1991–1995. All patients had completed a prosthetic training program at the Institute for Rehabilitation and Orthopedic Devices (IROD) University Hospital Center Zagreb. All subjects were excellent walkers who used their prosthesis on

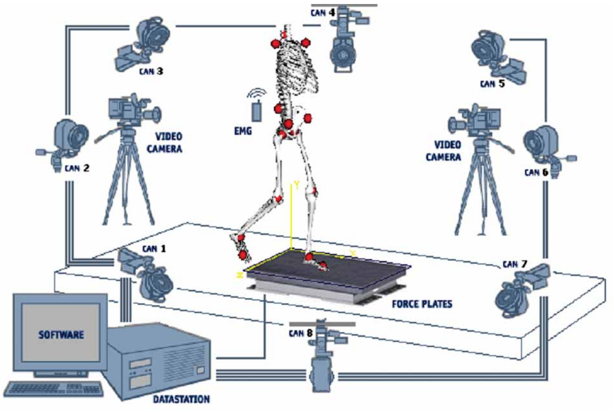

Fig. 1. Graphical representation of kinematics optoelectronic system and kinetic (force platform) motion analysis system.

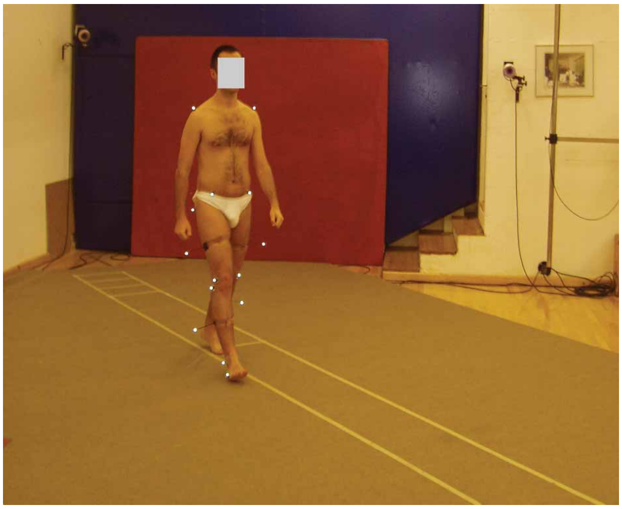

Fig. 2. Able-bodied person from control group equipped with reflective markers walking through the motion analysis center.

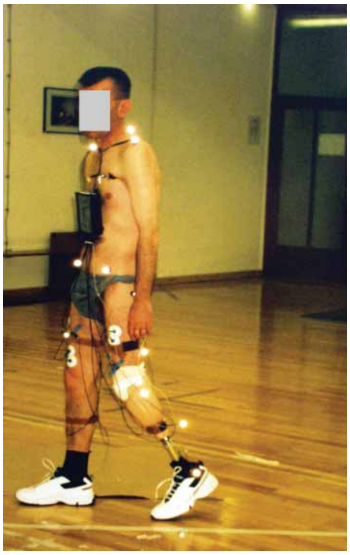

Fig. 3. Patient walking through the motion analysis center with reflective markers.

TABLE 1
STUDY POPULATION: 12 MALES WITH RIGHT TRANS-TIBIAL TRAUMATIC AMPUTATION AND CONTROL GROUP STUDY: 12 NON-AMPUTATED MALES

	Study population: 12 males with right TT traumatic amputation	Control group study: 12 non-amputated males
Mean age (yrs)	40.25±6 (31–52)	37.46±5.25 (27–44)
Mass (kg)	88.08±16.5 (62–111)	86.38±10.03 (74–103)
Height (cm)	182.08±5.1 (175–191)	177.9±5.0 (173–188)

a regular basis and were leading an normal active life. They were not suffering from any severe concurrent illnesses. Prosthetic alignment was similar for all patients. All trans-tibial prosthesis had full contact socket. Prosthetic feet were similar, but not the same type (Dynamic foot had 7 patients, Greissenger foot had 2 patients and Flex foot walk had 2 patients). The sample for the study was selected to be homogeneous according to etiology of amputation, gender and age of amputees, but it was not possible to provide the same type of all prosthetic components. The time lapse between the date of amputation and the time of testing ranged from 8 to 12 years (mean time 10.08+1.5 years). Control group study consisted of 12 non-amputated males with normal gait, in mean age 37.46±5.25 years (27–44). They were employees in Croatian Armed Forces, in good health condition but were not specially trained in sport or another physical activity. Their anthropometric characteristics were similar to those in amputee group.

