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Original scientific paper

Ground Reaction Force Analysis in Traumatic Transtibial Amputees' Gait

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A B S T R A C T

The study gives up findings of ground reaction force (GRF) measurement in traumatic transtibial amputees (TT) equipped with prosthesis. Results disclose significant asymmetries between the amputated and healthy legs, as well as between transtibial amputees and non-disabled persons. Decreased GRF of prosthesis (max. horizontal force Fx2 and medio-lateral Fy1 (p<0.05), max. vertical force Fz1 during the loading response phase and Fz 3 – max. vertical force in late terminal stance; Fx 1 – max. horizontal force and Fy 2 – max. lateral force) were registered in comparison to healthy legs of amputees. The only exception represents vertical force Fz2 showing larger magnitude on prosthetic legs (p<0.1). Nearly all forces (Fz1 and Fz3 – max. vertical force, Fx1 and Fx2 – max. horizontal forces and Fy1– max. medial force) were decreased for prosthetic legs in comparison to the healthy legs of amputees and to able-bodied persons.

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

Introduction

Amputees with trauma related amputation represent a very specific group of patients, first of all because of their age; mostly working age adults. It is well known that amputation is a reason of significant impact on quality of life and employment during the next 40 to 50 years of remaining life of the young amputee patient. However, they have great potential for enhancement of function through appropriate rehabilitation and use of effective prosthetic devices. Very often they adapt a unique way of ambulating with prosthesis. Most of the adaptations in their walk can be discerned by means of observation but it is not sufficient enough to note walking complexity, so, objective gait analysis becomes necessary[1–3].

Kinetic analysis is used to determine the net forces and torques (moments) exerted on the body as a result of the combined effects of the ground reaction force, inertia, and muscle contractions. Kinetic analysis requires the simultaneous collection of kinematical information and ground reaction forces, which are collected when subjects walk over force plates. This paper, however, is focused only to directly measurable kinetic information during gait, i.e. the ground reaction force 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 by The Ministry of Science, Education and Sports, Republic of Croatia[4,5].

The ground reaction force as measured by a force platform reflect the net vertical and shear forces acting between the foot (shoe) and force platform. This is a 3-dimensional vector quantity, typically displayed in three orthogonal components defined by the walkway coordinate system. The profiles of the ground reaction force components reflect the dynamics of gait and are indicative of the accelerations imposed on the body's center of mass. GRF is signal presented as a % of body weight (BW). The vertical component of the ground reaction force is the largest, and most studied, of the three components, and has a characteristic double hump for able-bodied individuals walking at comfortable self-selected speeds. The first peak of the vertical ground reaction force is believed to be particularly important for analyz-

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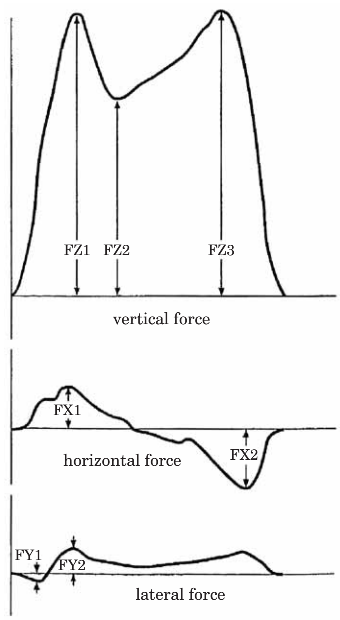

Fig 1. Normal ground reaction force (GRF) pattern during stance phase of gait, a) Vertical force (Fz) : Fz1, Fz2, Fz3, b) Horizontal force, fore-aft. (Fx): Fx1, Fx2 and c) Lateral force, medio-lateral (Fy): Fy1, Fy2.

