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**Original Article**

# Methods of functional training for lower limb amputees

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**Abstract:**
**Annotation.**The purpose of thisStudy is to develop a functional training method for lower limb amputees to assistthem to stand on prostheses and learn to walk.The hypothesis of thisStudy is the idea that integrating methods of functional training (wave gymnastics, hypoxic training and Key method developed by K. Aliyev) into the rehabilitation program on learning to walk with prostheses will have both mental and physical impact on the patients' organisms and provide for successfulmastering of walking. Materials and Methods of thisStudy.ThisStudy involved30-60-year-oldmenafter midthigh amputation who took part in an Orthopedic Center Rehabilitation Program aimed at learning to walkwith prostheses within 20 weeks. The Study Methods consist in studying both Russian and foreign scientificworks regarding the issues raised in thisStudy, goniometry, methods of functional training level assessment, rheovasography, Spielberger and Hanin test, statistical processing of the data under Student's t-criterion. We extended a regular physical training with A.S.Strelnikova breathing exercises, hypoxic training and Khasai Aliyev Key Method of Mental and Physical State Correction. We also adapted the methods of wave gymnastics on the Agashin machine for lower limb amputees to improve general and peripheral hemodynamic values. We developed a functional training method for lower limb amputees to assist them to stand on prostheses and learn to walk, which has a comprehensive mental and physical impact on patients' organisms and provides for successful mastering of walking with prostheses because it includes elements of wave gymnastics, hypoxic training and K. Aliyev Key method alongside with the physical rehabilitation. One of the most significant results of the 20-week functional training is that the participants of the experimental group can walk on a treadmill within 1-3 minutes without losing right biomechanics.
**Keyword. Functional training, physical and mental state, rehabilitation of persons with lower limb amputations, learning to walk with prostheses.**

## Introduction

It is well known that standing on prostheses and learning to walk with them is a very stress-causing factor for lower limb amputees, which may affect values of body homeostasis(Rau, Bonvin, & de Bie, 2007; Evseev et al., 2010, 2016). Specialists note that one of the big problem of prosthetics is that the people with prostheses don't actually use them. The reason is that between three weeks up to twelve monthsare necessary to get fittedwith a prostheses socket. If the patient did not get a comprehensive preparation for prosthetics and following process of mastering a prosthesis, she/he will not use even an expensive one in the everyday life due to considerable pain sensations. Hight level of stress, felt by the people who get their first prostheses is up to 64,5% of all cases(Evseev et al., 2010). After the amputation this results in depression, development and deepening of secondary affections, such as myodystrophy, contractures, muscular skewness and twisted pelvis, deterioration of functionality of cardiovascular and respiratory systems, development of vascular and autonomic dysfunction.

Ülger, Şahan & Çelik (2018) and Munin et al. (2001) in their studies proved that a positive effect on the functional state and gait of patients who have undergone amputations of the lower extremities is provided by the timely use of a prosthesis in physiotherapy rehabilitation.

The methods of assisting in learning to stand and walk with the prostheses is too limited to the very process of standing and walking. But a human life requires much more various movements which means much more time is needed for the adaptation process in reality. Besides, frequent residual limb pain leads to the fact that the patients either try using prostheses as seldom as possible, or try getting used to them at all costs. That is why it is necessary to use both psychological and physical approach, where walking is only a part of a broader functional training.


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The rehabilitation process is restrained by stress, depression and anxiety provoked by the amputation. Any standard rehabilitation method foresees the work of a psychologist on a separate basis. Many patients either ignore or do not trust a psychologist. The method, developed by K. Aliyev has some advantages to that point and is accessible to all. And it has never been used for the rehabilitation of such patients.

Many complications develop also when a person needs to wait too long for the prosthetics operation quota. As a result, when the person becomes the permission for operation and prostheses, (she) he has already some functional disorder, which impedes the process of mastering the prostheses and adapt to it.This vicious circle only worsens the problem of social parasitism. All thoseproblems determined the purpose of our study.

**The purpose of our study** is to develop a method of functional training for lower limbs amputees allowing them to learn to stand and walk with a prostheses.

**The hypothesis** of thisStudy is the idea that integrating methods of functional training (wave gymnastics, hypoxic training and Key method developed by K. Aliyev) into the rehabilitation program on learning to walk with prostheses will have both mental and physical impact on the patients' organisms and provide for successful gain training.