From all kinematic variables which could be studied, a total of 11 variables were selected and than statistically analyzed; for group of 12 TT amputees and for 12 non--amputated persons. Six temporal parameters and 5 distance parameters of gait cycle were analyzed; nomencla-

TABLE 2
RESULTS (MEAN VALUES AND SD) OF TEMPORAL MEASUREMENTS FOR AMPUTEES AND ABLE-BODIED PERSONS

Variable	Leg	Number of measurements	$\overline{X}$	SD
Stance time__ms	R PRO A	11	680.90	55.22
Stance time__ms	R L C	13	678.77	31.08
Stance time__ms	L L A	11	716.36	52.01
Stance time__ms	L L C	13	680.21	27.04
Swing time__ms	R PRO A	11	470.91	43.00
Swing time__ms	R L C	13	415.96	39.87
Swing time__ms	L L A	11	429.09	32.08
Swing time__ms	L L C	13	416.79	34.67
Stance time_ % stride	R PRO A	11	59.27	2.24
Stance time_ % stride	R L C	13	62.01	1.79
Stance time_ % stride	L L A	11	62.54	1.04
Stance time_ % stride	L LC	13	62.12	1.55
Swing time_ % stride	R PRO A	11	40.73	2.24
Swing time_ % stride	R L C	13	37.64	1.78
Swing time_ % stride	L L A	11	38.00	1.03
Swing time_ % stride	L L C	13	38.90	1.55
Stride time__ms	R PRO A	11	1150.91	80.43
Stride time__ms	R L C	13	1094.73	62.77
Stride time__ms	L L A	11	1145.45	80.67
Stride time__ms	L L C	13	1097.00	55.53
Double supp _time__ms	R PRO A	11	123.64	27.67
Double supp time__ms	R L C	13	131.54	14.78
Double supp_time__ms	L L A	11	128.18	21.83
Double supp time__ms	L L C	13	132.18	17.235
Double supp time – % stride	R PRO A	11	10.73	2.15
Double supp time_ % stride	R L C	13	12.05	1.66
Double supp time_ % stride	L L A	11	11.10	1.51
Double supp time_ % stride	L L C	13	12.18	1.84

R PRO A – right leg (prosthesis) of amputees; L L A – left leg (sound) of amputees
R L C – right leg of able-bodied persons, control group; L L C – left leg of able-bodied persons, control group

ture according to manufacturer of optoelectronic system Elite Biomech (BTS Bioengineering, Milano). Temporal parameters (msec) were: Stance time [msec], Swing time [msec], Stance time [% stride], Swing time [% stride], Stride time [msec], Cadence [step/min], Double supp. time [msec], Double supp. [% stride] while distance parameters were: Anterior step length [mm], Velocity [m/sec], Swing velocity [m/sec], Stride length [mm], Step width [mm], Mean velocity [m/sec]. The data were processed by using means differences with standard t-test; p-test was modified because of multiple tests (3×12=36). Statistical Software SAS procedure MULTTEST was used. Results were compared, by means of statistical method: a) in generally, TT amputees-able-bodied persons, b) right, prosthetic legs of TT amputees – right legs of non able-bodied persons and c) left legs of TT amputees-lefts legs of non-able persons. As well, kinematic measurements results of prosthetic legs were analyzed by comparison with results of left, healthy legs of amputees.

Results

Results of kinematic measurements of temporal and spatial measurements for prosthetic and healthy, contralateral leg of amputees and both legs of able-bodied persons are presented by mean values and SD (Table 2 and 3) and presented by Box plot diagrams (Figure 4, 5 and 6). Results of statistical testing of kinematic outcomes, presented in Table 4 show a statistically significant difference in comparison between: a) amputees to able-bodied persons, b) right prosthetic legs to left, sound legs of amputees and c) left legs of amputees to left legs of able-bodied persons for several parameters: a) swing-time (ms) p=0.0579, comparing amputees to able-bodied persons, b) swing-time (ms) p=0.0182, comparing right legs of able-bodied persons, control group with right prosthetic legs, c) swing-time % stride p=0.0072, comparing right legs of able-bodied persons, control group with right prosthetic legs and d) stance-time % stride p=0.0072, comparing right legs of able-bodied persons, control group with right prosthetic legs. No statistically significant difference was established for other variables.

Comparison of kinematic results between amputee persons and control group persons without amputation, generally, (AP-CG: amputees – control group) showed that significant difference p=0.0579 was reached for swing time (ms). Swing time (ms) was 470.91 ms for prosthesis (R PRO A); 429.09 ms for left leg of amputees and 415.96 ms for right leg and 416.79 ms for left leg of able-bodied persons.

