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# Disturbance of the stato-dynamic function in patients with foot amputation defects and their compensation by prosthetic orthopedic products

**A.A. Trofimov[1], L.M. Smirnova[1,2], I.V. Shvedovchenko[1], O.E. Gaevskaya[1]**

[1]Federal Scientific Center of Rehabilitation of the Disabled named after G.A. Albrecht, Saint Petersburg, Russian Federation
[2]St. Petersburg State Electrotechnical University LETI, Saint Petersburg, Russian Federation

**Material and methods** The article discusses the features of the changes in the dynamic characteristics of the foot-support interaction in patients with foot amputation defects that reflect the state of their stato-dynamic function and the success of compensating of its disorders with prosthetic orthopedic products. The importance of this issue is due to a large number of patients with this pathology, difficulties in their prosthetic fitting, lack of a unified approach to prosthetic orthopedic support and subsequent evaluation of its quality. **Result** The results of locomotion disorders in patients with a unilateral foot stump and the effect of a prosthetic orthopedic shoe insole were estimated using the method of intra-footwear dynamobaroplantography. **Conclusion** Instrumental biomechanical studies allowed obtaining objective data on local overloads of the foot stump, bilateral asymmetry of load distribution and partial compensation of them with the use of prosthetic orthopedic products.
**Keywords**: foot stump, biomechanics of walking, rehabilitation, prosthetics

## INTRODUCTION

Prosthetic management of patients after amputations within the foot has a great medical and social significance. This issue has not lost its importance to these days due to the fact that injuries take one of the first places among the causes of disability. Moreover, in the total of injuries, foot trauma makes up to 10.6 %, and the percentage of foot truncation at different levels is from 15.3 to 18 % relative to all amputations of the lower extremities. The main causes of amputation and disarticulation within the foot are mechanical trauma (80 %), thermal damage (15 %), and vascular diseases (about 3 %) [1-6].

These patients often develop stump diseases under the impact of static and dynamic loads. According to scientific sources, from 75 to 91 % of patients with foot stumps develop deformities, skin disorders, osteophytes and other diseases of the stump that reduce or completely exclude their ability to weight-bearing, and consequently, make subsequent prosthetic and orthopedic support difficult or impossible [ 7, 8]. However, a significant number of disabled individuals after amputations within the foot are persons of working age. The effectiveness of restorative treatment and prosthetic fitting after amputation of the lower extremities is inextricably linked with the improvement of the methods of objective control, analysis of errors and elimination of identified shortcomings. In this regard, it seems relevant to conduct an objective instrumental biomechanical examination of the status of the static and dynamic function in such patients and to control the results of its recovery after provision prosthetic and orthopedic products (POP) supplied with inserts.

## MATRIAL AND METHODS

Study design: a controlled experimental study of a series of patients with fitted prostheses due to foot stumps. Biomechanical studies were approved by the ethics committee and conducted at the clinic of the "Federal Albrecht Scientific Center for Rehabilitation of the Disabled" of the Ministry of Labor and Social Protection of the Russian Federation. The inclusion criteria were patients with a unilateral foot stump at the proximal and middle truncation levels (long and middle stump) and age from 18 to 70 years. The exclusion criteria were congenital defects such as foot stump, concomitant pathology accompanied by disturbance of the static and dynamic function, stump defects that prevent walking even with POPs (osteophytes, ulcers, etc.), patients who did not have any inserted prosthetic and orthopedic products, or unable to walk independently without any additional support. A total of 20 patients with a unilateral stump of the foot were examined: 11 males and 9 females. The

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average age in the study group was 44 years. All cases were consequences of trauma.

The patients were examined with the software complex "DiSled-M-Scan" [9] before and after prosthetic and orthopedic support. Examinations by the method of intra-footwear dynamobaroplantography enable to reveal both anatomical and functional foot disorders. All patients gave informed written consent to participate in the study.

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

## RESULTS

The anatomical features of the affected foot in the study group were a reduced support area of the foot, rough skin callus, sore spots, rough scars at the end of the stump, areas of hyperkeratosis in places of excessive pressure. Deformations of the middle and hind foot were also observed: equinus or equino-varus deformities.