**Materials and Methods of Research.**

ThisStudy involved 30-60-year-old men after midthigh amputation who took part in an Orthopedic center rehabilitation program aimed at learning to walk with prostheses within 20 weeks (the Control Group n=14, the Experimental Group n=16). At the beginning of the experiment the randomly formed groups did not have any significant differences.The Control Group (CG) worked on a standard program. The Experiment Group (EG) worked under the functional training program, we developed. During the training we constantly used variation and combination of different regimes of muscle work, which provide for mutual influence of different muscle groups and improves intermuscular coordination as wellas for their adaptation to the changing life conditions. All the participants to the experiment got acquainted with the World Medical Association Declaration of Helsinki and signed the agreement to take part in the experiment. **Study methods**consist in studying both Russian and foreign scientists'works regarding the issues raised in thisStudy, goniometry, methods of functional training level assessment, rheovasography, Spielberger and Hanin test, statistical processing of the data under Student's t-criterion.

**Results of thisStudy and Discussion.**We have analyzed methodological literature and scientific works of different authors to determine main fields of physical rehabilitation forlower limb amputees and systemize the means of physical training, which may be used to meet those goals. The results of that analysis are shown in Table 1.

Table 1

Means and Methods of Physical Training, Recommended for Rehabilitation of Lower Limb Amputees

| **Preparationformasteringprostheses** | |
|---|---|
| **Goal** | **Means and Methods** |
| to raise muscle tonus of the residual limp | Isometric contractions, reflection and ideomotorexercises, exercises using resistance |
| to get rid of contracture and joint stiffness | Active and passive limb movements |
| to train balance | Exercises using fit ball |
| to strengthen the muscles of the upper body and shoulder gridle | Weights exercises with extra weights and resistant bands |
| to raise functional capacity of cardio-vascular system | Breathing exercises with resistance, full body massage, controlled walking with crutches, sport games on a wheelchair. |
| to prepare the residual limp for the support | Tactile exercises |
| to teach independent life skills | Walking with crunches, moving in a wheelchair, maneuvering a wheelchair |
| to correct psycho-emotional state | Art therapy, psychotherapy, auto-training, competitions and games, intensive weight training, aquatraining |
| **Teaching to stand and walk with prostheses** | |
| to train balance and support | Patients learn to stand distributing weight equally on both limbs, to transfer weight in frontal plane and keep balance. |
| to teach walking | To transfer weight in sagittal plane, to train support and moving phase of a step for both a limb with the prostheses and the sane limb. |
| to teach other moving skills for walking with prostheses | To choose individual rhythm of stepping movements, walking on steep slope, turns, stair climbing, cross-country walking. |

It is possible to underline the following methodical principles:

- spreading load throughout the day;
- varying load training and relaxation;
- adequacy and cycle-based process of physical rehabilitation.

Our method is based on the Theory of Functional Training. The methodology of functional training regards a man as an evolving but still integral biomechanical system, which provides for sustainable, biologically

viable functioning. All parts of the human biological system are interconnected and the muscles "cross and weave in different layers, under different angles, providing for coordinated movement by endless variety of forms of interaction between them"(Parmuzina, Spitsinova, & Parmuzina, 2018).The main difference is that putting into practice those anatomical aspects of a man, this method allows training not only separate muscles, but a great number of muscle groups at the same time, including the coremuscles which allow our body to perform necessary static and dynamic work by keeping the right position of the spine and resisting the gravity forces. Thus, functional training has an adjusted biomechanical impact on the whole body and not a selective impact on its separate parts. Such training results in functional optimum, personalized for everyone.In this regard we used weight training with extension, weight training on balance board, weight training without given vector of movement in several axes(Semenova, 2014; Nenakhov, & Shevtsov, 2016; Semenova, & Reznikov, 2015).

We combined physical training with breathing exercises developed by A.S. Strelnikova, hypoxic training and method of psycho-emotional correction by Khasai Aliyev. We also adapted the methods of wave gymnastics on the Agashin machine for lower limb amputees with a view to improve general and peripheral values of hemodynamics.All the methods listed above provide for a system exposure on the body(Semenova, 2014).