ing shock absorption that occurs during the loading response phase of gait. Commonly, these vertical forces are designed as Fz1, Fz2 i Fz3 (Figure 1). The peak Fz1 occurs at the onset of mid stance in response to the weight accepting during loading response. In late mid stance, the valley is created by the rise of the center of gravity as the body rolls forward over the stationary foot. The second peak Fz3, occurring in late terminal stance, again indicates downward acceleration and lowering center of gravity as body weight falls forward over the forefoot rocker in terminal stance. The vertical force reflects the accelerations due to gravity as well as the vertical acceleration in the plane of progression. The value of the peaks approximates 110% of body weight, while force in the valley is about 80%. The forces generated parallel to the walking surface are called horizontal shear. Horizontal forces in anterior-posterior (AP) plane occur when the ground reaction force vector deviates from the vertical. The exchange of body weight from one limb to the other creates horizontal medio-lateral shear force (Fy). In the absence of adequate friction at the foot/ floor interface, this shear pattern would result in sliding and potential threats to stability. The magnitude of the horizontal forces compared to the vertical one, are small. The magnitude of medial-lateral (Fy) is less than 10% body weight. Peak medial shear (5% BW) occurs about mid loading response while lateral shear reaches a peak (7% BW) in terminal stance. The horizontal, anterior-posterior shear force (Fx) has a characteristic negative phase followed by positive phase. During the first half of stance phase the body is decelerating and during the later half it is accelerating. The peaks of these forces change with cadence. The magnitude of the horizontal anterior-posterior shear force (Fx) is less than 25% BW; the first peak is about 13% BW at the end of loading response and the 23% BW throughout terminal stance[6–8]. Persons with unilateral trans-tibial or trans-femoral amputations have been reported to walk with decreased vertical and fore-aft ground reaction forces under their prosthetic limb compared with able-bodied individuals, whereas the forces under their healthy limb are slightly greater[9–12]. Regarding possible clinic application of these measures one may refer to Gauthier-Gagnon[13] and Gard[14]. According to Gauthier-Gagnon[13], some variables like static weight-bearing, gait velocity and vertical loading of the prosthesis during gait, could be used as an indicator of gait training progression for trans-femoral amputees.

Material and Methods

Kinetic analyses were performed by collection of ground reaction forces data as subjects walked over force plate (Kistler) embedded into the floor of the laboratory. Gait analysis consisted of ground reaction force kinetics of both the amputated and non-amputated legs, compared to able bodied persons.

Study population consisted of twelve (12) males with right transtibial traumatic amputation in mean age 40.25+6 years (31–52) volunteered to participate in this study. 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 in the Institute for Rehabilitation and Orthopedic Devices (IROD) University Hospital Center Zagreb. All subjects were excellent walkers who used their prosthesis on a regular basis and were leading an active normal life. They were not suffering from any severe concurrent illnesses (Table 1).

TABLE 1
STUDY POPULATION OF 12 MALES WITH RIGHT TRANS-TIBIAL TRAUMATIC AMPUTATION AND CONTROL GROUP STUDY OF 12 ABLE-BODIED MALES

	Study population: 12 males with right TT traumatic amputation	Control group study: 12 able-bodied males, without amputation
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)

Prosthetic alignments were similar for all patients. All transtibial prostheses had full contact socket. Another prosthetic components were not of the same type; prosthetic feet were different type so 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-amputed 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. The experimental sessions were carried out in the Biomechanics Laboratory at the Faculty of Kinesiology in Zagreb. Prosthetic rehabilitation of all TT amputees was performed in Institute for Rehabilitation and Orthopedic Devices University Hospital Center Zagreb in Zagreb. The equipment we used was 12 m long walkway instrumented with force plate (Kistler). Kinetic analyses were performed by collection of ground reaction forces data as subjects walk over force plates embedded into the floor of the laboratory. Kinetic analysis was only one part of a gait analysis of traumatic TT amputees that we performed. Simultaneous, kinematics procedures measure the motion of the body and limb segments data were assessed by optoelectronic system Elite Biomech (BTS Bioengineering, Milano) with eight-camera high-speed video system. 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[5,15,16].

From all kinetic variables, which could be studied, 7 variables was selected. Testing of statistically significant differences, by statistical method, for ground reaction force results were performed comparing kinetic variables between: a) amputees to able-bodied persons, b) right prosthetic leg to left, sound leg of amputees and c) left legs of amputees to left legs of able-bodied persons were performed. As well, kinetic measurements results of prosthetic legs were analyzed by comparison with results of left, healthy legs of amputees. The data were processed by using means differences with standard t-test which was modified because of multiple tests (4x7=21). Statistical Software SAS procedure multitest was used.

