

ASSESSMENT OF FUNCTIONAL MUSCLE STRENGTH PARAMETERS IN WOUNDED MILITARY PERSONNEL WITH SARCOPENIA AND SEQUELAE OF TRANSTIBIAL AMPUTATION FOLLOWING PHYSICAL THERAPY

ДОСЛІДЖЕННЯ ФУНКЦІОНАЛЬНИХ СИЛОВИХ ПАРАМЕТРІВ У ПОРАНЕНИХ ВІЙСЬКОВОСЛУЖБОВЦІВ З САРКОПЕНІЄЮ ТА НАСЛІДКАМИ ТРАНСТИБІАЛЬНОЇ АМПУТАЦІЇ ПІД ВПЛИВОМ ФІЗИЧНОЇ ТЕРАПІЇ

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Abstracts

Purpose. To determine the effectiveness of the developed comprehensive physical therapy program based on functional strength parameters in wounded servicemen with sarcopenia and consequences of transtibial amputation of the lower limb.

Material and methods. The study involved 95 male servicemen. The control group included 36 apparently healthy men aged 28.4 ± 2.7 years. The study group consisted of 59 wounded servicemen aged 30.5 ± 3.0 years with transtibial amputation and sarcopenia who were randomly divided into two subgroups. Study group 1 (SG1, $n=30$) underwent a standard 12-week physical therapy program aimed at stump preparation for prosthetic fitting and training in the use of a temporary prosthesis. Study group 2 (SG2, $n=29$) followed a developed comprehensive 12-week physical therapy program that additionally included interventions targeting sarcopenia. Patient status was assessed at baseline, after 4 weeks, and after 12 weeks. Handgrip strength, deadlift strength, and isometric strength of major muscle groups of the upper and lower limbs were evaluated.

Results. At baseline, wounded servicemen with transtibial amputation and sarcopenia demonstrated a pronounced reduction in strength parameters compared with the control group. The strength deficit had a generalized pattern and involved both upper and lower limbs, although it was most pronounced in the muscles of the injured lower limb (during movements in the hip and knee). During physical therapy, both study groups demonstrated positive dynamics in most strength indicators, reflecting improvement in the functional state of the muscular system. However, in the group that followed the comprehensive physical therapy program, improvements occurred earlier and were more pronounced. Already at the intermediate stage, this group more frequently demonstrated statistically significant increases in the strength of individual muscle groups, particularly in the injured lower limb. After completion of the 12-week intervention, both groups showed significant improvement in most strength parameters compared with baseline values. Nevertheless, the increase was greater in SG2 for both local muscle strength indicators of the upper and lower limbs and integral strength parameters. The most notable intergroup advantages of the comprehensive program were observed in the strength of muscles of the injured lower limb, as well as in certain indicators of handgrip and deadlift strength. These findings indicate that the inclusion of sarcopenia-targeted interventions enhances the effectiveness of physical therapy and promotes better recovery of muscle strength.

Conclusions. Wounded servicemen with sarcopenia and transtibial amputation demonstrate a systemic deficit in muscle strength of both the upper and lower limbs. The developed comprehensive physical therapy program proved to be more effective than the standard rehabilitation approach, providing faster and more pronounced recovery of both local and integral strength parameters. These findings support the inclusion of sarcopenia-targeted interventions in rehabilitation programs for this category of patients.

Keywords: physical therapy, rehabilitation, amputation, sarcopenia, gait disorders, lower limb injury, combat-related trauma, wounded servicemen.

Мета. Визначити ефективність розробленої комплексної програми фізичної терапії за функціональними силовими показниками у поранених військовослужбовців із саркопенією та наслідками транстибіальної ампутації нижньої кінцівки.

Матеріал. У дослідженні взяли участь 95 чоловіків-військовослужбовців. Контрольну групу становили 36 умовно здорових чоловіків віком $28,4 \pm 2,7$ року. До досліджуваної групи увійшли 59 поранених військовослужбовців віком $30,5 \pm 3,0$ року з транстибіальною ампутацією та саркопенією, яких рандомізовано розподілили на дві підгрупи. ДГ1 ($n=30$) проходила стандартну 12-тижневу програму фізичної терапії, спрямовану на підготовку кукуси до протезування

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та навчання користуванню тимчасовим протезом. ДГ2 (n=29) виконувала розроблену комплексну 12-тижневу програму, що додатково включала втручання для подолання саркопенії. Стан пацієнтів оцінювали первинно, через 4 та 12 тижнів. Досліджували силу кисті, станову силу та ізометричну силу основних м'язових груп верхніх і нижніх кінцівок.

Результати. На початковому етапі у поранених військовослужбовців із транстибіальною ампутацією та саркопенією виявлено виражене зниження силових показників порівняно з контрольною групою. Дефіцит сили мав генералізований характер і охоплював як верхні, так і нижні кінцівки, однак найбільш вираженим був у м'язах травмованої нижньої кінцівки (при виконанні рухів у кульшовому та колінному суглобах). У процесі фізичної терапії в обох досліджуваних групах спостерігалася позитивна динаміка більшості показників, що свідчило про покращення функціонального стану м'язової системи. Водночас у групі, яка проходила комплексну програму фізичної терапії, позитивні зміни розвивалися швидше та були більш вираженими. Уже на проміжному етапі в цій групі частіше реєстрували статистично значуще покращення сили окремих м'язових груп, насамперед травмованої нижньої кінцівки. Після завершення 12-тижневого курсу в обох групах відзначали достовірне покращення більшості силових характеристик порівняно з вихідним рівнем, однак у ДГ2 приріст був більш вираженим як за локальними показниками сили м'язів верхніх і нижніх кінцівок, так і за інтегральними силовими показниками. Найбільш помітні міжгрупові переваги комплексної програми виявлялися щодо сили м'язів травмованої нижньої кінцівки, а також за окремими показниками сили кисті та станової сили. Отримані дані свідчили, що включення втручань, спрямованих на подолання саркопенії, підвищувало ефективність фізичної терапії та сприяло кращому відновленню м'язової сили.