Besides, during the training sessions we constantly used variation und combination of different regimes of muscle work, which allow mutual influence of different muscle groups and improve intermuscular coordination, as well as provide for their adaptation to changing life conditions.The duration of the rehabilitation stages is shown in Table 2.

Table 2.

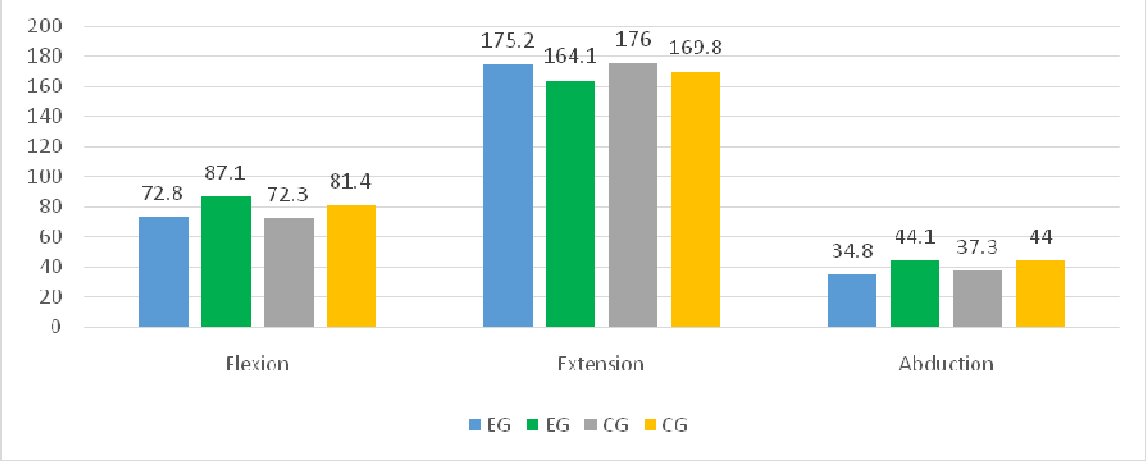
Duration of stages of the main and experimental methods

| stage \ a week | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EG | introductory | + | + | + | + | | | | | | | | | | | | | | | | |
| | preparatory | | | | | + | + | + | + | | | | | | | | | | | | |
| | coaching | | | | | | | | | * | * | * | * | * | * | | | | | | |
| | actively training | | | | | | | | | | | | | | | * | * | * | * | * | * |
| CG | preparatory | + | + | + | + | + | + | + | + | | | | | | | | | | | | |
| | main | | | | | | | | | * | * | * | * | * | * | * | * | | | | |
| | ending | | | | | | | | | | | | | | | | | * | * | * | * |

*+ - 50-60 minutes 3 times a week.* **- 60-90 minutes 3 times a week.*

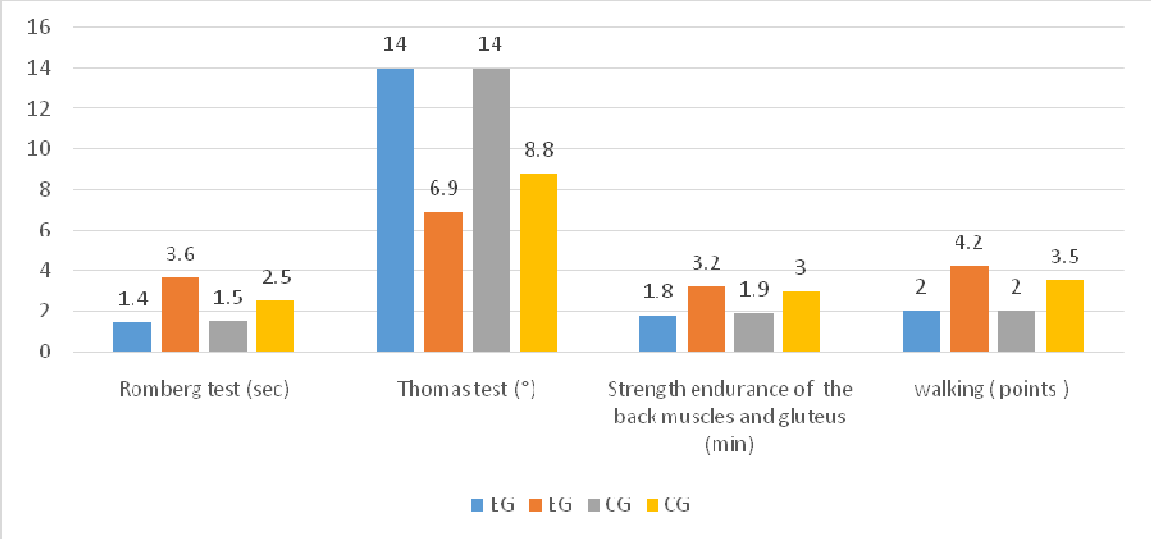
The efficiency of the experimental method of functional training was assessed according to the dynamics of the tested criteria. We divided them into three groups: mobility of the hip joint, functional condition of the locomotor system, rheovasogravy values and anxiety indicator. Each criterion was assessed before and after the program.