The biomechanical examination detected characteristic changes in the static and dynamic function in patients with this pathology.

First of all, the expressed local overloads of the foot stump even in a standing posture were revealed, i.e. in the conditions of the greatest possibility of compensating for the reduction of the stump's ability to bear weight by transferring the load to the contralateral limb (**Fig. 1 a**).

In addition, in a standing position, bilateral asymmetry of load distribution in the support contour of the feet was observed in all patients: first, as displacement of the center of pressure (COP) towards the limb contralateral to the stump, and, second, as a diagonal shift of the support to the feet (**Fig. 1**). We regard such changes as an objective confirmation of the expected decrease in supportability of the truncated foot.

To quantify these changes, parameters of bilateral asymmetry of load distribution in the foot contour were calculated, or decentralization of the main load vector in a static position (**Fig. 2**):

– $d_x$ – frontal (medio-lateral) shift (x) of the common center of pressure (CCOP) in the support contour of the feet relative to its medial axis in fractions of the width of the support contour "W" (distance from the extreme lateral points of the mnemonic contour of the left and right foot);

– $d_y$ – sagittal (antero-posterior) shift (y) of the CCOP in the foot support contour relative to its frontal axis in fractions of the length of the reference contour "L" (distance from the line of the extreme frontal points to the line of the extreme posterior points of the mnemonic contours of the feet).

Given the small size of the sample data, their distribution was conventionally considered to be different from the normal, and to determine the differences in the patients without POP and with POP on, the Wilcoxon pair test was used. The results of the analysis showed a significant difference between these groups in the variable dx (the level of statistical significance is 0.028 (Asymp.Sig. (2-tailed)) and not significant in dy (0.457).

The average statistical value of the frontal decentralization dx of the main load vector in the stance (standing) reached 16 % in the group from the width of the reference mnemonic contour of the foot in the section of the beams – the level of the heads of the middle metatarsal bones. The standard deviation was ± 8 %.

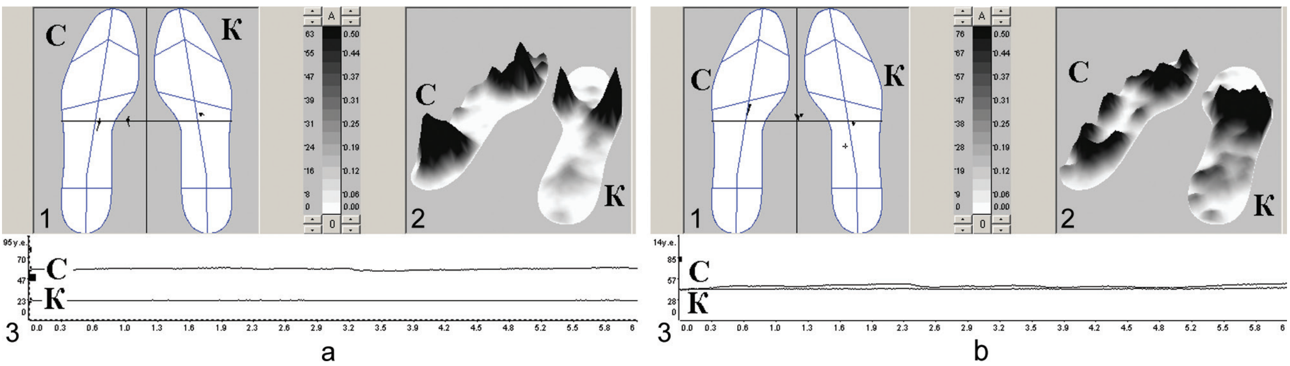


**Fig. 1** Results of examination in patient B. with a foot stump in the static position: a – without POP; b – with POP. Notation: 1 – balanceogram (reflects COP in the support contour of the feet and the common pressure center); 2 – barogram (pressure distribution map) under the feet; 3 – dynamogram (graphs of the total pressure change under the feet along the time axis); C – unaffected foot; K – foot stump