Results

Ground reaction force results for prosthetic legs and contra-lateral legs of amputees and for both legs of able bodied persons are presented by mean values and SD (Table 2, 3 and 4) and presented by Box plot diagrams (Figure 2). Results of kinetic analysis comparing ground reaction forces between amputee persons and control group persons without amputation, generally, (AP-CG: amputees – control group), showed that amputees had significantly decreased ($p<0.05$): Fz3 – max. vertical force in late terminal stance; Fx1 – max.horizontal force at the end of loading response and Fy1 – max.medial force (medio-lateral) ground reaction force.

Statistical analysis of results for prosthesis, comparing GRF of prosthesis with GRF of right legs healthy persons without amputation showed that amputees had significantly decreased GRF ($p<0.05$) on the side of prosthetic legs for: Fz3 – max. vertical force in late terminal stance, Fx1 – max. horizontal force at the end of loading response and Fy1 – max. medial force (medio-lateral). When comparing GRF results for left, healthy legs of am-

TABLE 2

RESULTS (MEAN VALUES AND SD OF MEASUREMENTS OF MAXIMUM OF VERTICAL FORCe-Fz 1, Fz 2 and Fz 3 UNDER PROSTHETIC, RIGHT LEG AND LEFT LEG (SOUND) OF AMPUTEES AND BOTH LEGS OF ABLE BODIED PERSONS (N/KG)

Variable	Leg	Number of measurements	$\bar{X}$ force N/kg	Standard deviation
Fz 1	R PRO A	14	1.04	0.07
Fz 1	R L C	13	1.08	0.11
Fz 1	L L A	14	1.17	0.10
Fz 1	L L C	13	1.06	0.10
Fz 2	R PRO A	14	0.81	0.05
Fz 2	R L C	13	0.75	0.08
Fz 2	L L A	14	0.76	0.07
Fz 2	L L C	13	0.72	0.08
Fz 3	R PRO A	14	0.99	0.04
Fz 3	R L C	13	1.07	0.06
Fz 3	L L A	14	1.06	0.06
Fz 3	L L C	13	1.07	0.05

R PRO A – right leg (prosthesis) of amputees, L L A – left leg of amputees, R L C – right leg of able bodied persons, L L C – left leg of able bodied persons

TABLE 3

RESULTS (MEAN VALUES AND SD OF MEASUREMENTS (MEAN VALUES AND SD) FOR THE MAXIMUM OF HORIZONTAL FORE-AFT SHEAR FX 1 AND FX 2 (N/KG)

Variable	Leg	Number of measurements	$\bar{X}$ force N/kg	Standard deviation
Fx 1	R PRO A	14	0.12	0.05
Fx 1	R L C	13	0.23	0.04
Fx 1	L L A	14	0.21	0.04
Fx 1	L L C	13	0.24	0.09
Fx 2	R PRO A	14	0.16	0.05
Fx 2	R L C	13	0.18	0.03
Fx 2	L L A	14	0.21	0.03
Fx 2	L L C	13	0.19	0.04

R PRO A – right leg (prosthesis) of amputees, L L A – left leg of amputees, R L C – right leg of able bodied persons, L L C – left leg of able bodied persons