Results of analysis of temporal measurements for prosthetic legs in comparison amputees to able-bodied persons, right prosthetic legs to left, sound legs of amputees and left legs of amputees to left legs of able-bodied persons showed statistically significant differences for several parameters: 1) decreased stance time (% stride): 59.3% stride for prosthesis (R PRO A); 62.5% stride for left leg of amputees and both legs off able-bodied persons

TABLE 3
RESULTS (MEAN VALUES AND SD) OF SPATIAL MEASUREMENTS FOR AMPUTEES AND ABLE-BODIED PERSONS

Variable	Leg	Number of measurements	$\overline{X}$	SD
Anterior step length__mm	R PRO A	11	753.71	51.45
Anterior step length__mm	R L C	13	702.96	40.87
Anterior step length__mm	L L A	11	678.95	50.67
Anterior step length__mm	L L C	13	714.23	62.46
Velocity__m_s	R PRO A	11	1.23	0.12
Velocity__m_s	R L C	13	1.30	0.15
Velocity__m_s	L L A	11	1.26	0.11
Velocity__m_s	L L C	13	1.30	0.15
Swing velocity__m_s	R PRO A	11	3.02	0.29
Swing velocity__m_s	R L C	13	3.4505	050
Swing velocity__m_s	L L A	11	3.36	0.32
Swing velocity__m_s	L L C	13	3.45	0.52
Stride length__mm	R PRO A	11	1409.04	84.59
Stride length__mm	R L C	13	1413.85	99.10
Stride length__mm	L L A	11	1438.58	65.16
Stride length__mm	L L C	13	1394.58	134.27
Cadence__step_min	R PRO A	11	104.91	7.78
Cadence__step_min	R L C	13	109.93	5.99
Cadence__step_min	L L A	11	105.09	7.57

R PRO A – right leg (prosthesis) of amputees; L L A – left leg (sound) of amputees
R L C – right leg of able-bodied persons, control group; L L C – left leg of able-bodied persons, control group

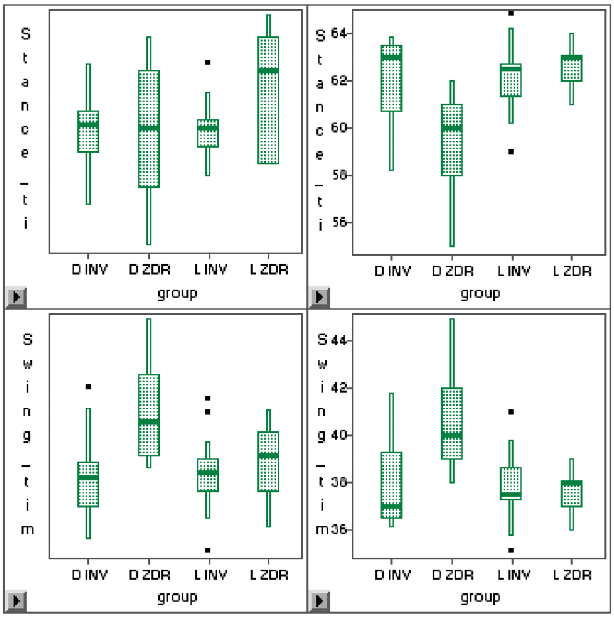

Fig. 4. Results for temporal kinematic variables: Stance-time (ms), Swing-time (ms), Stance-time (% stride) and Swing-time (% stride), for the amputees and control group, presented by Box plot diagrams, D INV – right leg (prosthesis) of amputees; L INV – left leg (sound) of amputee, D ZDR – right leg of able-bodied persons, control group and L ZDR-left leg of able-bodied persons, control group.

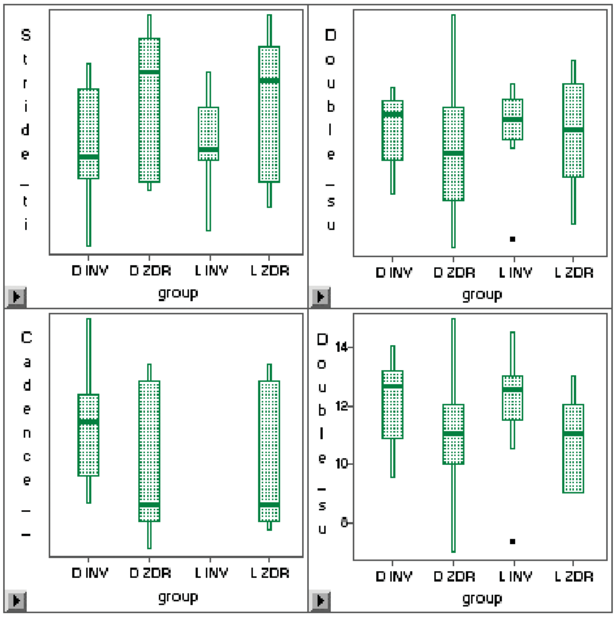

Fig. 5. Results for temporal kinematics variables: Stride-time (ms), Double-supp-time (ms), Double-supp-time (% stride) and Cadence (step-min), for the amputees and control group, presented by Box plot diagrams, D INV – right leg (prosthesis) of amputees; L INV – left leg (sound) of amputees, D ZDR – right leg of able-bodied persons, control group, L ZDR-left leg of able-bodied persons, control group.