Висновки. У поранених військовослужбовців із саркопенією та наслідками транстибіальної ампутації виявлено системний дефіцит м'язової сили верхніх і нижніх кінцівок. Розроблена комплексна програма фізичної терапії виявилася ефективнішою за стандартну, забезпечивши більш швидке та виражене відновлення локальних і інтегральних силових показників, що підтвердило доцільність включення компонентів корекції саркопенії до реабілітаційних програм цієї категорії пацієнтів.

Ключові слова: фізична терапія, реабілітація, ампутація, саркопенія, порушення ходи, травма нижніх кінцівок, бойова травма, поранені військовослужбовці.

Introduction. In the context of ongoing intensive military operations, lower limb amputations among military personnel represent a critically important medical and rehabilitation challenge. According to recent scientific publications, comprehensive physical rehabilitation following lower limb amputation is a key factor in restoring function, mobility, and quality of life in patients. However, further improvement and evaluation of the effectiveness of different physical therapy approaches are required for various categories of injured individuals, including military patients of different ages and physiological conditions [13].

In recent years, particular attention has been paid to the syndrome of sarcopenia – a progressive loss of muscle mass and strength associated with multiple negative consequences for patients' functional capacity. Sarcopenia is defined as a complex pathological condition characterized by a reduction in skeletal muscle mass and muscle strength, which is associated with decreased ability to perform daily activities and poorer rehabilitation outcomes [5, 11]. In wounded servicemen experiencing critical conditions, the mechanisms of sarcopenia may be aggravated not only by tissue loss resulting from trauma but also by prolonged immobilization, metabolic disturbances, and systemic intoxication caused by combat-related injuries. In addition, admission to intensive care units in wounded servicemen with polytrauma may be associated with several concurrent mechanisms contributing to the development of secondary sarcopenia, including traumatic, nutritional, and septic factors [1].

Changes in muscle mass over time may play a significant role in identifying patients at increased risk of adverse clinical outcomes. Evidence from previous studies indicates that loss of skeletal muscle in critically ill patients is associated with prolonged mechanical ventilation, longer hospital stays, and increased mortality [15]. In this context, assessment of muscle mass and its structural characteristics

is of considerable importance, as it may help identify patients with a more favorable rehabilitation prognosis and allow clinicians to better tailor therapeutic interventions.

Sarcopenia is not only a pathological phenomenon associated with aging but is also linked to significantly worse clinical outcomes in patients with amputations. Studies have shown that the presence of sarcopenia in patients who have undergone lower limb amputation is associated with an increased risk of mortality, reduced likelihood of full functional recovery, and a higher incidence of complications in the medium- and long-term periods [7, 16]. These findings emphasize the need for a deeper understanding not only of the mechanisms underlying sarcopenia but also of its impact on muscle tissue parameters in patients following severe trauma and amputation.

Physical therapy, as a component of rehabilitation, aims to restore physical function, improve muscle strength, enhance movement coordination, and increase the ability to perform independent motor activities [6, 9]. It represents a central element of rehabilitation programs after lower limb amputation, contributing to improved muscular endurance, coordination, and balance, and providing the basis for patients' reintegration into social life [12]. At the same time, there is a limited number of studies specifically analyzing muscle strength parameters in military patients with sarcopenia following transtibial amputation within the context of different physical therapy programs. This highlights the scientific and practical relevance of systematically investigating and quantitatively assessing changes in these parameters depending on the intensity and type of therapeutic intervention.

Existing studies indicate that strength deficits in lower limb prosthesis users can significantly affect balance, mobility, and walking performance [3]. For military personnel, who often face high physical demands in order to

return to active life or military service, identifying optimal methods for assessing and correcting such deficits is critically important. Accordingly, physical therapy programs should consider not only the general principles of rehabilitation after amputation [3, 8], but also the specific needs of individuals with sarcopenia [2, 10], which may improve prognosis, quality of life, and functional capacity in this patient population.

Therefore, conducting a study that analyzes the functional strength parameters of muscle tissue in wounded servicemen with sarcopenia following transtibial amputation and evaluates their changes under the influence of a physical therapy program is highly relevant. Such research may provide important insights into the prerequisites for full restoration of patients' social, professional, and daily functioning.

Purpose. To determine the effectiveness of a developed comprehensive physical therapy program based on functional strength indicators in wounded servicemen with sarcopenia and consequences of transtibial lower limb amputation.

Materials and Methods. The study involved 95 male servicemen. The control group (CG) consisted of 36 men aged 28.4±2.7 years (22-42 years) without significant musculoskeletal disorders (apparently healthy individuals). The study group (SG) included 59 men aged 30.5±3.0 years (24-46 years) who were wounded servicemen with transtibial amputation and sarcopenia. Participants were randomly divided into two subgroups.

Study group 1 (SG1) included 30 men who underwent a 12-week rehabilitation program based on standard principles of stump preparation for prosthetic fitting and adaptation to a temporary prosthesis, including gait training with the prosthesis. The program consisted of therapeutic exercises aimed at strengthening the stump muscles, exercises to increase the range of motion in the knee and hip joints, static and dynamic balance training in the standing position, stump preparation for prosthetic fitting, training in safe mobility techniques using crutches, and instruction in prosthesis use.

Study group 2 (SG2) included 29 men who followed a developed comprehensive 12-week physical therapy program which, in addition to the above components, included a set of interventions aimed at overcoming sarcopenia.

Inclusion criteria: History of strict bed rest with limited physical activity for at least 28 days (including treatment in an intensive care unit), associated with polytrauma and considered a risk factor for sarcopenia related to critical illness and hypodynamia;

- Secondary sarcopenia;
- Transtibial amputation at the level of the middle third of the lower leg;
- Preserved cognitive function;
- Residual stump pain not exceeding 5 points;
- Preserved upper limb function (ability to bear axial load, grasp, and hold objects);
- Ability to ambulate independently with the use of two crutches;
- Subacute rehabilitation period: preparation for primary prosthetic fitting and adaptation to a temporary prosthesis;
- Informed consent to participate in the study.

