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Biomechanical indicators of intact limb overload in transtibial and transfemural amputees and patients with disarticulation in the hip joint

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Introduction Compensatory overloading of the contralateral (intact) limb in patients after unilateral lower limb amputation can lead to an additional decline in their quality of life. **Purpose** To determine reliable biomechanical indicators of the intact extremity overloading in patients with prostheses and to draw attention to the need of providing them with orthopedic support means **Methods** Databases of the biomechanical tests saved with a software system "DiaSled-M-Skan" were studied. Statistical differences in the parameters of interaction between support feet were defined for 4 groups with different grades of static and dynamic functional disorders. Group 1 was control group (without dysfunctions in the lower extremities); group 2 wore prosthesis after transtibial amputation while group 3 had prostheses after transfemoral amputation; and group 4 patients wore prostheses for an excessively short stump of the femur or had higher level of amputation. **Results** Parameters of foot interaction were determined that were the most sensitive to functional depression of the truncated extremity: coefficients of bilateral asymmetry for duration of foot support and bilateral asymmetry of conditional work for a step. They permitted to determine the level of overloading in the intact foot. In patients on prosthesis after transfemoral amputation (group 3) duration of the roll over the intact foot was one third longer and the conditional work for a step was two times greater than with the artificial one. **Discussion** Results of the research prove the existence of a compensatory mechanical overload of the intact foot in patients after unilateral lower limb amputation. This indicates that there is a need of continuity in the work of the prosthetist and the orthopedist. A timely indication to wear an orthopedic insole for patients with prosthesis after unilateral amputation reduces the risk of an intact limb overload, pathological changes in its joints and intact foot deformity.

Keywords*:* rehabilitation, prosthetics, intact lower limb, foot, overload, biomechanics

INTRODUCTION

Patients' quality of life after unilateral (monolateral) amputation of the lower limb (i.e. only left or right side) depends both on the results of prosthetic fitting and on the condition of the contralateral (intact or preserved) limb which actively participates in compensating for functional deficiency of the limb with the prosthesis on.

There is a scientific evidence that the incidence of arthritis in the intact limb is much higher than in the limb with prosthetic devices and also than in the individuals without any amputation [1, 2]. Moreover, the risk of arthritis in the patients that wear prostheses after amputation at the femur level is higher than in those that had it at the level of the tibia [3]. In addition, prolonged overloading of the intact limb leads to structural and functional changes in the foot and metatarsalgia which may require an osteotomy in severe cases [4]. Overloading of the lower extremity is especially dangerous for patients with obliterating vascular diseases and diabetes mellitus who constitute a significant part in the total number of amputees. In their case, the initially high risk of necrosis, ulceration and subsequent amputation of the foot will additionally grow due to mechanical overloads [5, 6].

Therefore, compensatory overloading of the preserved limb in patients with prosthetic appliances is associated with a high risk of foot deformity, development of joint pathology and secondary disorders of the locomotor functions.

The results of separate cases after one-sided lower limb amputation that were followed up show the need for their orthopedic support to prevent mechanical overloads on the contralateral limb [7]. Despite this, until now, this problem has not been given a due attention during rehabilitation of such patients. One of the reasons for such an attitude is the fact that foot deformity in the patients with the prostheses on the other leg was not considered to be the consequence of its compensatory overload, but as a pathology that had existed prior to amputation. In this connection, the goal of this work was to identify reliable biomechanical indicators which specifically testify to the overload of the preserved lower limb due to its participation in compensating for static and dynamic functions of the limb with the prosthesis on, and to attract specialists' attention to the need for orthopedic support in these cases.

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MATERIAL AND METHODS

An observational one-stage analytical study was conducted in order to reveal the biomechanical parameters of overloading impact on the preserved limb in patients with prostheses on after a unilateral amputation. The material for it was samples from a general database of biomechanical instrumental surveys performed with the DiaSled-M-Scan hardware and software complex (registration number No FFR 2009/06416 and No FSR 2010/07441) [8] conducted at the Albrecht Federal Scientific Center for Rehabilitation of the Disabled of the RF Ministry of Labour within the framework of biomechanical control of the results of prosthetic fitting before delivery of the prosthesis to the patient.

DiaSled-M-Scan hardware and software complex (Version 5.0.160) was used for possessing of the findings and calculations.