(right leg 62% stride, left leg 63% stride). Statistically significant difference was reached in comparison with right legs of able-bodied persons, p=0.0072 increased swing time (% stride): 40.73% stride for prosthesis (R PRO A); 37.64 % stride for left leg of amputees and both legs off able-bodied persons (right leg 38% stride, left leg 37.9% stride). Statistically significant difference was reached in comparison with right legs of able-bodied persons, p=0.0072 and 3) increased swing time (ms): 470.91 ms for prosthesis (R PRO A); 429.09 ms for left leg of amputees and both legs off able-bodied persons (415.96 ms-right leg, left leg 416.79 ms). Statistically significant difference was reached in comparison with right legs of able-bodied persons, p=0.0182.

Right legs of able-bodied persons from control group reach statistically significant differences for some temporal measurements like: 1) increased stance time (% stride) for right legs of able-bodied persons of 62.02% stride

TABLE 4

STATISTICALLY SIGNIFICANT DIFFERENCES OF RESULTS BY MEANS OF STANDARD AND MODIFIED T-TESTS (P-VALUES) FOR ALL KINEMATIC PARAMETERS COMPARING: A) AMPUTEES TO ABLE-BODIED PERSONS, B) RIGHT PROSTHETIC LEGS TO LEFT LEGS OF AMPUTEES AND C) LEFT LEGS OF AMPUTEES TO LEFT LEGS OF ABLE-BODIED PERSONS

p-values			
Variables	Comparison	Standard t-test	Modified t-test
Swing-time-ms	AP *vs.* CG	0.0035	0.0597* 0.05<p<0.1
Swing-time-ms	R L C *vs.* R PRO A	0.0009	0.0182⁺⁺ 0.01<p<0.05
Swing-time % stride	R L C *vs.* R PRO A	0.0003	0.0072*** p<0.01
Stance-time % stride	R L C *vs.* R PRO A	0.0003	0.0071*** p<0.01

R PRO A – right leg (prosthesis) of amputees; L L A – left leg (sound) of amputees,
R L C – right leg of able-bodied persons, control group, L L C – left leg of able-bodied persons, control group,
AP-CG – amputees – control group
p – level of significance: *0.05<p<0.1, **0.01<p<0.05, ***p<0.01)

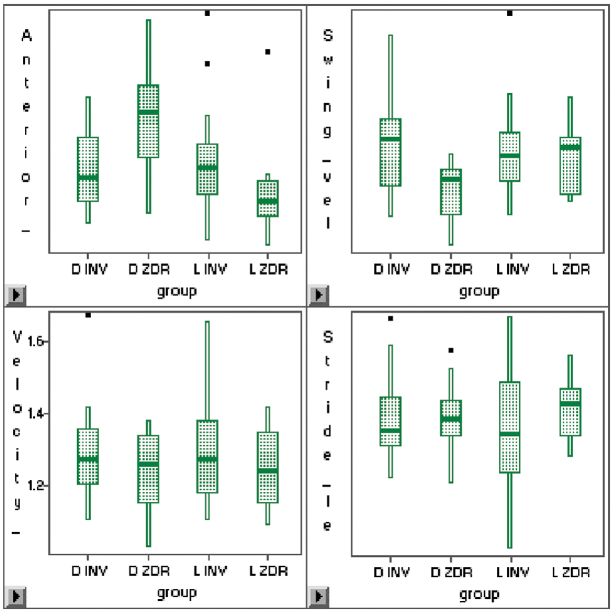

Fig. 6. Results for distance kinematic variables: Anterior step length (mm), Velocity (m/s), Swing-velocity (m/s) and Stride-length (mm), for the amputees and control group, presented by Box plot diagram, D INV – right leg (prosthesis) of amputees, L INV – left leg (sound) of amputees, D ZDR – right leg of able-bodied persons, control group, L ZDR-left leg of able-bodied persons, control group.

comparing to 59.27% stride for prosthetic legs, while decreased from left legs of able-bodied persons (62.55% stride). Statistically significant difference was reached in comparison between right legs of able-bodied persons and prosthetic legs of amputees, p=0.0072; 2) decreased swing time (ms) for right legs of able-bodied persons of 415.96 ms, comparing to 470.91 ms for prosthetic legs of amputees and left legs of amputee persons (429.09 ms) and left legs of able-bodied persons (416.79 ms). Statistically significant difference was reached in comparison between right legs of able-bodied persons and right, prosthetic legs of amputees, p=0.0182 and 3) decreased swing time (% stride) for right legs of able-bodied persons of 38.0% stride comparing to 40.73% stride for prosthetic legs while increased in comparison with left legs of amputee persons (37.64% stride) and left legs of able-bodied persons (37.90% stride). Statistically significant difference was reached in comparison between right legs of able-bodied persons and right, prosthetic legs of amputees, p=0.0072.