Exclusion criteria:

- Moderate or severe traumatic brain injury;
- Moderate or severe cognitive impairment;
- Burn injury of grade II-IV;
- Spinal cord injury;
- Uncorrected injury of the intact lower limb at the time of examination that affected the possibility of verticalization and independent ambulation;
- Presence of a gastrostomy or colostomy at baseline examination;
- Age over 60 years (primary sarcopenia);
- Refusal to participate in the study.
- The developed 12-week physical therapy program was structured as presented in Table 1.

Table 1

Structure of the developed physical therapy program for wounded servicemen with sarcopenia and transtibial amputation

Component / intervention period	Weeks 1-4 (pre-prosthetic preparation)	Weeks 5-8 (adaptation period)	Weeks 9-12
Intervention format	Inpatient	Outpatient, independent exercise sessions	Independent exercise sessions according to the prescribed program, with supervision via video communication
Intervention frequency	Daily	Daily	At least three times per week
Session duration	90 min	60-90 min	60 min
Rehabilitation goals	Preparation of the stump for prosthetic fitting Training in prosthesis use Reduction of sarcopenia manifestations Improvement of balance Increase in muscle strength of the upper and lower limbs and trunk Improvement of joint range of motion Increase in physical endurance Improvement of psycho-emotional status	Stump adaptation to the prosthesis Gait training with the prosthesis using assistive mobility devices Increase in muscle strength of the upper and lower limbs and trunk Improvement of joint range of motion Increase in physical endurance Improvement of psycho-emotional status	Gait training with the prosthesis with limited use of assistive mobility devices Increase in muscle strength of the upper and lower limbs and trunk Improvement of physical endurance and work capacity

1. Therapeutic exercise program			
Mandatory component (correction of changes associated with sarcopenia and amputation) – circuit training	Strength exercises for the upper and lower limbs (25-30% of the session time) Exercises to improve the range of motion of the amputated limb (10-15%) Balance and gait training (15-20% of the session time) Exercises to improve movement coordination	Strength exercises (30-40% of the session time) Exercises to improve the range of motion of the amputated limb (10-15%) Balance and gait training (25-30% of the session time)	Strength exercises (40-50% of the session time) Exercises to improve the range of motion of the amputated limb (5-10%) Balance and gait training (10-15% of the session time)
Variable component (individualized rehabilitation addressing manifestations of polytrauma) – individualized programs	Breathing exercises (to address respiratory dysfunction following a critical illness state) Strength exercises for the trunk Exercises to improve range of motion in the spinal and limb joints Exercises to improve movement coordination	Strength exercises for the trunk Exercises to improve range of motion in the spinal and limb joints Exercises to improve movement coordination	Strength exercises for the trunk Exercises to improve the range of motion in the spinal and limb joints Exercises to improve movement coordination
2. Interventions in the stump area	Anti-edema measures (compression bandaging) Scar mobilization Instrument-assisted soft tissue mobilization of the stump Stump conditioning using progressive weight-bearing and texture stimulation Electrical muscle stimulation Stump self-management (self-conditioning of the stump and self-monitoring of stump condition)	Stump self-management	Stump self-management
3. Educational component	Expansion of daily physical activity (walking, stair climbing, etc.) and activities of daily living aimed at reducing dependence on other individuals.		
	Nutritional recommendations, including increased protein intake (1.2-2 g/kg/day) and ensuring adequate caloric intake and balanced nutritional composition.		

The exercises used in the program were aimed at improving endurance and gait speed (with gradual increases in walking distance and the ability to ascend higher floors), flexibility (dynamic and static stretching of the major muscle groups), and muscle strength (concentric and eccentric dynamic exercises targeting key muscle groups, including plantar flexors, knee extensors, hip extensors, flexors, abductors and adductors, as well as abdominal muscles). Strength training included dumbbell lifting, heel raises, hip abduction exercises, and additional resistance using elastic bands and medicine balls on a therapeutic rebounder.

Exercises for dynamic balance included picking up objects from the floor, balancing on unstable surfaces, and training on the «MFT Challenge Disc balance platform» (MFT Bodyteamwork GmbH, Austria), as well as gait training under various conditions. The training sessions were individualized according to the level of resistance, body position (e.g., movements assisted by gravity or performed against gravity, in sitting or standing positions), and the patient's functional progress.

The condition of participants in the study groups was assessed dynamically at three time points: baseline assessment (prior to the implementation of the developed

physical therapy program), intermediate assessment after 4 weeks of intervention (during the stage of initial prosthetic fitting), and final assessment after 12 weeks of intervention. These evaluations were based on indicators characterizing the structural and functional state of the muscular system. During the implementation of the program, continuous monitoring of patients' condition and achievement of individual rehabilitation goals was also carried out.

Functional strength parameters were assessed using the digital dynamometer «ActivForce 2» (Activbody Inc., USA) and its mobile application ActivForce App. Muscle strength during basic upper- and lower-limb movement patterns was measured according to the manufacturer's recommendations [4,14]. During lower-limb strength measurements, the dynamometer was positioned symmetrically below the knee joint.

Grip strength was additionally assessed using a hand dynamometer DRP-120, and deadlift strength was measured using a DS-200 dynamometer. During this test, the physical therapist provided stabilization to ensure the prosthetic limb remained in a secure and stable position.

The study protocol was reviewed and approved by the Bioethics Committee of Vasyly Stefanyk Carpathian National

University. All participants provided written informed consent. The study complied with ethical standards for patient safety and human dignity in accordance with the principles of Good Clinical Practice (GCP), the Council of Europe Convention on Human Rights and Biomedicine (04.04.1977), the Declaration of Helsinki of the World Medical Association on Ethical Principles for Medical Research Involving Human Subjects (1964-2000), and the Order of the Ministry of Health of Ukraine No. 281 (01.11.2000).

Statistical analysis was performed using the Statistica 12 software package. Normality of distribution was assessed using the Shapiro-Wilk test. Data with normal distribution were presented as mean \pm standard deviation, whereas non-normally distributed data were presented as median with 25th and 75th percentiles. Comparisons between two samples with non-normal distribution were performed using the Mann-Whitney test, while comparisons between normally distributed samples were conducted using the Student's t-test.