Four groups were selected from the Center's database. Group 1 was a control group (without dysfunctions in static and dynamic functions); group 2 had prostheses after transtibial amputation; group 3 was with prostheses after transfemoral amputation; and group 4 patients wore prostheses for an excessively short femur stump, following hip disarticulation or after transpelvic amputation (AIA – amputatio interileo-abdommalis). The groups had different grades of static and dynamic functional disorders due to different amputation levels as far as functions of the hip or knee joints were used in ones during walking while others had prostheses supplied with hinge devices.

Inclusion criteria were men and women in the age from 16 to 70 years after unilateral limb amputation at the level of the tibia or above in the groups of patients on prostheses, and men and women of the similar age in the control group (16–70 years old) without clinical signs of the diseases that are accompanied by asymmetry of kinematic and dynamic characteristics by walking and standing. Exclusion criteria for all groups were severe co-morbidities at the time of examination accompanied by musculoskeletal functional disorders; pain in the spine and lower limbs (including the truncated one) at the time of examination. Additional exclusion criteria for patients' groups were lack of experience of walking on the prosthesis; insufficient quality of the prosthesis in the opinion of the medical and technical inspection board that did not allow delivery of the prosthesis to the patient.

Taking into account that the research was undertaken as a preliminary and pilot one, and under conditions of objective limitations due to inability to accumulate a large sample for biomechanical examinations of patients on prostheses with a high amputation level, the number of subjects in each group was assumed equal to 10, and the total of cases was 40 persons.

The databases from the DiaSled-M-Scan complex included biomedical information about the interaction of the supportable feet in the patients examined in a standing and walking positions. The following methods were used: balance pedography in the foot support contour or analysis of the balance of loads under the feet; cyclodynamography of the step or analysis of the time and power characteristics of the step and foot roll-over; baroplantography or analysis of the distribution of pressure along the plantar surface of the feet. To record the pressure under the feet, matrix sensors in the shape of insoles were used in the footwear which is part of the "DiaSled-M-Scan" complex. For examination of the feet in the control group, methods of computer plantography and three-coordinate pedometry were also used. At the same time, the image of the feet was recorded by the method of optical flatbed scanning with a three-axis scanner, which is part of the same complex.

Statistical analysis of the data was conducted using the statistical package SPSS 13.0 for Windows.

RESULTS

Fairly homogeneous groups of subjects were formed for the analysis. The mean age in the groups did not differ by more than 13 % and the maximum age by 16 % (**Fig. 1**). The groups differed significantly in the minimum age: the youngest of the patients with the tibial prosthesis was 16 years old while with the femur prosthesis the youngest was 27 years old. However, given that significant age-related changes in the musculoskeletal functions in the 16-to-27-year-old age range do not occur, such differences were accepted as unessential for the reliability of the study results. Even smaller differences were found between the total of all patients on the prosthesis when compared with the control group. The difference in their mean age was < 7 % and in the maximum age < 11 %.

In the statistical analysis of the data, the group designation numbers were taken as an independent rank variable, reflecting the grade of the static and dynamic functional disorders of the limb from the minimal (1 – control group) to the maximum (4 – on the prosthesis for an excessively short stump of the thigh, after hip disarticulation and AIA). The choice of dependent variables for proving limb overload was based on the following theoretical considerations.

It is known that a decrease in the supportability of one limb is accompanied by a compensatory preference of the other, more supportive, and the shift of the loading in its direction, i.e. asymmetry of load distribution between the legs. In addition, in a standing position, the patient has the opportunity to increase stability by shifting the load forward and, moreover, by diagonal inclination of the support by shifting the load under one foot forward, and under the other – backwards. All these compensation options can be accompanied by irrational distribution of the load on the plantar surface of the foot and cause its zonal overload. Such changes can be assessed by analyzing the balance in pedograms in the foot support contour (**Fig. 2**) and calculating the following biomechanical parameters: dx_{cpc_s} (frontal displacement of the CPC (common pressure center) in the foot contour in the static position, dy_{cpc_s} (sagittal CPC shift in the foot contour in static position; dy_{cp_s} (bilateral asymmetry of the sagittal displacement of the CP (center of pressure) in the support contour of the feet in the static position (**Table 1**).