For all other results of temporal or spatial measurements which did not reach statistically significant difference, it has to be pointed out that if number of patients had been greater, maybe some of these results could have reached statistical significance.

Results of kinematic outcomes of temporal and spatial parameters for prosthetic legs (R PRO A) and left legs of amputee persons (L L C) were statistically analyzed by comparison of results between both of them. The data were processed by using means values, as presented in Table 5, while differences with standard t-test and with nonparametric tests for dependent pairs, presented in Table 6. Statistical Software SAS procedure MULTTEST was used.

Statistically significant kinematic results for right prosthetic legs comparing to the left, sound legs of amputees, presented in Table 5, were reached for 7 parameters : 1) increased anterior step length (mm): 753.71±51.45 mm *vs*. 678.9±50.66mm; p=0.0052, 2) decreased stance-time (% stride): 59.27±2.24 % stride *vs*. 62.54±1.036 % stride, p=0.0010, 3) decreased stance time [ms]: 680.90±55.21

TABLE 5

RESULTS (MEAN VALUES AND SD) FOR 13 TEMPORAL-SPATIAL PARAMETERS FOR RIGHT, PROSTHETIC LEGS AND FOR LEFT LEGS OF TT AMPUTEES

Variable	PROSTHESIS (R PRO A) $\overline{X}$±SD	HEALTHY LEG (L L A) $\overline{X}$±SD	Number of trials
Stance_time__ms	680.91±55.22	716.36±52.01	11
Swing_time__ms	470.91±43.00	429.10±32.08	11
Stance_time_ % CH	59.27±2.24	62.55±1.036	11
Swing_time_ % CH	40.73±2.24	37.64±1.03	11
Stride_time_ms	1150.91±80.43	1145.45±80.67	11
Double supp_time__ms	123.64±27.67	128.18±21.83	11
Double supp__time_ % CH	10.73±2.15	11.09±1.51	11
Anterior step_length_mm	753.71±51.45	678.94±50.67	11
Velocity__m_s	1.23±0.12	1.26±0.11	11
Swing velocity__m_s	3.02±0.29	3.36±0.32	11
Stride length__mm	1409.04±84.59	1438.58±65.16	11
Cadence _step_min	104.91±7.78	105.09±7.57	11
Mean velocity__m_s	1.25±0.11	1.24±0.11	11

R PRO A – right leg (prosthesis) of amputees, L L A – left, healthy leg of amputees

TABLE 6
RESULTS OF TEMPORAL AND SPATIAL PARAMETERS (7 VARIABLES) WHICH REACHED STATISTICALLY SIGNIFICANT DIFFERENCES (P-VALUES <0.05) BY MEANS OF T-TESTS, COMPARING RIGHT PROSTHETIC LEGS TO LEFT, SOUND LEGS OF AMPUTEES

Variables	Student's t-test	p-values
Anterior step length [mm]	–3.55927	0.0052***
Stance time [%]	4.579397	0.0010***
Stance time [ms]	4.138645	0.0020***
Swing time [%]	–4.0872	0.0022***
Swing time [ms]	–3.97676	0.0026***
Swing velocity [m/s]	4.96979	0.0006***
Stride length [mm]	2.682315	0.0230*

p – level of significance: *0.05<p<0.1, **0.01<p<0.05, ***p<0.01)

ms *vs*. 716.36±52.01 ms; p=0.0020, 4) increased swing-time (% stride): 40.73±2.24 % stride *vs*. 37.63±1.027 mm; p=0.0022, 5) increased swing-time (ms) 470.911±43.00 ms *vs*. 429.09±32.07 mm p=0.0026, 6) decreased swing velocity (m/s) 3.02±0.29 m/s *vs*. 3.36±0.32 m/s; p=0.0006 and 7) decreased stride length (mm) 1409.04±84.59 mm *vs*.1438.58±65.20 mm; p=0.0230.

Discussion

Results of our kinematic study for right prosthetic legs in comparison with results of the left, sound legs of TT amputees discloses statistically significant increased anterior step length (mm), decreased stance-time, presented in % stride in ms; increased swing-time (% stride and in ms), decreased swing velocity (m/s) and decreased stride length (p<0.05) for right, prosthetic legs. Similar kinematic analysis was performed by Isakov and coauthors (18) and comparison of these results with the ones in our study showed similarity for most parameters (increased step, prolonged swing phase and increased stance phase for prosthetic leg). The only difference was found in variable – stride length (mm) which was not increased but decreased in our study.