Results. The analysis of upper limb muscle strength demonstrated that servicemen with transtibial amputation and sarcopenia exhibited a marked reduction in the strength of major upper limb muscle groups at baseline compared with conditionally healthy men, indicating a pronounced muscle strength deficit (table 2). Measurements of isometric force reflected the functional status of the main muscle groups of the shoulder and elbow, which play a crucial role in maintaining postural stability, using assistive mobility devices (crutches, walkers), and performing activities of daily living.

Indicators of isometric muscle strength reflect the ability of muscles to generate maximal static force. Their reduction is considered one of the clinical manifestations of sarcopenia, which is associated with decreased muscle mass and reduced functional capacity of skeletal muscles. Conversely, an increase in these indicators during rehabilitation was interpreted as a positive trend indicating improvement in muscle function, enhancement of strength capacity, and recovery of patients' physical performance.

The initial deficit in the strength of the muscles responsible for shoulder flexion of the dominant arm was 31.5% in SG1 and 28.6% in SG2 compared with the control group; in both groups these differences were statistically significant ($p < 0.05$). After 4 weeks, strength increased by 10.8% in SG1, although the value remained significantly lower than in the control group ($p < 0.05$). In SG2 the improvement reached 14.4%, but no statistically significant change compared with baseline was observed ($p > 0.05$). After 12 weeks, strength increased by 27.3% in SG1 compared with baseline and this improvement was statistically significant ($p < 0.05$), although the difference from the control group persisted. In SG2, the increase reached 28.7% ($p < 0.05$ compared with baseline) while the difference from the control group also remained significant ($p < 0.05$). During follow-up assessments, SG2 values exceeded those of SG1 by 7.4% at 4 weeks and by 5.3% at 12 weeks, although no statistically significant between-group differences were identified ($p > 0.05$).

For the shoulder flexors of the non-dominant arm, the baseline strength deficit relative to the control group was 31.9% in SG1 and 29.3% in SG2 ($p < 0.05$). After 4 weeks,

strength in SG1 increased by 9.7%, which was statistically significant compared with baseline ($p < 0.05$), but the value remained lower than in the control group ($p < 0.05$). In SG2, the increase reached 17.6%, although no statistically significant change relative to baseline was observed ($p > 0.05$). After 12 weeks, improvement amounted to 24.2% in SG1 and 31.1% in SG2; in SG2 the change was statistically significant compared with baseline ($p < 0.05$), while in both groups the values remained lower than those of the control group ($p < 0.05$). The advantage of SG2 over SG1 reached 11.3% after 4 weeks and 9.5% after 12 weeks, without statistically significant between-group differences ($p > 0.05$).

The baseline reduction in the strength of the shoulder abductors of the dominant arm was 26.2% in SG1 and 23.6% in SG2 compared with the control group ($p < 0.05$). After 4 weeks, the increase in strength was 14.7% in SG1 and 8.8% in SG2; however, no statistically significant changes relative to baseline were observed in either group ($p > 0.05$). After 12 weeks, improvement reached 26.4% in SG1 and 24.0% in SG2 ($p < 0.05$ compared with baseline). In SG1, the difference from the control group remained statistically significant, whereas in SG2 it was no longer detected ($p > 0.05$). The advantage of SG2 over SG1 was 4.8% after 4 weeks and 1.6% after 12 weeks, without statistically significant between-group differences ($p > 0.05$).

For the shoulder abductors of the non-dominant arm, the baseline deficit was 26.6% in SG1 and 24.7% in SG2 relative to the control group. After 4 weeks, improvement amounted to 12.1% in SG1 and 9.7% in SG2, although these changes were not statistically significant compared with baseline ($p > 0.05$). After 12 weeks, strength increased by 26.3% in SG1 and 24.1% in SG2, with statistically significant improvement compared with baseline in both groups ($p < 0.05$). During follow-up assessments, SG2 values exceeded those of SG1 by 0.5% after 4 weeks and by 0.8% after 12 weeks, without statistically significant differences between groups ($p > 0.05$).

Analysis of elbow joint muscle strength revealed the greatest baseline deficit in the flexor muscles. For the biceps brachii of the dominant arm, the reduction in strength was 42.9% in SG1 and 41.0% in SG2 compared with the control group ($p < 0.05$). After 4 weeks, improvement was 7.0% in SG1 and 12.0% in SG2, although these changes were not statistically significant ($p > 0.05$). After 12 weeks, the increase reached 38.4% in SG1 and 55.0% in SG2, with statistically significant improvement in SG2 ($p < 0.05$). The advantage of SG2 over SG1 was 8.1% after 4 weeks and 15.6% after 12 weeks, becoming statistically significant at the final assessment ($p < 0.05$).

For the elbow flexors of the non-dominant arm, the baseline deficit was 45.3% in SG1 and 43.0% in SG2 compared with the control group ($p < 0.05$). After 4 weeks, improvement reached 8.9% in SG1 and 12.5% in SG2 (both $p > 0.05$). After 12 weeks, strength increased by 28.9% in SG1 and 54.5% in SG2 ($p < 0.05$), and the value in SG2 was statistically significantly higher than in SG1 ($p < 0.05$). The percentage advantage of SG2 over SG1 was 7.6% after 4 weeks and 24.8% after 12 weeks, becoming statistically significant at the final stage.