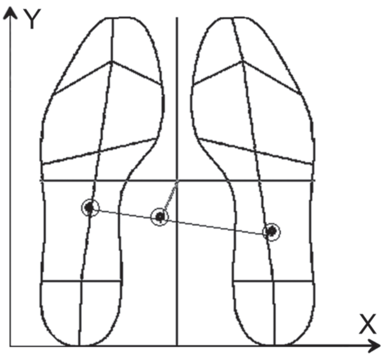


**Fig. 2** Diagram for determining the parameters of bilateral asymmetry of load distribution in the support contour of the feet: X and Y are the frontal and sagittal axes of the support contour. The rest of the notes are in the text

With the use of POP, it was possible to significantly improve the supportability the affected limb, which in statics was manifested by a decrease in the CCOP shift from the medial axis of the support contour and indicated an improvement in the comfort of the support on the stump when using an insert shoe rather than without it (**Fig. 1**). It was confirmed by a decrease in the frontal decentralization of the load dx with the use of POP by almost 3 times: the average statistical value for the group decreased from 16 to 6 % (the standard deviation did not change) (**Fig. 3 a**).

The pathological change in the distribution of load in the anteroposterior direction in patients with the foot stump was less pronounced (**Fig. 3 b**). However, some patients experienced an increase in the amplitude of COP migration under an unaffected foot, which we regard as a consequence of its participation in compensating for the decrease in the stability of the truncated foot.

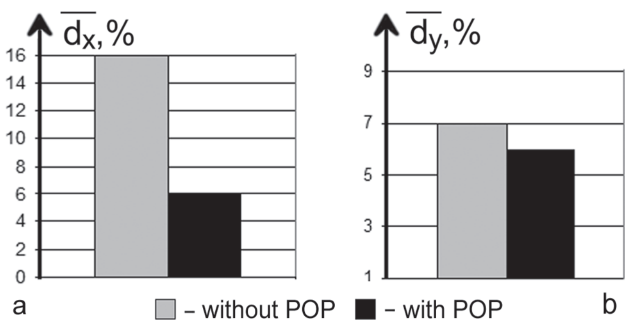


**Fig. 3** Decentralization of the common center of pressure in the foot contour: a – frontal ($d_x$), b – sagittal ($d_y$)

Table 1

Results of changes in the load distribution in the transverse ($d_x$) and longitudinal ($d_y$) directions of the patient's reference mnemonic contour in standing position (T-test is 0.018)

| Conditions | $d_x$ | $d_y$ |
|---|---|---|
| Without POP | (16 ± 8) % | (7 ± 5) % |
| With POP | (6 ± 8) % | (6 ± 2) % |

Since it is not possible to place a measuring insole with pressure sensors between the stump and the input shoe (due to an artificial end), the matrix pressure gauges had to be put under the orthopedic product. This does not reduce the reliability of the estimation of load distribution between the extremities when using this type of POP, but significantly reduces the accuracy of determining local overloads of the plantar surface of the feet. Therefore, we do not have quantitative information on the change in the pressure in the zone of contact between the stump and the POP and, therefore, can only indirectly relate the decrease in the asymmetry of the load distribution between the limbs in the support contour with the decrease in local overloads of the plantar stump surface.

Figure 4 shows an example of the results of disturbances in the interaction of the feet with the support during walking, typical for patients with the foot stump. When walking without POP, the disorder resulted in excluding from the support of the anterior part of the truncated foot, corresponding to its anatomical defect and significant overload of the plantar stump surface. Moreover, more pronounced overloads were observed not in the heel, but in the lateral and distal areas of the stump. This load distribution can be explained by anatomical changes in the stump in patients at long term after amputation, such as equinus and equino-varus deformities of the stump.

As in the static position, we could not assess the effect of the POP on the magnitude of the local hyperpressure on the plantar surface as it was impossible to place the sensor insole between the stump and the insert shoe. At the same time, placing such an insole between the shoe and footwear made it possible to identify the involvement of the forefoot (artificial) portion of the prosthetic limb in the roll, which was confirmed by an increase in the load in the anterior part of this foot and an increase in the length of the pressure center path under this foot due to its anterior part (**Fig. 4 a, b**). The increase in area of the prosthetic foot that perceived loading was 23 % on average ($p < 0.05$).