Comparisons of kinematic variables between amputee persons and control group persons without amputation, generally, showed that significant difference was reached for swing time (ms). Analysis of tempo-spatial measurements for prosthetic, right legs of amputees, in comparison with right legs of able-bodied persons, showed decreased stance time (% stride and ms) and increased swing time (% stride). Stance time was decreased (ms and % stride) for prosthetic legs (59.27±2.24% stride or 680.91 ms) compared to stance time for able-bodied persons (right leg 62.02±1.79% stride or 678.77±31.08 ms; left leg 62.12±1.55% stride or 680.21±27.04 ms). The longest stance time showed left leg of amputee persons (62.55±1.04% stride or 716.36±52.01 ms). The difference between prosthetic leg and left, healthy legs of amputees reached statistical difference. Several authors reported similar results for TT amputated persons like ours concerning the decreased stance phase for prosthetic leg in comparison to left, healthy legs like Bateni and Olney (19). As the consequence of decreased stance time for prosthetic leg, the swing phase was significantly increased (40.73±2.24% stride or 470.911±43.00 ms) compared with right legs of able-bodied persons (37.80±1.78% stride or 415.96 ms). Our result of prolonged swing time (% stride and ms) of prosthesis in comparison to contra lateral, healthy leg of amputees was similar to results of some other biomechanical studies of amputee gait[8,18,20–23]. The reason why stance phase of prosthetic leg is decreased is in the lack of amputee persons' trust toward prosthesis; and because of that they try to transfer body weight to the healthy, contra lateral leg, as soon as possible.

Able-bodied persons walking at freely-selected speeds generally adopt a stride length of about 1.4 to 1.5 m, with step lengths of approximately 0.7 to 0.75 m and the right and left step lengths are generally equal[24,25]. The amputee subjects in our study demonstrated a significantly longer anterior step length (mm) with their prosthesis than with sound leg (753.71±51.45 *vs*. 678.9±50.66 mm). This result is similar to the result of Isakov (0.739+0.058 m *vs*. 0.690+0.063 m) (24) and results of some other authors (21, 23). Statistically significant decreased stride length (mm) of prosthetic legs compared to stride length of left legs of amputees (1409.04±4.59 *vs*. 1438.58±65.16 mm) was demonstrated in our study. The result of 1409 mm stride length for prosthetic legs is similar to 1.44 mm measured by Isakov[18,26]. but it is longer than 1.27 m by Winter and Sienko[27]; 1.32 m by Robinson[21], 1.38 m by Skinner and Effeney[28] and 131.7±24.2 cm from Bateni and Olney[19]. Although it is obvious that stride length for prosthetic leg is increased in comparison to healthy leg of amputee persons, a satisfactory explanation for this was not found. Maybe the reason could be stability of prosthesis during stance time or function of prosthetic feet [6].

Decreased cadence for amputees (prosthetic leg 104.91±7.78 steps/min *vs*. 105.09±7.57 steps/min cadence for contra lateral leg of amputees) compared to 109.93±5.99 steps/min for legs of able-bodied persons, was reported in our study similar to some other studies[29,30].

Walking velocity (m/s) is one of the most studied variables of human gait and probably provides a better indication of a person's walking ability than any other quantitative gait measure[24,25,31]. Freely selected walking speed is not only most comfortable for the person but it is the most rational from the aspect of energy cost of walking. Walking velocity for the majority of adult persons, for freely selected walking speed, is 1.2–1.5 m/s according to Murray MP[24] and Kadaba[25] 1.37 m/s according to Finley FR[32] and 1.325 m/s to Winter DA[33]. Results of our study showed that mean walking velocity was slower for prosthetic legs (1.23 m/s) than for contra lateral, healthy legs (1.26 m/s) and both legs of able-bodied participants (1.30 m/s). The differences between the velocity of prosthetic legs and contra lateral, healthy legs of amputees reached statistical significance. Walking velocity for TT amputees, provided with prosthesis (1.23 m/s) in our study was slower than able-bodied persons velocities which correspond to results of several other authors[10,28,33–35]. Dysvascular trans-tibial amputees tend to walk even slower with freely selected walking speeds than traumatic amputees[35]. Walking velocity of our amputees demonstrates greatest similarity to those of 1–1.3 m/s by Winter DA[33], Gard[6] and Finley FR[34]. Walking velocity of our TT traumatic amputees was faster than that of their colleagues amputees from study from Robinson[21], Colborne[36], Kegel[37], Perry [29], Isakov[26] except from the participants in study reported by Postema (1.3–1.36 m/s)[38]. According to clinical experience, walking velocity could be considered as one of the indicators of successful prosthetic rehabilitation, so it can be concluded that TT traumatic amputees from our study had good prosthetic providing and were successfully rehabilitated. Partially, this could be the result of relatively young age of our patients, mean age 40.25±6 years (31–52).