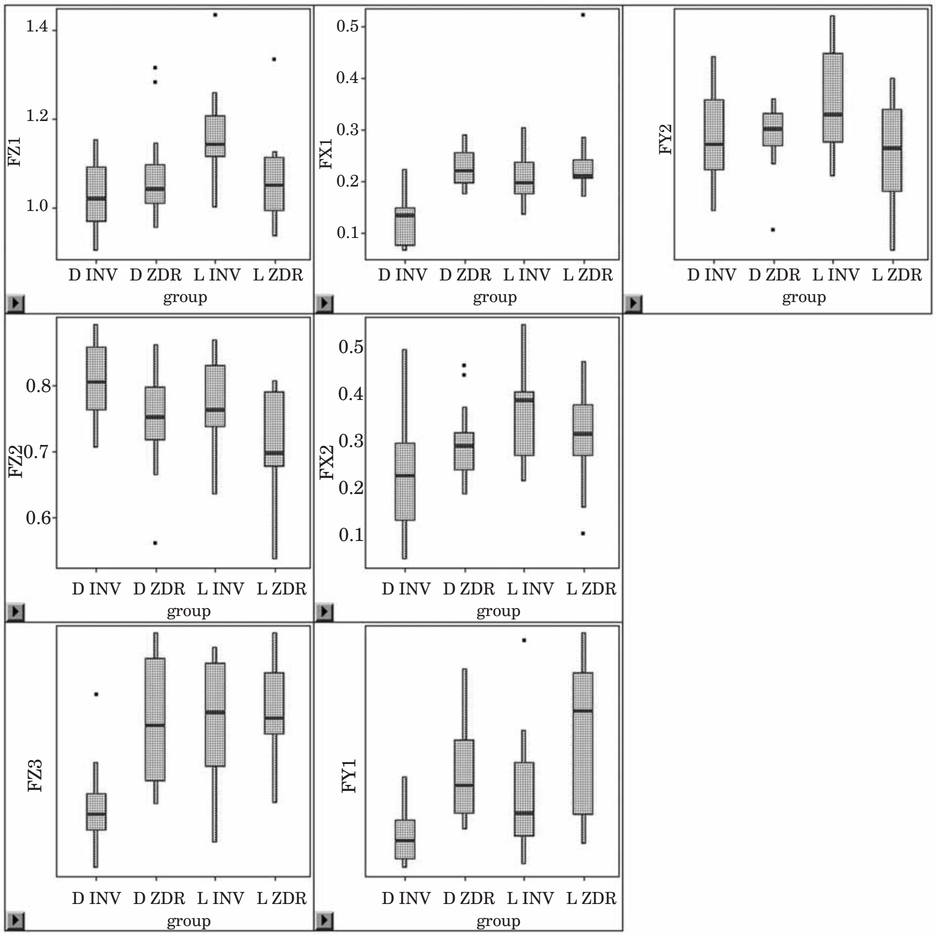

Fig. 2. Kinetic results of ground reaction forces (Fz, Fx and Fy forces) for the amputees and control group persons, presented by Box plot diagrams, Fz1 – max. vertical force during the loading response phase, Fz2 – max. vertical at the onset of mid stance, Fz3 – max. vertical force in late terminal stance, Fx1 – max. horizontal force at the end of loading response, Fx2 – max. horizontal force at the terminal stance, Fy1 – max. medial force (medio-lateral) Fy2 – max. lateral force (medio-lateral) and 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.

putee persons with GRF of prosthesis and with both legs of control persons without amputation, max. lateral force Fy 2, which was increased, differed significantly ($p<0.1$) in comparison with GRF of left legs of control persons, without amputation. Statistical analysis of GRF results for both legs of persons without amputation comparing with amputees, showed increased GRF with significantly difference ($p<0.05$) for: Fz1 – max. vertical force during the loading response phase; Fx1 – max. horizontal force at the end of loading response and Fy1 – max. medial force (medio-lateral). Results of measurements of ground reaction forces (N/kg) under prosthetic, right leg and healthy leg of amputees are presented in Table 5 and 6.

Results of kinetic analysis showed statistically decreased maximum of vertical force Fz 1 for prosthetic legs, compared to healthy, left legs of amputees (1.04±0.07 N/kg *vs*. 1.17±0.10 N/kg; p=0.0003) and decreased maximum of vertical force Fz 3 (0.99±0,04 N/kg *vs*. 1.06±0,06 N/kg; p=0.0003).