Table 2

Dynamics of upper limb muscle strength parameters measured using the dynamometer «ActivForce 2» in servicemen with sarcopenia and transtibial amputation following physical therapy, Me [25; 75]

Isometric muscle strength, kg	CG	SG1			SG2		
		Baseline	4 weeks	12 weeks	Baseline	4 weeks	12 weeks
Shoulder, flexion							
dominant arm	28,3 [25,1; 30,2]	19,4 [18,4; 22,6]*	21,5 [20,1; 24,7]*	24,7 [21,9; 27,0]* _o	20,2 [18,7; 23,8]*	23,1 [21;6; 25,7]*	26,0 [24,5; 27,4]* _o
non-dominant arm	27,3 [26, 1; 29,4]	18,6 [17,3; 22,5]*	20,4 [18,9; 22,7]* _o	23,1 [19,5; 2,0]*	19,3 [17,8; 22,4]*	22,7 [20,9; 24,7]*	25,3 [22,6; 26,2]* _o
Shoulder, abduction							
dominant arm	26,7 [24,1; 27,6]	19,7 [19,6; 22,8]*	22,6 [20,3; 23,5]*	24,9 [22,0; 26,8]* _o	20,4 [18,0; 21,3]*	22,2 [20,3; 23,9]*	25,3 [23,0; 26,8] _o
non-dominant arm	25,9 [23,4;]	19,0 [17,9; 21,0]*	21,3 [19,7; 22,7]*	24,0 [21,6; 25,9]* _o	19,5 [18,0; 21,0]*	21,4 [20,1; 23,2]*	24,2 [22,3; 25,9] _o
Elbow, flexion (biceps brachii muscle)							
dominant arm	32,4 [29,6; 34,0]	18,5 [17,3; 20,2]*	19,8 [18,5; 22,0]*	25,6 [21,4; 27,2]* _o	19,1 [17,8; 20,6]*	21,4 [18,0; 23,4]	29,6 [26,9; 32,6] _o * _‡
non-dominant arm	30,9 [27,9; 32,6]	16,9 [16,0; 18,4]*	18,4 [16,8; 20,5]*	21,8 [19,1; 23,6]* _o	17,6 [16,1; 19,2]	19,8 [17,1; 22,1]*	27,2 [23,2; 29,1]* _o * _‡
Elbow, extension (triceps brachii muscle)							
dominant arm	31,1 [28,3; 34,0]	19,2 [18,0; 21,1]*	22,4 [20,8; 25,2]*	25,2 [22,4; 27,1]* _o	20,3 [18,1; 22,0]*	25,0 [22,6; 27,0]*	29,1 [26,3; 32,0] _o * _‡
non-dominant arm	28,9 [27,3; 30,8]	17,6 [16,5; 19,6]*	20,7 [19,2; 23,7]*	23,7 [20,9; 25,4]* _o	18,7 [16,5; 20,4]*	23,4 [21,0; 25,5]	27,5 [24,7; 30,3] _o * _‡

Notes: * p<0,05 compared with the control group (CG);

o p<0,05 compared with the first (baseline) assessment;

‡ p<0,05 compared with the corresponding value of SG1.

For the elbow extensors (triceps brachii) of the dominant arm, the baseline strength deficit was 38.3% in SG1 and 34.7% in SG2 compared with the control group (p<0.05). After 4 weeks, improvement reached 16.7% in SG1 and 23.2% in SG2, and after 12 weeks it reached 31.3% and 43.3%, respectively (both p<0.05 compared with baseline). The value in SG2 was statistically significantly higher than in SG1 (p<0.05). The advantage of SG2 over SG1 was 11.6% after 4 weeks and 15.0% after 12 weeks (p<0.05 at the final assessment).

A similar pattern was observed for the elbow extensors of the non-dominant arm: the baseline deficit was 39.1% in SG1 and 35.3% in SG2 compared with the control group (p<0.05). After 4 weeks, improvement amounted to 17.6% in SG1 and 25.1% in SG2 without statistically significant changes (p>0.05). After 12 weeks, strength increased by 34.7% in SG1 and 47.1% in SG2 (p<0.05), and the value in SG2 was statistically significantly higher than in SG1 (p<0.05). The between-group difference reached 13.0% after 4 weeks and 15.8% after 12 weeks and was statistically significant at the final assessment (p<0.05).

The analysis of isometric strength parameters of the lower limb muscles, measured using the digital dynamometer «ActivForce 2», demonstrated that servicemen with transtibial amputation and sarcopenia exhibited a pronounced reduction in muscle strength of both the injured and the

preserved limbs compared with conditionally healthy men (table 3).

For the hip flexors of the preserved limb, the baseline strength deficit compared with the control group was 10.9% in SG1 and 9.0% in SG2 (p<0.05). After 4 weeks, the deficit slightly decreased to 9.0% and 6.1%, respectively; however, these changes were not statistically significant compared with baseline (p>0.05). After 12 weeks, strength increased by 6.8% in SG1 and 7.4% in SG2 (p<0.05), and the difference compared with the control group was no longer observed. During follow-up assessments, SG2 values exceeded those of SG1 by 3.2% after 4 weeks and by 2.8% after 12 weeks, without statistically significant between-group differences (p>0.05).

The strength of the hip flexors of the injured limb at baseline was lower than in the control group by 38.5% in SG1 and 35.0% in SG2 (p<0.05); these differences were also significant compared with the preserved limb. After 4 weeks, improvement in SG1 reached 12.2% (p>0.05), whereas in SG2 an increase of 16.9% was statistically significant (p<0.05). After 12 weeks, the increase reached 28.0% in SG1 and 39.6% in SG2 (p<0.05), and the values in SG2 were statistically significantly higher than those in SG1 (p<0.05). The advantage of SG2 over SG1 was 10.1% after 4 weeks and 15.2% after 12 weeks, becoming statistically significant only at the final stage.