Conclusion

Based on the results of our study, the following conclusion can be drawn:

Instrumented biomechanical quantitative gait analysis and evaluation of transtibial amputee persons compared to able-bodied person is able to provide objective assessment about the way prosthetic persons walk. Presented study focused on stride characteristics of TT amputees and gave objective, quantitative kinematic gait analysis and evaluation of different adaptive strategies of body in amputee patients wearing prosthesis of the lower limb. Although trans-tibial amputees tend to walk with similar kinematics as able-bodied individuals, subtle differences can be distinguished in kinematic data.

Results of our study discloses asymmetries in kinematic gait parameters between the prosthetic, amputated and contra lateral, left healthy legs of amputees, as well between prosthetic, right legs of trans-tibial amputees and both legs of non-disabled persons (specially with right legs). Significant differences were detected for 1) swing-time (ms), comparing amputees to able-bodied persons, 2) swing-time (ms), comparing right leg of able-bodied persons with right prosthetic legs, 3) swing-time % stride, comparing right leg of able-bodied persons with right prosthetic legs and 4) stance-time % stride, comparing right leg of able-bodied persons with right prosthetic legs. Temporal-spatial parameters of amputees, in comparison with able-bodied persons, generally, showed significantly increased swing-time (ms) ($p<0.01$). Prosthetic, right legs of amputees showed decreased stance-phase (ms and % GC) and increased swing-time (ms), compared with right legs of able-bodied persons. Significance were reached for decreased stance-time (% stride and ms), increased swing-time (% stride and ms), decreased swing velocity (m/s), increased anterior step length and decreased stride length of prosthetic legs compared with contra lateral, left legs of amputees Walking speed of amputee persons was slower.

The main explanation for asymmetries in kinematic, temporal-spatial measures of traumatic TT amputee gait which are different from able-bodied, in most cases, is prosthesis alone or different types of prosthetic components. Some differences among individual amputee subjects may relate to physical capabilities, training, confidence, and experience. Temporal-spatial measures are appealing because they are relatively simple to acquire and easy to comprehend when evaluating prosthetic gait. They can be beneficial for verifying visual observation, providing objective measurements that substantiate a subjective assessment and for identifying and addressing differences in a prosthetic user's gait from normal. Quantitative gait analysis is recognized as being useful for providing an objective assessment about amputee person gait and for documenting progress as a person undergoes rehabilitation. The overall goal of amputee rehabilitation is to return patients to their highest level of function and safety. Instrumented, computerized 3-D gait analysis can be one tool to facilitate this.

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REFERENCES

1. ESQUENAZI A, TALATY M, Gait analysis: Technology and Clinical Applications. In: BRADDOM RL (Ed) Physical medicine and Rehabilitation. Third Edition (Saunders Elselvier, London, 2007). — 2. WHITTLE M, Gait Analysis: An Introduction. Third Edition (Butterworth-Heinemann, Oxford, 2002). — 3. PERRY J, Gait Analysis: Normal and pathological function (SLACK Incorporated, New York, 1992). — 4. WU G, Kinematics Theory. In: CRAIK R, OATIS C (Eds) Gait Analysis – Theory and Application (Mosby, St. Luis, 1995). — 5. JELIĆ M, KOVAČ I, Epidemiological analysis of war amputees. In: Book of abstracts (Third ISPO Central and Eastern European Conference, Dubrovnik, 2002). — 6. GARD SA, JPO, 18 (2006) 93. — 7. REITMAN JS, POSTEMA K, GEERTZEN JHB, Prosthet Orthot Int, 26 (2002) 50. — 8. ISAKOV E, BURGER H, KRAJNIK DS, GREGORIĆ M, MARINČEK C, Scand J Rehab Med, 29 (1997) 75. — 9. BRAKEY J, Orthot Prosthet, 30 (1976) 17. — 10. WINTER DA, The Biomechanics and Motor Control of Human Gait: Normal, Elderly and Pathological Sec Ed (University of Waterloo Press, Walerloo Ontario Canada, 1991). — 11. ENGSBERG JR, LEE AG, PATTERSON LJ, HARDER JA, Arch Phys Med Rehabil, 72 (1991) 657.