TABLE 4
RESULTS (MEAN VALUES AND SD) OF MEASUREMENTS FOR THE MAXIMUM OF HORIZONTAL MEDIAL SHEAR FY 1 AND LATERAL SHEAR FY 2 (N/KG)

Variable	Leg	Number of measurements	$\overline{X}$ force N/kg	Standard deviation
Fy1	R PRO A	14	0.02	0.01
Fy1	R L C	13	0.05	0.02
Fy1	L L A	14	0.04	0.03
Fy1	L L C	13	0.06	0.04
Fy2	R PRO A	14	0.08	0.03
Fy2	R L C	13	0.08	0.02
Fy2	L L A	14	0.10	0.03
Fy2	L L C	13	0.07	0.03

R PRO A – right leg (prosthesis) of amputees, L L A – left leg of amputees, R L C – right leg of able bodied persons, L L C – left leg of able bodied persons

TABLE 5
STATISTICALLY SIGNIFICANT RESULTS OF STANDARD AND MODIFIED T-TESTS (P-VALUES) OF KINETIC PARAMETERS (GRF), COMPARING: 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

		p-values	
Variables (force)	Comparison	Standard t-test	Modified t-test
Fz 3	CG *vs.* AP	0.0031	0.0463 ** 0.01<p<0.05
Fz 3	R L C *vs.* R PRO A	0.0005	0.0075 *** p<0.01
Fx 1	CG *vs.* AP	<0.0001	0.00145 *** p<0.01
Fx 1	R L C *vs.* R PRO A	<0.0001	0.0006 *** p<0.01
Fy 1	CG *vs.* AP	0.0002	0.0028 *** p<0.01
Fy 1	R L C *vs.* R PRO A	0.0028	0.0415 ** 0.01<p<0.05
Fy 2	L LC *vs.* L LA	0.0056	0.0802 * 0.05< p< 0.1

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

Results of kinetic analysis showed increased maximum of vertical force Fz 2 for prosthetic legs, compared to healthy, left legs of amputees (0.81±0.05 N/kg *vs.* 0.76±0.07 N/kg; p<0.0433). Also, results showed statistically significant decreased forces for prosthetic legs like: maximum horizontal force Fx 1 (0.12±0.05 N/kg *vs.* 0.21±0.04 N/kg), p=0.0002); max. horizontal force Fx 2 (0.16±0,05 N/kg *vs.* 0.21±0,03 N/kg; p=0.0085; maximum lateral force Fy 1 (0.02±0.01 N/kg *vs.* 0.04±0.03 N/kg, p=0.0085 and maximum lateral force Fy 2 (0.08±0.03 N/kg *vs.* 0.10±0.03 N/kg; p=0.0633, compared to healthy, left legs of amputees.

Discussion

Supporting body weight, in static and dynamic condition, is one of the main functions of lower limb. Symmetrical weight shifting over the limbs during stance and gait is relevant clinical problem for people with a lower limb amputation. Through limb loss, the center of gravity is shifted laterally to the side of the non-amputated limb, a shift that is not fully compensated for by the mass of the prosthesis. Thus the increase in vertical loading on the non-amputated side is not only related to the difference between the weight of the prosthesis and the weight of the anatomical segment. Some other factors like postural instability and /or pain are probably responsible for the asymmetry of weight bearing during stance and gait[17–19.]

The average loading and GRF, normalized to stance duration, is almost equal for both legs[17–20]. There may be some variations in healthy people, due to gender, or less, to the age, or due to walking cadence[21,22]. For normal subjects, a mean difference of 6 to 10% of body weight has been reported. The best indicator of weight distribution in a sample is the average difference between two limbs[6–8,17]. The greatest cause of asymmetry of weight bearing and to GRF is some pathological process on one leg. Amputation of one leg could be the reason for differences between the intact and prosthetic leg.

TABLE 6
RESULTS OF GRF RESULTS (MEANS AND STANDARD DEVIATIONS) FOR PROSTHETIC LEGS AND SOUND LEGS OF AMPUTEES (N/ KG)

Force N/kg	Prosthesis (R PRO A) Means±SD	Healthy leg (L L A) Means±Std dev	No of trials
Fz 1	1.04±0.07	1.17±0.10	14
Fz 2	0.81±0.05	0.76±0.07	14
Fz 3	0.99±0.04	1.06±0,06	14
Fx 1	0.12±0.05	0.21±0.04	14
Fx 2	0.16±0.05	0.21±0.03	14
Fy 1	0.02±0.01	0.04±0.03	14
Fy 2	0.08±0.03	0.10±0.03	14

p – level:* 0.05<p<0.1 /** 0.01<p<0.05 /*** p<0.01)