Table 3

Dynamics of lower limb muscle strength parameters measured using the digital dynamometer «ActivForce 2» in servicemen with sarcopenia and transtibial amputation under the influence of physical therapy

Isometric muscle strength, kg	CG	SG1		SG2			
		Baseline	4 weeks	Baseline	4 weeks	Baseline	4 weeks
Hip, flexion							
preserved limb (right in CG)	41,3 [38,5; 43,2]	36,8 [34,6; 39,0]*	37,6 [35,1; 40,1]*	39,3 [38,0; 41,5]○	37,6 [35,1; 40,0]*	38,8 [36,5; 41,5]*	40,4 [37,8; 42,9]○
injured limb (left in CG)	40,0 [37,9; 42,5]	24,6 [21,9; 27,3]*∴	27,6 [24,9; 30,1]*∴	31,5 [29,0; 34,6]*○∴	26,0 [22,4; 27,9]*∴	30,4 [27,9; 32,3]*○∴	36,3 [32,5; 39,4]*○∴*
Hip, extension							
preserved limb (right in CG)	38,9 [37,0; 42,1]	32,6 [29,6; 35,0]*	33,9 [30,6; 34,8]*	36,8 [34,1; 39,2]○	30,8 [28,1; 34,1]*	35,7 [31,4; 40,0]*	38,0 [35,4; 42,1]○
injured limb (left in CG)	40,1 [38,2; 44,0]	26,5 [23,1; 29,7]*∴	27,3 [24,9; 30,8]*∴	30,6 [28,4; 32,2]*○∴	27,6 [24,0; 29,9]*∴	30,6 [27,6; 34,0]*∴	35,5 [31,0; 39,2]*○∴*
Hip, abduction							
preserved limb (right in CG)	33,9 [28,8; 37,5]	27,1 [24,8; 30,4]*	28,8 [26,0; 30,7]*	31,8 [27,5; 34,0]○	28,6 [25,1; 31,2]*	31,0 [27,9; 32,1]*	33,0 [29,4; 36,5]○
injured limb (left in CG)	31,5 [27,9; 36,4]	19,8 [17,2; 22,7]*∴	22,9 [19,1; 25,7]*∴	25,4 [21,8; 29,4]*○∴	20,6 [18,1; 23,4]*∴	24,5 [21,7; 28,6]*○∴	29,1 [25,8; 34,7]*○∴*
Hip, adduction							
preserved limb (right in CG)	32,6 [28,9; 36,7]	26,2 [23,8; 30,1]*	27,8 [23,6; 32,4]*	29,8 [25,7; 33,4]*○	27,2 [24,5; 31,0]*	30,9 [28,7; 32,4]*	31,6 [27,8; 33,9]○
injured limb (left in CG)	31,9 [27,8; 35,0]	19,2 [17,0; 23,1]*∴	22,5 [19,4; 25,8]*∴	25,3 [22,4; 29,5]*○∴	20,6 [17,8; 22,8]*∴	24,6 [20,1; 27,3]*○∴	28,1 [25,9; 32,0]*○∴*
Knee, extension (quadriceps muscle)							
preserved limb (right in CG)	44,8 [38,6; 47,5]	35,2 [31,0; 39,7]*	38,4 [35,7; 42,7]*○	40,6 [37,2; 44,3]*○	37,0 [34,6; 40,3]*	41,9 [37,6; 45,4]*○	43,8 [38,7; 46,9]○
injured limb (left in CG)	41,6 [37,5; 45,7]	22,6 [18,6; 26,0]*∴	25,3 [20,6; 29,7]*∴	30,4 [24,6; 33,7]*○∴	24,2 [19,8; 26,8]*∴	27,9 [22,9; 33,0]*○∴	35,7 [30,4; 41,6]*○∴*
Knee, flexion (hamstrings)							
preserved limb (right in CG)	31,6 [27,1; 34,8]	24,5 [21,9; 26,5]*	26,1 [23,7; 28,4]*	28,0 [25,4; 30,4]*○	25,3 [22,4; 26,8]*	28,0 [25,7; 31,5]*○	30,6 [27,4; 34,7]*○
injured limb (left in CG)	31,9 [26,5; 34,0]	17,8 [14,9; 21,9]*∴	19,5 [18,7; 22,5]*∴	21,0 [19,4; 24,8]*○∴	16,9 [13,8; 20,7]*∴	21,5 [18,7; 25,8]*○∴	25,9 [21,6; 29,8]*○∴*

Notes: * p<0,05 compared with the control group (CG);
 ○ p<0,05 compared with the first (baseline) assessment;
 * p<0,05 compared with the corresponding value of SG1;
 ∴ p<0,05 compared with the value of the preserved limb.

Table 4

Dynamics of strength parameters measured using analog dynamometers in servicemen with sarcopenia and transtibial amputation under the influence of physical therapy

Muscle strength, kg	CG	SG1		SG2			
		Baseline	4 weeks	Baseline	4 weeks	Baseline	4 weeks
Handgrip strength							
dominant hand	46,30±2,58	29,19±4,12*	33,26±4,01*	38,74±2,15*○	27,81±3,77*	35,60±2,71*	44,06±1,68*● ○
non-dominant hand	44,57±2,47	28,65±3,45*	32,08±3,16*	36,96±3,18*○	28,05±3,82*	36,54±3,29*	43,66±2,59* ○*
Deadlift strength	135,66±5,46	-	106,5±4,59*	117,23±3,06*●	-	109,81±5,13*	129,49±4,52* ●*

Notes: * p<0,05 compared with the control group (CG);
 ○ p<0,05 compared with the first (baseline) assessment;
 * p<0,05 compared with the corresponding value of SG1.

For the hip extensors of the preserved limb, the baseline strength deficit was 16.2% in SG1 and 20.8% in SG2 compared with the control group ($p<0.05$). After 4 weeks, strength increased by 4.0% in SG1 and 15.9% in SG2, although no statistically significant changes relative to baseline were observed ($p>0.05$). After 12 weeks, improvement reached 12.9% in SG1 and 23.4% in SG2 ($p<0.05$), and the difference from the control group was no longer detected. SG2 values exceeded those of SG1 by 5.3% after 4 weeks and by 3.3% after 12 weeks, without statistically significant between-group differences ($p>0.05$).

The strength of the hip extensors of the injured limb at baseline was reduced by 33.9% in SG1 and 31.2% in SG2 compared with the control group ($p<0.05$) and was also lower than that of the preserved limb. After 4 weeks, the increase in strength reached 3.0% in SG1 and 10.9% in SG2 ($p>0.05$). After 12 weeks, improvement reached 15.5% in SG1 and 28.6% in SG2 ($p<0.05$), with SG2 demonstrating significantly higher values than SG1 ($p<0.05$). The between-group difference was 12.1% after 4 weeks and 16.0% after 12 weeks and became statistically significant after completion of the physical therapy program.