Since the conditions of the left and the right sensor insoles were different (load is transmitted through the rigid element from the prosthetic limb – insert shoe, i.e. with a large transmission coefficient while from the intact one it was direct through the foot tissues, i.e. with a smaller coefficient), comparing the strength of the front or rear thrust (push) of one foot with respect to the parameters of the other foot would not be correct. In this case, it is more correct to determine bilateral asymmetry of the ratio of the push of one limb to the analogous parameter of the other. Figure 4 shows a decrease in this kind of bilateral asymmetry, achieved mainly by reducing the force of the front push by the heel of the unaffected limb when it enters the support. The probable reason for this is the normalization – reduction – of the speed of load transfer from the prosthetic limb to the unaffected one as a result of the stability increase of support on it at the rear push by engaging the anterior (artificial) foot part into a roll and, accordingly, increase in the stability on the prosthetic limb in the phase of a rear push.

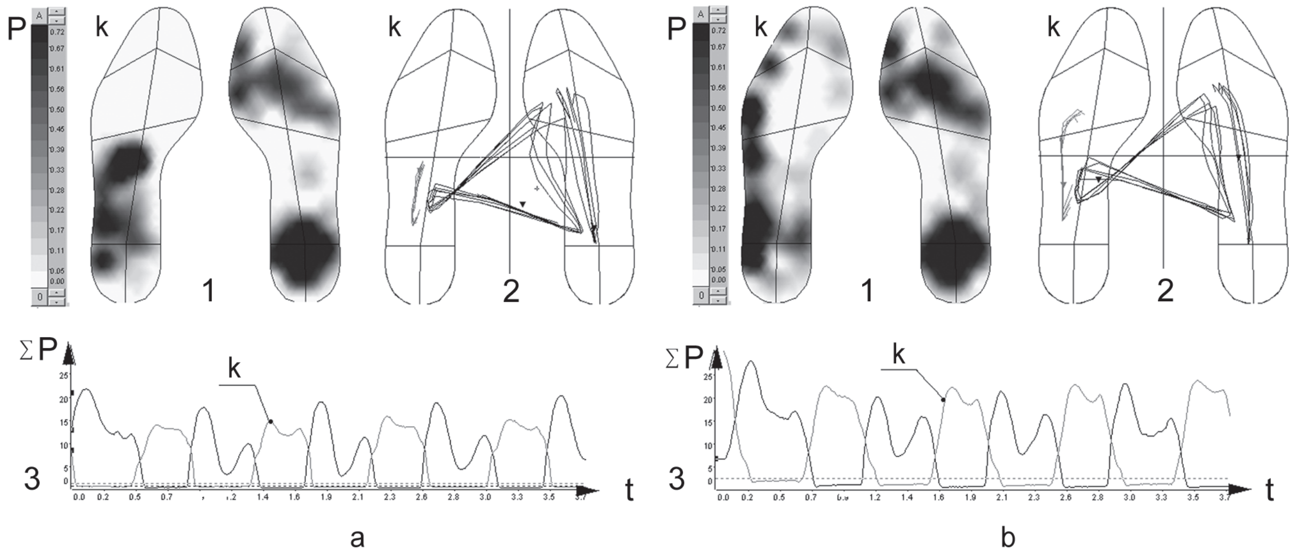


**Fig. 4** Results of examination of patient P. with a foot stump: a – without POP; b – with POP. Notation: 1 – balanceograms (show COP in the support contour of the feet and the CCOP); 2 – barograms (pressure distribution map) under the feet; 3 – dynamograms (graphs of total pressure change under the feet); k – foot stump

As is known, the integral index of increasing the limb's supportability with POP on is an increase in the duration of the support on it [10], especially of the single-support phase of the roll over the foot, in comparison with what was observed without the use of POP. Therefore, the unexpected fact was, at first glance, that when using the POP, despite the instrumentally confirmed increase in the supportability of the affected limb in the static position, the duration of the support on it during walking did not increase, and the bilateral asymmetry of the duration of the roll over the feet practically did not change. We attribute this situation to the fact that, possibly, the involvement of a prosthetic foot in the support of an artificial end, in addition to positive effects (increased stability in the performance of a rearward thrust with this limb and a decrease in the overloads of the plantar stump surface), resulted in a negative effect as well (an increase in the load on the end of the stump, transmitted as the force moment from the artificial forefoot end (**Fig. 5**).