When walking, the decrease in the function of one limb is compensated by an increase in the intensity of participation in the locomotion of the other, more functional limb, mainly due to the anterior or posterior part of its foot, which is accompanied by a change in the biomechanical parameters: dx_{cpc_w} – frontal displacement of the center of the migration trajectory of the CPC in the foot support contour during walking; dy_{cpc_w} – sagittal displacement of the center of the CPC migration trajectory in the foot contour during walking. A special value for evaluating the decrease in the function of one lower limb and compensating it by the other is the analysis of a cyclodynamogram of the step that reflects the energy characteristics of walking (**Fig. 3**). For this purpose, the manifestations of the biomechanical asymmetry of the foot overroll are investigated: the length of the CP migration trajectory under the feet K_{Ltcp_w}, the duration of the foot support by walking K_{T_w}, the maximum total pressure on the foot for one step K_{P_w}, the conditional work per step K_{A_w}, the conventional power of the overroll during walking K_{W_w}.

Thus, ten quantitative continuous variables were taken as dependent. All of them are derived from pressure under the feet and are calculated as non-limited values according to the formulas presented in Table 1. Due to the non-limited character of these values, the results of the test can be easily compared in patients with different foot sizes and at different walking speeds.

The results of descriptive statistics for the variables under study are presented in **Table 2**.

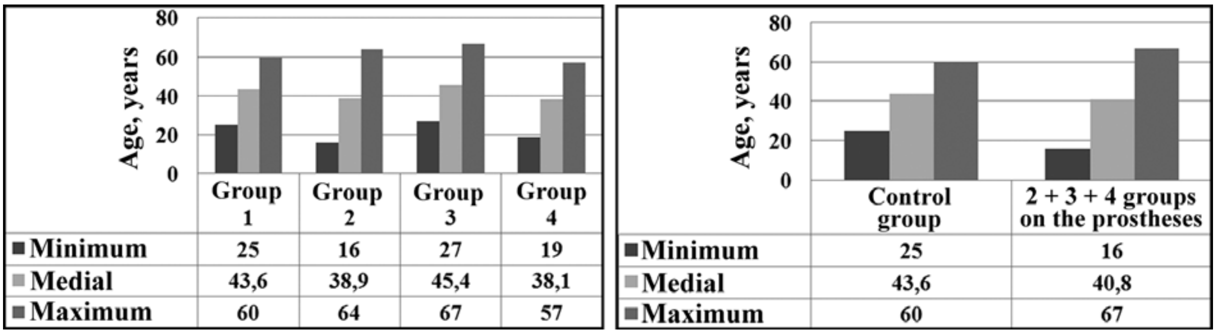

Fig. 1 Distribution of the subjects by age: 1 – control group; 2 – tibial prosthesis group; 3 –femur prosthesis group; 4 – group on the prosthesis for an excessively short stump of the thigh, after hip disarticulation or after AIA

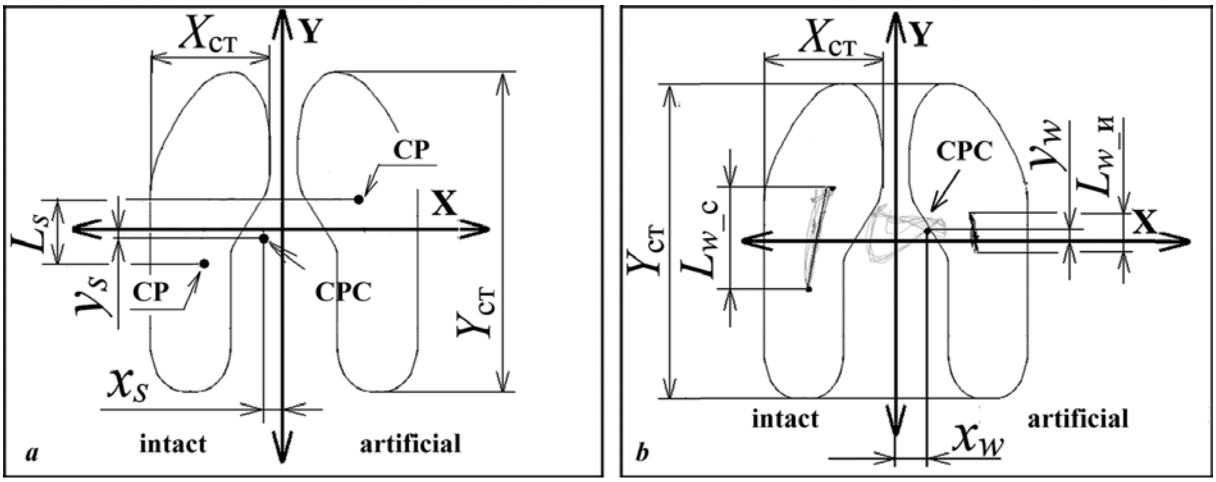

Fig. 2 Diagram to determine the parameters of the balance pedogram in the foot contour: a in a standing position; b while walking; X and Y are the frontal and sagittal axes of the support contour; Xf and Yf – the width and length of the foot; x_s and y_s are the frontal and sagittal shift of the common pressure center (CPC) in the static position; Ls is the distance between the pressure center (CP) of the left foot and the right one in the projection to the sagittal axis; x_w and y_w – frontal and sagittal shift of the center of the trajectory of CPC migration during walking; $L_{w\_и}$ and L_{w_c} – length of the migration trajectory of the CD under the left foot and right foot