Comparative analysis of hip joint goniometry data before and after the experiment showed positive dynamics in the movement range in the hip joint of the amputated limb (Pic. I). The EG Participants showed the best results in the curls of the limb(72,80±5,31°before, against 87,10±4,95°after) and abduction of the limb (34,80±2,38° before, against 44,10±2,43°after). The index grew by 19-26%. However, we did not succeed infully eliminatingmovement restrictions.The minimum result was achieved in the hip extension (72,80±5,31°before,against 87,10±4,95° after). After the end of the experiment, the EG and CG showed relevant difference with regard to hip curls (EG-87,10±4,95°,CG-81,40±5,20°) and hip extension(EG-164,10±2,46° CG-169,80±2,70°) ($p \leq 0,05$).




Pic. I. Indicators of the goniometer and the hip joint (°)

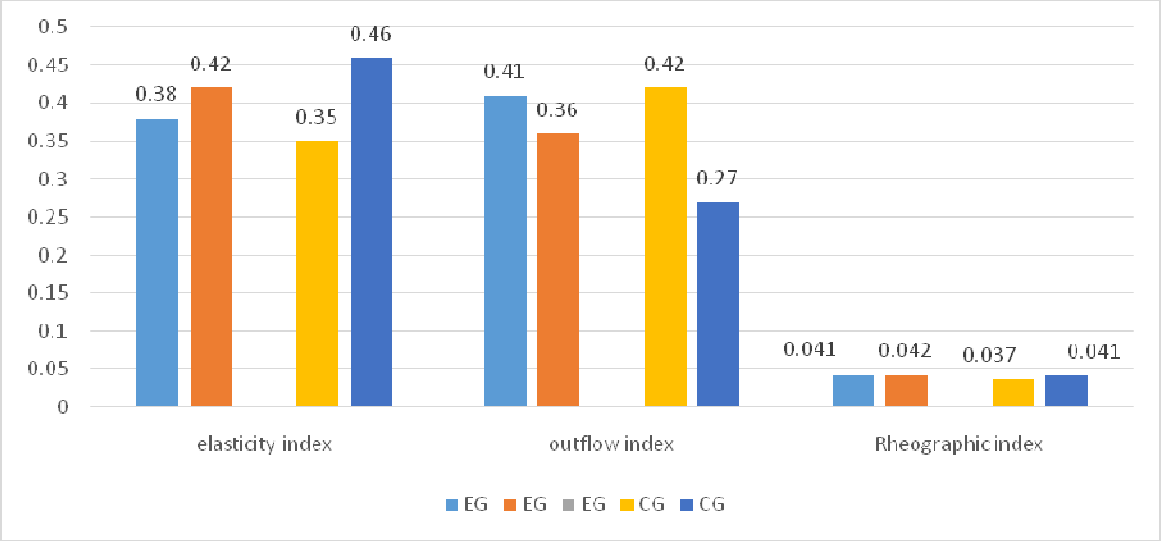
The EG showed maximum growth in the balance values (1,40±0,50 secbefore, against3,60±0,90 sec after) as well as in the strength of the back musclesand gluteus (1,80±0,83 min before, against3,20±1,30 min after), which reflet in general walking skills(2,00±0,50points before,against4,20±0,70points after). If at the beginningof the program 80% of the EG participants experienced difficulties walking on the treadmill with the speed of 2 km per hour, after the end of the program, all the EG participants could walk on the treadmill for 1-3 minutes without losing the given biomechanical characteristics for movement.The EG and CG showed relevant difference with regard to the Romberg test, Thomas test and the walking assessment($p \leq 0,05$)(Pic. II).