— 12. PRINCE F, ALLARD P, THERRIEN RG, MCFADYEN BJ, Prosthet Orthot Int, 16 (1992) 19. — 13. HEIMER Ž, Automated clinical measurement of biomechanics and kinesiology of human gait. MS thesis. In Croat (University of Zagreb, Zagreb, 2005). — 14. KOVAČ I, Biomechanical gait analysis of transtibial amputees' fitted with Patellar Tendon Bearing Prosthesis. PhD thesis. In Croat (University of Zagreb, Zagreb, 2007). — 15. DAVIS R, OUNPUU S, TYBURSKI D, GAGE J R, Human Movement Science, 10 (1991) 575. — 16. MEDVED V, Measurement of Human Locomotion (CRC Press LLC, New York, 2001). — 17. BTS, Declaration of ELITE system characteristics (BTS S.p.A, Milano, 2003). — 18. ISAKOV E, KAREN O, BENJUYA N, Prosth Orthot Int, 24 (2000) 216. — 19. BATENI H, OLNEY S, J Prosthet Orthot Sci JPO, 14 (2002) 2. — 20. SANDERS TG, Lower Limb Amputations: A Guide to Rehabilitation (F.A. Davis Company, New York, 1986). — 21. ROBINSON JL, SMIDT GL, ARORA JS, Phys Ther, 57 (1977) 898. — 22. NISSAN M, J of Rehab Research, 28 (1991) 1. — 23. SMIDT LG, Gait in Rehabilitation (Churchill Livingstone, New York, 1990). — 24. MURRAY MP, Am J Phys Med, 46 (1967) 290. — 25. KADABA MP, RAMAKRISHNAN HK, WOOTTEN ME, J Orthop Res, 8 (1990) 383. — 26. ISAKOV E, BURGER H, KRAJNIK DS, GREGORIĆ M, MARINČEK C, Influence of speed on gait parameters and on symmetry in bellow-knee amputees. In: Proceedings (9th International conference Mechanics in Medicine and Biology Ljubljana, Ljubljana, 1996). — 27. WINTER DA, SIENKO SE, J Biomech, 21 (1988) 361. — 28. SKINNER HB, EFFENEY DJ, Am J Phys Med, 64 (1985) 82. — 29. PERRY J, BOYD LA, RAO SS, MULROY SJ, IEEE Trans Rehabil Eng, 5 (1997) 283. — 30. TIBAREWALA DN, GANGULI S, J Biomed Eng, 4 (1982) 233. — 31.ANDRIACCHI TP, OGLE JA, GALANTE JO, J Biomech, 10 (1977) 261. — 32. FINLEY FR, CODY KA, Arc Phys Med Rehabil, 51 (1970) 423. — 33. WINTER DA, The Biomechanics and Motor Control of Human Gait (University of Waterloo Press, Waterloo, 1987). — 34. HUANG CT, JACKSON JR, MOORE NB, FINE PR, KUHLEMEIER KV,TRAUGH GH, SAUNDERS PT, Arch Phys Med Rehabil, 60 (1979) 18. — 35. HERMODSSON Y, EKDAHL C, PERSSON BM, ROXENDAL G, Prosthet Orthot Int, 18 (1994) 68. — 36. COLBORNE GR, NAUMANN S, LONGMUIR PE, BERBRAYER D, Am J Phys Med Rehabil, 71 (1992) 272. — 37. KEGEL B, BURGESS EM, STARR TW, DALY WK, Phys Ther, 61 (1981) 1419. — 38. POSTEMA K, HERMENS HJ, DE VRIES, KOOPMAN HFJM, EISMA WH, Prosthet Orthot Int, 7 (1983) 33.

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KINEMATIČKE, DUŽINSKO-VREMENSKE, KARAKTERISTIKE HODA OSOBA S TRAUMATSKOM POTKOLJENOM AMPUTACIJOM

SAŽETAK

Cilj istraživanja je kinematička evaluacija hoda kod 12 protetički opskrbljenih osoba s traumatskom, potkoljenom amputacijom, na temelju dužinsko-vremenskih parametara analize donjih udova u usporedbi sa hodom 12 ispitanika bez amputacije. Rezultati pokazuju asimetričnost kinematičkih parametara hoda osoba s amputacijom i zdravih osoba, općenito, s značajno produženom fazom zamaha (ms) kod osoba s amputacijom ($p<0{,}01$). Proteički opskrbljene noge manifestiraju značajno skraćenu fazu oslonca (ms i % CH) ($p<0{,}01$) te značajno produženu fazu zamaha nogu s protezom ($p<0{,}05$) u usporedbi s desnim nogama zdravih osoba, a statistički značajno ($p<0{,}01$) kraće trajanje faze oslonca (u % CH i u ms), duže trajanje faze zamaha (% CH i ms), sporiju brzinu zamaha (m/s), duži korak mm te smanjenu dužina ciklusa koraka ($p<0{,}05$), u usporedbi s kontralateralnom nogom. Rezultati našeg biomehničkog ispitivanja hoda osoba s potkoljenom amputacijom potvrđuju postojanje objektivnih kinematičkih parametara koje karakteriziraju hod osobe s potkoljenom amputacijom.