Table 1

Parameters of studies

Variables				Calculation formula	No
Type		Designation	Name		
variables	Based on the analysis of CP and CPC and trajectories of their migration in the foot support contourт	dx_{cpc_s}	Frontal shift of CPC in the foot support contour in static position	$Dx_{cpc\_s} = x_s / X_{ст}$, (see **Fig.** 2)	1
		dy_{cpc_s}	Sagittal shift of CPC in the foot support contour in static position	$dy_{cpc\_s} = y_s / Y_{ст}$ (see **Fig. 2**)	2
		Dy_{cp_s}	Bilateral assimetry of saggittal shift of CP in the foot support contour in static position	$Dy_{cpc\_s} = L_s / Y_{ст}$ (see, **Fig. 2**)	3
		dx_{cpc_w}	Frontal shift of CPC migration trajectory centre in foot support contour by walking	$dx_{cpc\_w} = x_w / X_{ст}$ (see **Fig. 2**)	4
		dy_{cpc_w}	Sagittal shift of CPC migration trajectory centre in foot support contour by walking	$dy_{cpc\_w} = y_w / Y_{ст}$ (see **Fig. 2**)	5
		K_{Ltcp_w}	Bilateral asymmetry of CP migration trajectory length under the feet	$K_{Ltcp\_w} = L_{w\_и} / L_{w\_c}$ (see **Fig. 2**)	6
	Base on the analysis of total pressure changes on feet by walking	K_{T_w}	Bilateral asymmetry of foot support duration by walking	$K_{T\_w} = T_{w\_и} / T_{w\_c}$ (see **Fig. 3**)	7
		K_{P_w}	Bilateral asymmetry of the maximum total pressure on the foot for one step	$K_{P\_w} = P_{max\_w\_и} / P_{max\_w\_c}$ (see **Fig. 3**)	8
		K_{A_w}	Bilateral asymmetry of conditional work for a step	$K_{A\_w} = A_{w\_и} / A_{w\_c}$, $A_{w\_i} = \int_{t_{o\_i}}^{t_{T\_i}} f(P,t)\,dt$ *	9
		K_{W_w}	Bilateral asymmetry of conditional rolling power by walking	$K_{W\_w} = W_{w\_и} / W_{w\_c}$, where $W_{w\_i} = A_{w\_i} / T_{w\_i}$	10
Independent		Gr	Group of the subjects examined	Gr	11

* The conditional work per step was calculated with the graph of the change in the total pressure on the feet as an integral of the total pressure over time for the period of support on the foot (the area under the graph of the total load) (**Fig. 3**)

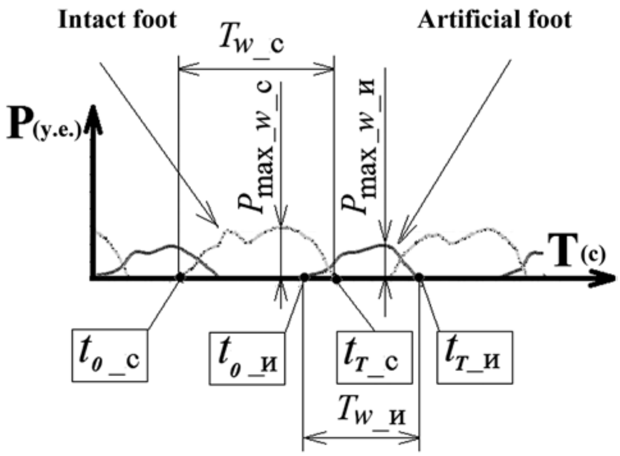

Fig. 3 Scheme for determining the parameters of the cyclodynamogram of the step: T – time axis (seconds); P – axis of total pressure on the pressure sensors under the feet (in conventional units); $T_{w\text{-}a}$ and $T_{w\text{-}i}$ – the duration of support on the artificial foot and an intact foot by walking; $t_{0\_и}$ and $t_{T\_и}$ – moments of the beginning and end of artificial foot rolling, t_{0_c} and t_{T_c} – the same for the intact foot; $P_{max\_w\text{-}a}$ and $P_{max\_w\_i}$ – maximum total pressure on the foot per step