Pic. II. Indicatorsfunctional condition of the locomotor system

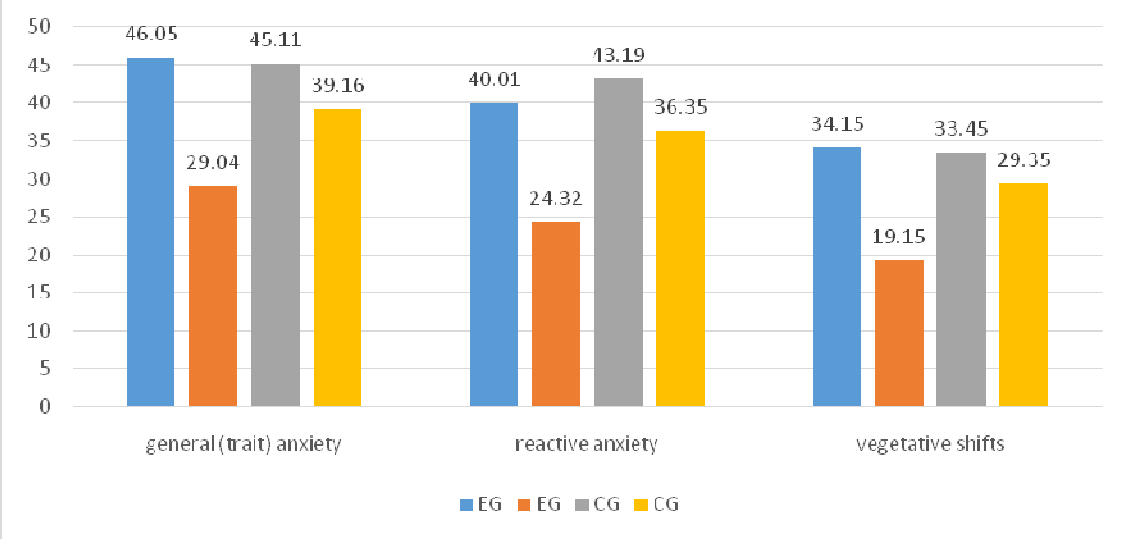
The EG participants witnessed positive dynamics in data on lower limb muscles. Electromyography (EMG) showed the increase of the amplitude of the maximum muscular contraction by 68 - 116%.

When analyzing rheovasography data, obtained before the experiment, we found a considerable decrease of all main values, which witnessed a low level of adaptation capabilities and weak collateral perfusion.After the experiment the EG participants showed relevant changes in the value of vessel wall elasticity (0,35±0,02before, against0,46±0,02after) and outflow (0,42±0,001 – before, against 0,27±0,003 after). Rheographic index also witnessed positive dynamics, but the data is not relevant and amounts to 8-15% (Pic. III).The EG and CG showed relevant difference with regard to the values of elasticity index and outflow index($p \leq 0,05$).




Pic. III. Rheovasogravy values (units)

Complex use of hypoxic training and K. Aliyev method lead to a relevant decrease of general (trait) anxiety (46,05±6,15 points before against 29,04±3,11 points after) as well as of state (reactive) anxiety (40,01±7,12 points before against 24,32±4,02 points after) and increase of adaptation capabilities in general among the EG participants (vegetative shifts 34,15±4,99 points before against 19,15±3,18 points after). The EG and CG showed relevant difference with regard to all values studied (Pic. IV) ($p \leq 0,05$).




Pic. IV. Anxiety indicator according to Spielberg-Khanin (points)

**Discussion**

We analyzed scientific publications and did not find any Russian standard method for lower limbs amputees allowing them to learn to stand and walk with prostheses. There exist methods of rehabilitation of such patients, found in the manuals on exercise therapy published in the 1960s. Nowadays each center of physical rehabilitation mainly uses its own set of methods and works according to general methods offered by Kaptelin (1999), Shapkova (2007), Popov, Epifanova,& Mukhin (2004), Evseevet al., (2010), using only some fragments of methods and means.

White, et al. (1997) studied clinical and operational risk factors, which influence upon the speed of aidless mobility after the amputation of a lower limb.