For the hip abductors of the preserved limb, the baseline deficit compared with the control group was 20.1% in SG1 and 15.6% in SG2 ($p<0.05$). After 4 weeks, improvement reached 6.3% in SG1 and 8.4% in SG2 ($p>0.05$). After 12 weeks, strength increased by 17.3% and 15.4%, respectively ($p<0.05$). SG2 values exceeded those of SG1 by 7.6% after 4 weeks and by 3.8% after 12 weeks, although these differences were not statistically significant ($p>0.05$).

For the hip abductors of the injured limb, the baseline strength deficit was 37.1% in SG1 and 34.6% in SG2 compared with the control group ($p<0.05$), and it was also significant relative to the preserved limb. After 4 weeks, improvement reached 15.7% in SG1 ($p>0.05$), whereas an increase of 18.9% in SG2 was statistically significant ($p<0.05$). After 12 weeks, improvement amounted to 28.3% in SG1 and 41.3% in SG2 ($p<0.05$), with SG2 demonstrating significantly higher values than SG1 ($p<0.05$). The advantage of SG2 over SG1 was 7.0% after 4 weeks and 14.6% after 12 weeks, becoming statistically significant only at the final stage of the intervention.

For the hip adductors of the preserved limb, the baseline deficit relative to the control group was 19.6% in SG1 and 16.6% in SG2 ($p<0.05$). After 4 weeks, improvement reached 6.1% and 13.6%, respectively ($p>0.05$). After 12 weeks, strength increased by 13.7% in SG1 and 16.2% in SG2 ($p<0.05$). In SG1, the difference from the control group remained statistically significant, whereas in SG2 it was no longer observed. The advantage of SG2 over SG1 was 11.2% after 4 weeks and 6.0% after 12 weeks without statistically significant between-group differences ($p>0.05$).

For the hip adductors of the injured limb, the baseline deficit was 39.8% in SG1 and 35.4% in SG2 compared with the control group ($p<0.05$) and was also significant relative to the preserved limb. After 4 weeks, improvement reached 17.2% in SG1 ($p>0.05$) and 19.4% in SG2 ($p<0.05$). After 12 weeks, the increase reached 31.8% in SG1 and 36.4% in SG2 ($p<0.05$), and the value in SG2 was statistically significantly higher than in SG1 ($p<0.05$). The between-group difference was 9.3% after 4 weeks and 11.1% after 12 weeks, becoming statistically significant only at the final stage.

The strength of the knee extensors of the preserved limb at baseline was lower than in the control group by 21.4% in SG1 and 17.4% in SG2 ($p<0.05$). After 4 weeks, improvement reached 9.1% and 13.2%, respectively ($p<0.05$), although the values remained lower than those of the control group. After 12 weeks, improvement reached 15.3% in SG1 and 18.4% in SG2 ($p<0.05$). In SG1 the difference from the control group persisted, whereas in SG2 it was no longer observed. The between-group difference was 9.1% after 4 weeks and 7.9% after 12 weeks without statistical significance ($p>0.05$).

For the knee extensors of the injured limb, the baseline deficit was among the largest – 45.7% in SG1 and 41.8% in SG2 compared with the control group ($p<0.05$)—and was also lower than the values of the preserved limb. After 4 weeks, improvement reached 11.9% in SG1 ($p>0.05$) and 15.3% in SG2 ($p<0.05$). After 12 weeks, strength increased by 34.5% in SG1 and 47.5% in SG2 ($p<0.05$), with SG2 demonstrating significantly higher values than SG1 ($p<0.05$). The advantage of SG2 over SG1 was 10.3% after 4 weeks and 17.4% after 12 weeks and became statistically significant only at the final stage of the study.

For the knee flexors of the preserved limb, the baseline deficit relative to the control group was 22.5% in SG1 and 19.9% in SG2 ($p<0.05$). After 4 weeks, improvement reached 6.5% in SG1 ($p>0.05$) and 10.7% in SG2 ($p<0.05$). After 12 weeks, improvement amounted to 14.3% and 20.9%, respectively ($p<0.05$), although the values in both groups remained significantly lower than in the control group. The advantage of SG2 over SG1 was 7.3% after 4 weeks and 9.3% after 12 weeks without statistically significant differences ($p>0.05$).

For the knee flexors of the injured limb, the baseline deficit was 44.2% in SG1 and 47.0% in SG2 compared with the control group ($p<0.05$) and was also statistically significant relative to the preserved limb. After 4 weeks, improvement in SG1 reached 9.6% ($p>0.05$), whereas in SG2 an increase of 27.2% was statistically significant ($p<0.05$). After 12 weeks, improvement reached 18.0% in SG1 and 53.3% in SG2 ($p<0.05$). At the final stage, SG2 values were significantly higher than those in SG1 ($p<0.05$), and the between-group difference reached 10.3% after 4 weeks and 23.3% after 12 weeks, becoming statistically significant only at the end of the intervention. This indicated a more effective recovery of hamstring muscle function in SG2.

A decrease in handgrip strength and deadlift strength is a characteristic feature of sarcopenia, as it reflects the loss of muscle mass and functional capacity of skeletal muscles [2]. Accordingly, an increase in these parameters over time was interpreted as a positive functional adaptation indicating recovery of muscle strength and improvement of the overall physical condition of patients (table 4).

For handgrip strength of the dominant hand, a statistically significant reduction compared with the control group was observed at baseline: 37.0% in SG1 and 39.9% in SG2 ($p<0.05$). After 4 weeks, both groups demonstrated positive dynamics: strength increased by 14.0% in SG1 and by 28.0% in SG2; however, the values remained significantly lower than those of the control group. In SG1, the improvement was statistically significant compared with baseline ($p<0.05$). After 12 weeks, the increase reached 32.7% in SG1 and 58.4% in SG2; in SG2 the value was significantly higher

than at the second assessment ($p < 0.05$), although it still remained lower than in the control group ($p < 0.05$). SG2 values exceeded those of SG1 by 7.0% after 4 weeks and by 13.7% after 12 weeks, although the between-group difference was not statistically significant ($p > 0.05$).