As thin tape sensors to measure the pressure between the artificial insert shoe and the end of the stump were not available, we were forced to rely only on logic of reasoning and on subjective evaluation of the quality of the prosthesis by the patients themselves. Most of them confirmed that, despite the fact that without POP they had great difficulty to move, walking with POP was painful. Many of the patients reported pain at the end of the stump, but others who had neuro-receptor disorders in the lower limb, for example, due to diabetes, could not determine the nature and localization of this pain. Nevertheless, careful interviewing of all patients along with palpation of their feet convinced us that when using the insert shoe the main discomfort during walking was associated with painful sensations in the area of the stump end. In some patients, hyperkeratosis was observed in this area as a sign of excessive long-term pressure.

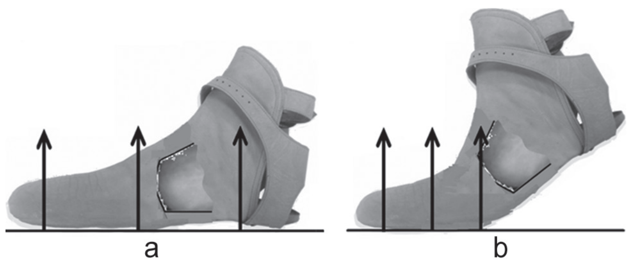


**Fig. 5** Foot stump in the prosthetic and orthopedic product: a – static position; b – in the phase of rolling

DISCUSSION

Thus, the insert shoe increased the supportability of the truncated foot in the static position, as well as stability during the roll over the prosthetic foot during walking, and reduced the overload of the heel area of the preserved foot in the patients examined. At the same time, despite these positive functional properties of the insert shoe, there is a pronounced risk of hyperpressure to the end of the stump when it is used, despite the fact that, in accordance with the requirements for the design of this type of POP, it is manufactured so that provides a guaranteed gap between it and the end of the stump, not allowing their contact. The possible cause of the pressure exerted from the inner surface of the toe end of the embedded shoe on the end of the stump is an uncontrolled "sliding" of the inner shoe forward due to insufficient retention by fastening elements, deformation of the product during its use, and changes in the volume of the stump that affect the quality of shoe fixation. In any case, such a situation requires solution, first, by searching for new technical designs for POP to ensure that the stump is not pressed by the POP and, second, by biomechanical control over the fulfillment of these requirements.

## CONCLUSION

Instrumental examination of the dynamics of pressure distribution under the feet in the static and walking patterns confirmed persistent disorders in the static and dynamic function in patients with foot stumps and enabled to specify them by obtaining quantitative data.

Prosthetic fitting in patients after foot amputation makes it possible to improve weight-bearing of the affected limb in static position and stability when rolling over it while walking.

When walking with an embedded shoe, there is a high risk of hyperpressure on the end face of the stump (not adapted to the perceived load) in the rear push phase due to poor manufacturing, insufficient fixation of the stump in the POP, changes in the volume of the stump or the parameters of the shoe due to its wear. Therefore, these patients need systematic dynamic follow-ups using objective biomechanical methods of examination.

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**Information about the authors:**

1. Andrei A. Trofimov, M.D.,
Federal Albrecht Scientific Center for Rehabilitation of the Disabled, Saint Petersburg, Russian Federation,
Email: Dr.trofimov@bk.ru
2. Ludmila M. Smirnova, Ph.D. of Technical Sciences,
[1] Federal Albrecht Scientific Center for Rehabilitation of the Disabled, Saint Petersburg, Russian Federation,
[2] St. Petersburg State Electrotechnical University LETI, Saint Petersburg, Russian Federation,
Email: info@diaserv.ru
3. Igor' V. Shvedovchenko, M.D., Ph.D., Professor,
Federal Albrecht Scientific Center for Rehabilitation of the Disabled of the RF Ministry of Labor, Saint Petersburg, Russian Federation,
Email: schwed.i@mail.ru
4. Oksana E. Gaevskaya, M.D., Ph.D.,
Federal Albrecht Scientific Center for Rehabilitation of the Disabled, Saint Petersburg, Russian Federation,
Email: gaevskaya-office@mail.ru