Sinha, Wim, Heuvel & Arokiasamy (2014) in their study determined that the most important factors contributing to the placement of prostheses and walking training of persons with lower limb amputations are the daily use of prostheses, age, and the use of assistive devices.

The impact of lower limb amputations on aesthetic self-perception and quality of life was studied by Holzer et al. (2014). Dajpratham, Tantiniramai, Lukkapichonchut & Kaewnaree (2008) identified factors associated with the professional reintegration of lower-limb amputees. They found that the rehabilitation process should take into account the level of education, the etiology of amputation and the age of people with amputated lower limbs, which ultimately will help these people to become full and successful members of society.

Shin et al. (2018) concluded in their studies that the use of lower back strengthening exercises in amputee patients with chronic lower back pain resulted in reduced pain, increased strength of the abdominal muscles, back extensors, and a significant increase in flexion and extension of the lumbar spine.

We also believe that our exercise program will help prevent secondary disability due to lower back pain in people with amputated lower limbs and restore their ability to return to society. It will also help expand the treatment options for new amputee patients in the future.

At the same time, Seymour (2002) and Gailey et al. (2020) developed and presented a rehabilitation program allowing to increase functional mobility of lower limb amputees after a physiotherapy programand to learn them to walk with prostheses. This program is based on individual sets of training therapy.

The studies of Kunisada, et al. (2019) и Kaufman, Wyatt, Sessoms, & Grabiner (2014)focus on the program of walking on a non-stable support in a virtual environment when teachinglower limb amputees. This proved its efficiency when solving problems of the fear of falling, stress condition, depression, anxiety felt by lower limb amputees. Those programs provided for the improvement of walking function and mediolateral stability of the patient.

Camacho-Cardenosa et al. (2019)presented the assessment of the impact of the full body vibrational training on the lower limb muscle strength in the conditions of normobaric cycle hypoxia for aged people. They concluded that combining vibrational training with normobaric cycle hypoxia does not influence upon the strengthelements among healthy aged people.

In summary, we should note, that currently there exist neither comprehensive program nor method including not only physical rehabilitation but also mental and physical impact on a patient, despite all the attempts of many scientists to introduce different programs and methods of rehabilitation forlower limb amputees. The specialists also do not take into consideration the method, offered by K. Aliyev, although it was tested in the hardest stress situations after terrorist attacks and is available for use and does not take much time(Bridko et al., 2012). We did not also find any information on the use of the Agashin machine and vibration platform. Hypoxic training as a powerful activator of adaptation resources was not mentioned in any of the studied sources.

Chin et al., (1997, 2002), Van Velzen et al. (2006), Barthuly, Bohannon & Gorack (2012) believe that orthopedic walking should be supplemented with endurance training in order to improve the physical fitness of amputees.

The lack of randomized control studies highlights the need for additional and better studies of the clinical benefits of specific exercise programs in rehabilitation after lower limb amputation.

**Conclusion**

Until now, the scientific community has not formed a consensus on the methods and methods of rehabilitation of persons with amputations of the lower extremities for placing on prostheses and learning to walk.

We developed the method of functional training for lower limb amputeesto assist them to stand and learn to walk with prostheses. This method has an integral impact on the patient's body as well as provides for successful mastering of walking with prostheses, because it uses wave gymnastics, hypoxic training and K. Aliyev method alongside with the regular means of physical rehabilitation.

The research results in the development of an efficient methodology of functional training for lower limb amputees to assist them to stand on protheses and learn to walk. This method:

- has an adjusted biomechanical impact on the body as a whole and not a selective impact on separate parts of the body;
- provides for better goniometric data of the hip joint, increases the movement range in the hip joint of the amputated limb;
-has positive impact on the values of balance, which is reflected in general parameters of walking;
- has positive impact on the values of rheovasography, that improves collateral perfusion;
- allows increasing the maximum muscle contraction range;
- decreasesgenerally state and trait anxiety and increases adaptation skills of the body as a whole.

One of the important results of this 20-week program of functional training was the possibility of the EG participants to walk on a treadmill within 1-3 minutes without losing the right biomechanics.

This method of functional training for lower limb amputees to assist them to stand on protheses and learn to walk may be individually adapted for every age and health condition.

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**Competing Interests** The authors declare there are no competing interests.

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