Table 2

Mean values (M) and standard deviation (δ) in the groups

Variable	Group1		Group 2		Group 3		Group 4	
	M	δ	M	δ	M	δ	M	δ
$dx_{cpc\ s}$	-0.60	1.26	16.80	11.49	17.70	8.74	21.30	11.94
$dy_{cpc\ s}$	-1.90	3.87	-4.80	2.86	-4.70	4.32	-0.90	4.95
$Dy_{cp\ s}$	0.70	2.00	1.90	10.67	1.20	10.94	1.80	14.02
$dx_{cpc\ w}$	-1.20	2.30	0.30	3.37	-6.90	4.41	-11.80	9.02
$dy_{cpc\ w}$	4.00	1.89	0.80	1.93	0.80	3.52	2.20	2.90
$K_{Ltcp\ w}$	0.96	0.07	0.96	0.13	0.78	0.15	0.71	0.23
$K_{T\ w}$	0.98	0.02	0.93	0.05	0.75	0.08	0.76	0.09
$K_{P\ w}$	0.95	0.02	0.81	0.16	0.67	0.19	0.61	0.18
$K_{A\ w}$	0.94	0.04	0.73	0.14	0.49	0.22	0.42	0.14
$K_{W\ w}$	0.94	0.06	0.78	0.13	0.64	0.26	0.55	0.17

Despite the fact that the distribution type of variables according to the Shapiro-Wilk statistical criterion turned out to be normal for almost all variables, nonparametric methods were used for statistical data analysis due to the small sample size. In particular, the nonparametric Kruskal-Wallis H-test was chosen to determine the group differences in the four groups compared (**Table 3**).

In view of the known problem of multiple comparisons, a new critical level was calculated instead of the traditionally accepted in the medical literature critical significance level of 0.05 in order to avoid the error of the 1st row, i.e. to decide whether there are differences in places where they really do not exist. [9]:

$$p^* = 1 - 0.95^{1/n},$$

where n is the number of comparisons made.

This critical level for four groups examined $p^* = 1 - 0.95^{0.17} = 0.0085$.

With regard to this level p^*, significant differences between the groups were observed only for six of ten variables studied (see **Table 3**): dx_{cpc_s} – frontal CPC shift in the foot support contour in static positions; dx_{cpc_w} – frontal shift of the CPC migration trajectory center in the foot support centre by walking; K_{T_w} – bilateral asymmetry of foot support duration by walking; K_{P_w} – bilateral asymmetry of the maximum total pressure on the foot per step; K_{A_w} – bilateral asymmetry of the conditional work per step; K_{W_w} – bilateral asymmetry of the conditional power of the foot roll by walking. These six variables were further analyzed for determination of the differences between the groups.

Thus, the differences were revealed for six variables in the four groups.

In order to determine which groups differ from each other, the analysis of a posteriori group differences by the Mann-Whitney criterion was required. The results of this analysis are presented in **Tables 4** and **5**.

The results of the posteriori differences by the Mann-Whitney test (**Table 4**) indicate that significant differences were not observed only between the group 3 (on the femur prosthesis) and 4 (on the prosthesis for an excessively short stump of the thigh, after hip diarticulation and after AIA). In the other groups, there are significant differences in several variables at once.

Attention should be drawn to that fact that significant differences were observed for the variable dx_{cpc_s} for each of the patients' groups when compared with the control group; but when the groups of patients were compared between each other, there were no significant differences in this variable between them.

Based on the level of significance of differences (see Table 4), the variables K_{T_w} and K_{A_w} turned out to be the most sensitive in detecting the risk of compensatory overloading on the preserved limb.

To determine the dependence of these variables on the state of the static-dynamic functions of the prosthetic limb, the average ranks were assessed (**Table 5**). Their values show that for groups with lesser disorders in the static-dynamic function of the prosthetic limb, smaller ranks of the variables K_{T_w} and K_{A_w} are observed. An illustration of this relationship is shown in **Figure 4**.