TABLE 7
STATISTICALLY SIGNIFICANT RESULTS OF T-TESTS (P-VALUES), STANDARD AND MODIFIED, COMPARING GRF BETWEEN PROSTHETIC LEGS AND SOUND LEGS OF AMPUTEES

		p-values		
Force (N/ kg)	Comparison	Standard t-test	No of trials	Modified t-test
Fz1	R PRO A-L L A	4.64	13	0.0005 ***
Fz2	R PRO A-L L A	–2.24	13	0.0433 **
Fz3	R PRO A-L L A	4.95	13	0.0003 ***
Fx1	R PRO A-L L A	5.02	13	0.0002 ***
Fx2	R PRO A-L L A	3.10	13	0.0085 ***
Fy1	R PRO A-L L A	3.10	13	0.0085 ***
Fy2	R PRO A-L L A	2.03	13	0.0633 *

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

Results of our gait analysis disclosed asymmetries in kinetic gait parameters between the amputated and healthy legs, as well between trans-tibial amputees and non-disabled persons, which were confirmed by the statistical testing. Results of kinetic analysis comparing ground reaction forces between amputee persons and control group persons without amputation, generally, showed that amputees had significantly decreased ($p<0.05$): Fz3 – max. vertical force in late terminal stance; Fx1 – max. horizontal force at the end of loading response and Fy1 – max. medial force (medio-lateral). Comparison of GRF results of prosthetic legs with GRF of right legs persons without amputation showed that amputees had significantly decreased ($p<0.05$) on the side of prosthetic legs Fz3 – max. vertical force in late terminal stance, Fx1 – max. horizontal force at the end of loading response and Fy1 – max. medial force (medio-lateral). Left, sound legs of amputee persons showed significantly increased Fy 2 ($p<0.1$), which differed in comparison with GRF of left legs of control persons, without amputation.

Comparison of GRF between prosthetic legs and sound legs of amputee persons showed statistically significant differences for results of ground reaction force for prosthetic legs, compared to sound legs; almost all ground reaction forces on prosthetic side of amputees were decreased in comparison with their healthy, left legs. They reach statistical significant difference ($p<0.05$) for maximum horizontal force (Fx 2) and medio-lateral Fy1 and highly significant difference ($p<0.01$) for other forces like maximum of vertical force (Fz 1), maximum vertical force (Fz 3), maximum horizontal force (Fx 1) and maximum lateral force (Fy 2). The only exception represents Fz 2 which had larger magnitude of vertical force Fz 2 on prosthetic legs, which reach significant difference ($p<0.1$).

Prosthetic legs of amputee persons showed decreased weight bearing possibilities and decreased vertical ground reaction force but similar results were found for their sound, non amputated legs in comparison to GRF of control, healthy persons, except vertical force Fz2 at the onset of mid stance, which is increased under prosthetic leg.

Horizontal shear are the forces generated parallel to the walking surface. Horizontal antero-posterior force (Fx1) represents force which is important for the propulsion of the body forward. Horizontal medial-lateral shear force (Fy) are parameter which is result of excange of body weight from one limb to the other. Without adequate friction at the foot/ floor interface, these shear pattern would result in sliding and potential threats to stability. Both of horizontal forces, antero-posterior forces (Fx1) and medial-lateral shear force (Fy), were decreased under prosthetic legs, in comparison to GRF under their non amputated legs and the GRF of legs of healthy persons; their maximal values were very similar.

Decreasing of almost all ground reaction forces under the prosthetic legs in comparison with the non amputated legs of amputees, could be explained by caution at loading of the prosthesis, because of some insecurity and instability with prosthesis. More weight bearing is putting to the healthy leg, so result off that is asymmetry in gait and decreasing off acceleration and deceleration of prosthetic leg[23].

Summary of results between GRF for prosthetic, non amputated legs and prosthetic about showed that healthy legs of amputees, had greater GRF in comparison between prosthetic leg and healthy, control population. These result are similar to many others authors who showed greatest GRF for healthy legs of amputees comparing amputees and healthy, control study population[11,18,20,24–28]. There were some problems in comparison of our results with the results of other authors, because of different equipment and methodology that were used in various kinetic studies.