For example, for group 2 (on a femur prosthesis) K_{T_w} was equal to 0.75 ± 0.08. Thus, the duration of the overroll of the intact foot was one-third greater than for the prosthetic limb foot. For the same group, K_{A_w} = 0.49 ± 0.22 of the conditional work per step for the preserved limb was 2 times higher than for the limb on the prosthesis. For comparison: in the control group K_{T_w} (coefficient of asymmetry of the duration of foot overroll) was 0.98 ± 0.02 and the conditional work per step was 0.94 ± 0.04. At the same time, the value of K_{T_w} in the control group, as calculated by our study, was consistent with the values found in healthy people by other researchers with the same equipment (the difference in the results is only 0.04 %) [10]. Values of the asymmetry of the conditional work for a step in the norm were not found in the available scientific literature sources.

Figure 5 is an example of the examination of the patient on the femur prosthesis presented in a graphical form with the signs of pronounced biomechanical bilateral asymmetry: an increase in the work per step in the intact limb, a longer rolling time of an intact foot and its forefoot overloading.

Table 2

Mean values (M) and standard deviation (δ) in the groups

Variable	Group1		Group 2		Group 3		Group 4	
	M	δ	M	δ	M	δ	M	δ
dx_{cpc_s}	-0.60	1.26	16.80	11.49	17.70	8.74	21.30	11.94
dy_{cpc_s}	-1.90	3.87	-4.80	2.86	-4.70	4.32	-0.90	4.95
Dy_{cp_s}	0.70	2.00	1.90	10.67	1.20	10.94	1.80	14.02
dx_{cpc_w}	-1.20	2.30	0.30	3.37	-6.90	4.41	-11.80	9.02
dy_{cpc_w}	4.00	1.89	0.80	1.93	0.80	3.52	2.20	2.90
K_{Ltcp_w}	0.96	0.07	0.96	0.13	0.78	0.15	0.71	0.23
K_{T_w}	0.98	0.02	0.93	0.05	0.75	0.08	0.76	0.09
K_{P_w}	0.95	0.02	0.81	0.16	0.67	0.19	0.61	0.18
K_{A_w}	0.94	0.04	0.73	0.14	0.49	0.22	0.42	0.14
K_{W_w}	0.94	0.06	0.78	0.13	0.64	0.26	0.55	0.17

Table 3

Results of the analysis of group differences using the Kruskel-Wallis criterion with grouping variable Gr in the SPSS 13.0 software for Widows

	Dependant variables									
	Dx_{cpc_s}	Dy_{cpc_s}	Dy_{cp_s}	Dx_{cpc_w}	Dy_{cpc_w}	K_{Ltcp_w}	K_{T_w}	K_{P_w}	K_{A_w}	K_{W_w}
χ^2 (Chi-Square)	19.56	5.32	0.61	20.33	10.33	15.27	30.32	20.40	27.84	18.37
df	3	3	3	3	3	3	3	3	3	3
Asymp. Sig.	0.000	0.150	0.892	0.000	0.016	0.002	0.000	0.000	0.000	0.000

Table 4

Posteriori differences in groups by the Mann-Whitney criterion (U) for variables for which significant differences were shown by the Kruskel-Wallis test

Groups	Level of difference significance (Asymp. Sig. (2-tailed))					
	Dx_{cpc_s}	Dx_{cpc_w}	K_{T_w}	K_{P_w}	K_{A_w}	K_{W_w}
1 and 2	0.002	0.376	0.003	0.128	0.001	0.012
1 and 3	0	0.004	0	0	0	0.019
1 and 4	0	0.002	0	0	0	0
2 and 3	0.97	0.002	0	0.103	0.017	0.13
2 and 4	0.544	0.001	0	0.023	0.001	0.006
3 and 4	0.65	0.212	0.82	0.185	0.384	0.272

Table 5

Average ranks of the variables K_{T_w} and K_{A_w} in the groups compared according to the results of the Mann-Whitney test

Variables	Study groups compared											
	1 and 2		1 and 3		1 and 4		2 and 3		2 and 4		3 and 4	
	1	2	1	3	1	4	2	3	2	4	3	4
K_{T_w}	14.40	6.60	15.50	5.50	15.50	5.50	15.30	5.70	15.15	5.85	10.20	10.80
K_{A_w}	14.90	6.10	15.50	5.50	15.50	5.50	13.65	7.35	15.00	6.00	11.65	9.35

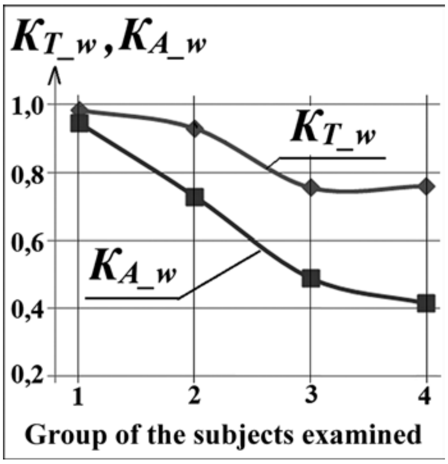

Fig. 4 Dependence of the ranks of the variables of the bilateral asymmetry of walking parameters on the degree of disturbance of the statodynamic function of the prosthetic limb: K_{T_w} – duration of the foot rest K_{A_w} – conditional work per step; 1 – control group; 2 – group on the tibial prosthesis; 3 – on the femoral prosthesis; 4 – on the prosthesis for an excessively short stump of the femur, after disarticulation or after AIA

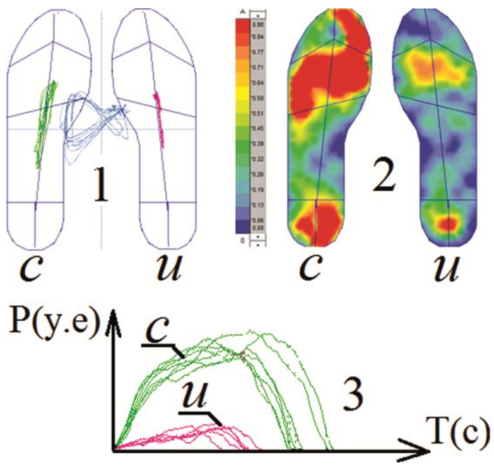

Fig. 5 Results of the examination with the "DiSled-M-Scan" complex of the patient with a femoral prosthesis: 1 – balance pedogram in the foot contour; 2 – baroplantogram; 3 – cyclodynamogram of the step; c is a preserved foot; and *u* – artificial foot

DISCUSSION

The results of the study showed that patients on a tibial prosthesis and prosthesis for a higher level of amputation experience a contralateral limb overload which indirect signs are the corresponding changes in the following biomechanical parameters: dx_{cpc_s} – frontal CPC shift in the support contour of the feet in static position; dx_{cpc_w} – frontal displacement of the center of the CPC migration trajectory in the foot contour during walking; K_{T_w} – bilateral asymmetry of the foot support duration when walking; K_{P_w} – bilateral asymmetry of the maximum total pressure on the foot per step; K_{A_w} – bilateral asymmetry of the conditional work per step; K_{W_w} – bilateral asymmetry of the conditional roll-over power during walking. Significant differences in these parameters were observed for each of the groups of patients that differed in the level of amputation and, consequently, in the type of prosthetic appliance in comparison with the control group.

The most sensitive biomechanical parameters with indirect signs of compensatory overload of the preserved limb were the bilateral asymmetry of the duration of foot support when walking (K_{T_w}) and, especially, the asymmetry of the conditional work per step (K_{A_w}). These variables revealed significant differences of each group of patients on the prosthesis not only when compared to the control group but also in between, with the exception of a pair of groups 3 (femur prosthesis) and 4 (prosthesis for an excessively short stump of the thigh, after hip disarticulation and AIA). The differences between these groups were not significant.

For the pair of group3" (prosthesis after amputation at the femur level) and 4 (prosthesis for an excessively short thigh stump, after hip disarticulation or AIA), no significant differences in biomechanical indices of compensatory overload of the preserved limb were revealed, despite their differences in terms of the level of amputation and the possibility of using the hip function on the affected side. Such an unexpected result can be explained by the fact that a more pronounced decrease in the static-dynamic function in patients in group 4 (compared with group 3) was assisted with an additional support - walking sticks and crutches by walking and reducing the speed of movements, and thus of the magnitude of strain loads on the lower limbs. Consequently, in patients with a femur prosthesis, who use the hip functions of the truncated limb, the risk of overloading the preserved limb is as high as well as in patients which have to replace the hip function with to the hinged hip prosthesis part due to the high level of amputation TBS.

CONCLUSIONS

Analysis of the interaction of the foot support functions made it possible to reliably confirm the significant compensatory overload of the preserved limb in patients on the prosthesis after unilateral amputation of the limb at the level of the tibia and higher.

The most sensitive biomechanical index of such an overload is the conditional work of the roll-over (the integral of the function of change in the total pressure over the time during the rolling) which is significantly higher for a preserved limb than for the prosthetic one and depends on the degree of disturbance of the static-dynamic function of the prosthetic limb as well as on the compensation for these disorders using the means of additional support (crutches, canes, etc.).