Another problem presented different ways of presentation of ground reaction force. Most frequently GRF is expressed by means of % of body weight (% BW). Another possibility, that which we used, is presentation by N/kg. Most studies had small number of study participants, so, our opinion was that there was not correct to compare the absolute values of GRP. Superior method is to compare results of measurements inside of each study and then compare it with other studies. By applying this type of analysis, our study results discloses asymmetries in kinetic gait parameters between the prosthetic leg and non-amputed, healthy leg in amputees.

Our results are similar to those reporting that persons with unilateral trans-tibial amputations walk with decreased vertical and fore-aft ground reaction forces under their prosthetic limb compared with able-bodied individuals, whereas the forces under their healthy limb are slightly greater[10,18,19,20,24,25,28]. Vertical ground reaction forces under their prosthetic limb compared with the forces under their healthy limb were decreased in amputees, according to several authors[11,27–29] and about 17% according to Chao[22]. Study results of Geurts ACH. and Isakov E, also, showed that the anterior–posterior foot–ground reactive forces generated by the amputated limb were significantly smaller compared with the sound leg[19,30]. Hermodsson and coauthors[31], also had been reported about significantly smaller anterior–posterior and medio-lateral horizontal ground reactive forces generated by the amputated limb compared with the sound leg for traumatic trans-tibial amputees.

These asymmetries, which are manifested, are related mainly to the rigid prosthetic ankle-foot component. Amputee subjects consistently demonstrate reduced ankle power in late prosthetic stance phase but increase power generation by the anatomical knee and hip joints of their residual limbs, compared with able-bodied ambulatories[32].

Conclusion

Results of our kinetic quantitative gait analysis study and evaluation of trans-tibial amputee persons compared to able bodied person provide objective assessment about the way prosthetic persons walk. Study results of gait analysis of our traumatic amputees who had been walking with prosthesis for more than 8 years, discloses asymmetries in kinetic gait parameters between the amputated and sound legs, as well between trans-tibial amputees and non-disabled persons. It is well known that body weight transfer over the prosthesis when standing and walking is an important goal in rehabilitation of people with a lower limb amputation. Based up to our results we can conclude that kinetic measures of walking are useful because they convey information that cannot be discerned visually by an observer, and they may directly relate to what the prosthetic user perceives while they walk.

Ground reaction forces analysis under prosthesis and non-amputated leg during gait, could be used as a method of analyzing prosthetic feet[6–8] or for prosthetic evaluation off symmetry in kinetic gait parameters between the prosthetic and sound leg[20,34,35].

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KARAKTERISTIKE SILE REAKCIJE PODLOGE HODA OSOBA S TRAUMATSKOM POTKOLJENOM AMPUTACIJOM

SAŽETAK

U studiji su prezentirani rezultati mjerenja sile reakcije podloge (SRP) 12-orice protetički opskrbljenih muškaraca s traumatskom transtibijalnom amputacijom. Rezultati su bili značajno različiti za nogu s protezom u usporedbi s njihovom zdravom nogom, kao i između osoba s amputacijom i zdravih osoba. Statistički značajno niže vrijednosti noge s protezom su manifestirane za Fx2 – maksimalnu horizontalnu silu odraza od podloge i Fy1 – maksimalnu medijalnu silu ($p<0,05$) te Fz1 – maksimalnu okomitu sila u početnom dijelu oslonca na podlogu, Fz3 – okomitu silu kod odraza, Fx1 – maksimalnu horizontalnu silu impulsnog sraza pete s podlogom i Fy2 – maksimalnu lateralnu silu ($p<0,1$) u

usporedbi s kontralateralnom, zdravom nogom. Iznimku je predstavljala Fz2 – okomita sila u srednjoj fazi oslonca koja je veća na nozi s protezom. Gotovo sve komponente SRP (Fz1 i Fz3 – maksimalna okomita sila, Fx1 i Fx2 – maksimalna horizontalna sila i Fy1 – maksimalna medijalna sila) bile su niže na nogama s protezom u usporedbi sa zdravim nogama osoba s amputacijom kao i obje noge zdravih osoba.