After unilateral amputation of the lower limb, continuity in the work of the prosthetist and the orthopedist is necessary for the timely orthopedic support of the patient in order to reduce the risk of overloading on the preserved limb, pathological changes in its joints and foot deformity.

The results of this preliminary study show that it should be continued and involve a bigger sample for deepening the knowledge about the overload mechanisms in the preserved limb in patients on prostheses and search for options of its compensation.

REFERENCES

1. Struyf P.A.. Van Heugten C.M.. Hitters M.W.. Smeets R.J. The prevalence of osteoarthritis of the intact hip and knee among traumatic leg amputees. *Arch. Phys. Med. Rehabil*.. 2009. vol. 90. no. 3. pp. 440-446. DOI: 10.1016/j.apmr.2008.08.220.
2. Silverman A.K.. Neptune R.R. Three-dimensional knee joint contact forces during walking in unilateral transtibial amputees. *J. Biomech*.. 2014. vol. 47. no. 11. pp. 2556-2562. DOI: 10.1016/j.jbiomech.2014.06.006.
3. Chang Y.H.. Bae T.S.. Kim S.K.. Mun M.S.. Lee W.-H. Intact hip and knee joint moment in coronal plane with unilateral transfemoral amputee. *International Journal of Precision Engineering and Manufacturing*. 2011. vol. 12. no. 1. pp. 129-134.
4. Bobrov D.S.. Sliniakov L.Iu.. Rigin N.V. Peregruzochnaia metatarzalgiia: patogenez. biomekhanika i khirurgicheskoe lechenie (analiticheskii obzor literatury) [Overload metatarsalgia: pathogenesis. biomechanics and surgical treatment (Analytical review of the literature)]. *Vestnik Rossiiskoi Akademii Meditsinskikh Nauk*. 2017. vol. 72. no. 1. pp. 53-58. (In Russ.)
5. Galstian G.R.. Strakhova G.Iu. Sovremennye tekhnologii razgruzki nizhnei konechnosti v kompleksnom lechenii neiropaticheskoi formy sindroma diabeticheskoi stopy [Current technologies of the lower limb unloading in complex treatment of the diabetic foot neuropathic syndrome]. *Endokrinnaia Khirurgiia*. 2007. no. 1(1). pp. 29-32. (In Russ.)
6. Larin A.S.. Taran E.V.. Iuzvenko T.Iu.. Giriavenko E.Ia.. A.I. Gavretskii Patogenez pressornykh iazv u bol'nykh sakharnym diabetom i vozmozhnosti ikh profilaktiki [Pathogenesis of pressure ulcers in patients with diabetes mellitus and their prevention scopes]. *Klinichna Endokrinologiia ta Endokrinna Khirurgiia*. 2012. no. 1 (38). pp. 58-67. (In Russ.)
7. Smirnova L.M. Osobennosti ortopedicheskogo obespecheniia vkladnymi obuvnymi prisposobleniiami patsientov posle amputatsii nizhnei konechnosti [Special features of orthopedic support by inset footwear appliances for patients after lower limb amputation]. *Vestnik Gil'dii Protezistov-ortopedov*. 1999. no. 1. pp. 35. (In Russ.)
8. Smirnova L.M. Programmno-apparatnyi kompleks dlia otsenki anatomo-funktsional'nykh narushenii i effektivnosti ortezirovaniia pri patologii stopy [Software-hardware complex to evaluate the anatomic and functional disorders and the effectiveness of orthosing for foot pathology]. *Meditsinskaia Tekhnika*. 2009. no. 6. pp. 22-26. (In Russ.)
9. Grzhibovskii A.M. Analiz trekh i bolee nezavisimykh grupp kolichestvennykh dannykh [Analysis of three and more independent groups of quantitative data]. *Ekologiia Cheloveka*. 2008. no. 3. pp. 50-58. (In Russ.)
10. Dolganov D.V.. Dolganova T.I.. Sazonova N.V.. Shchurov V.A. Nekotorye kolichestvennye pokazateli biomekhanicheskikh parametrov pokhodki u zdorovykh obsleduemykh [Some quantitative values of gait biochemical parameters in normal subjects under examination]. *Vestnik Novykh Meditsinskikh Tekhnologii*. 2008. vol. 15. no. 3. pp. 123. (In Russ.)

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