For handgrip strength of the non-dominant hand, the baseline deficit relative to the control group was 35.7% in SG1 and 37.1% in SG2 ($p < 0.05$). After 4 weeks, improvement in SG1 reached 12.0% and was statistically significant compared with baseline ($p < 0.05$), although the value remained lower than in the control group (deficit 28.0%; $p < 0.05$). In SG2, the increase was more pronounced, reaching 30.3%, although the difference from the control group persisted ($p < 0.05$). After 12 weeks, the increase reached 29.0% in SG1 and 55.7% in SG2; the value in SG2 was significantly higher than in SG1 ($p < 0.05$), although it remained lower than in the control group ($p < 0.05$). The advantage of SG2 over SG1 was 13.9% after 4 weeks and 18.1% after 12 weeks and became statistically significant only at the final stage ($p < 0.05$), indicating a more pronounced recovery of functional handgrip strength in SG2.

The analysis of deadlift strength was performed only at the 4- and 12-week stages, when patients were able to use the prosthesis. After 4 weeks, the deficit relative to the control group was 21.5% in SG1 and 19.1% in SG2 ($p < 0.05$). After 12 weeks, the increase in SG1 compared with the second assessment reached 10.1%, and the deficit relative to the control group decreased to 13.6%; this improvement was statistically significant compared with the second assessment ($p < 0.05$), although the difference from the control group remained ($p < 0.05$). In SG2, the increase reached 17.9%, and the deficit relative to the control group decreased to 4.5%. The value was significantly higher than at the second assessment ($p < 0.05$) and also significantly higher than in SG1 ($p < 0.05$), although it still did not reach the level of the control group. The between-group difference was 3.1% after 4 weeks and 10.5% after 12 weeks and became statistically significant only at the final stage ($p < 0.05$), indicating a more pronounced recovery of the integral strength potential in SG2.

Discussion. The analysis of the summarized study results made it possible to identify systemic relationships between upper and lower limb muscle strength parameters and integral strength characteristics in wounded servicemen with transtibial amputation and sarcopenia. The findings indicated that the reduction in strength parameters had a generalized character and reflected systemic manifestations of sarcopenia rather than only local changes in the injured limb. Strength deficits were observed both in the muscles of the lower limbs, which are responsible for support and locomotion, and in the muscles of the upper limbs, which contribute to body stabilization and mobility using assistive devices.

A functional relationship was identified between handgrip strength and the isometric strength of the upper limb muscles. A decrease in handgrip strength was accompanied by reduced strength of the shoulder and elbow flexors and extensors, confirming the interconnected functioning of these muscle groups. At the same time, an association was observed between the strength of the lower limb muscles and integral strength indicators, particularly deadlift strength. Increased strength of the hip and knee flexors and extensors was accompanied by an increase in

deadlift strength, reflecting the restoration of functional activity of large muscle groups of the trunk and lower limbs. In this context, deadlift strength can be considered an integral indicator of the overall strength potential of the musculoskeletal system.

An association was also identified between the strength characteristics of the upper and lower limbs: patients with a more pronounced deficit in lower limb muscle strength also demonstrated greater reductions in the strength of the shoulder and elbow muscles, which confirmed the systemic nature of sarcopenic changes. The dynamics of strength parameters during physical therapy demonstrated synchronous recovery in functionally related muscle groups: an increase in the strength of the shoulder and elbow muscles was accompanied by an increase in handgrip strength, whereas improvement in the strength of the hip and knee muscles was associated with an increase in deadlift strength. In addition, a relationship was identified between the rate of recovery of strength characteristics and the type of physical therapy program applied. The group that received the comprehensive program with sarcopenia-targeted interventions demonstrated a more pronounced positive dynamic both in local muscle strength indicators and in integral strength parameters (handgrip strength and deadlift strength).

The obtained results are consistent with contemporary concepts of sarcopenia as a syndrome characterized by progressive loss of muscle strength and function, which directly affects mobility, balance, and overall functional independence of patients. According to the updated European Working Group on Sarcopenia in Older People consensus, reduced muscle strength is considered the primary feature of sarcopenia, while further decline in physical performance reflects more severe stages of the condition [2].

The results also correspond with previous studies demonstrating that individuals after lower limb amputation exhibit a pronounced deficit in muscle strength, which may negatively affect balance, endurance, and gait efficiency when using a prosthesis [3]. Muscle weakness, particularly of proximal muscle groups, is one of the key factors contributing to impaired functional mobility in prosthesis users, emphasizing the importance of targeted strength training in rehabilitation programs [3,5].

The analysis of strength dynamics in the present study showed that physical therapy contributed to gradual improvement in the strength of both upper and lower limb muscles in both study groups. Similar findings have been reported in previous studies, which indicate that systematic physical exercise, especially resistance training, helps reduce muscle atrophy, increase muscle strength, and improve functional capacity in individuals with lower limb amputations. For example, a systematic review by Rosario et al. demonstrated that strength training programs in people with amputations contribute to improved body stabilization, increased hip muscle strength, and enhanced gait performance [10].

In the present study, the most pronounced positive changes were observed in muscle groups that play a key role in maintaining upright posture and ambulation with a prosthesis, particularly the flexors and extensors of the hip and knee joints. This finding is consistent with previous research indicating that targeted strengthening of these

muscle groups is essential for developing stable gait patterns and improving functional independence in individuals with lower limb amputations [8].

Conclusions.

1. In wounded servicemen with sarcopenia and transtibial amputation, pronounced functional manifestations of muscle dysfunction were identified, characterized by reduced strength of both the upper and lower limbs. In particular, decreased handgrip strength, deadlift strength, and reduced isometric strength of the major muscle groups of the shoulder, elbow, hip, and knee joints were observed. These findings reflected the systemic nature of sarcopenic changes in the muscular system and a decline in the overall muscular strength potential of the body.

2. Muscle strength parameters of the upper and lower limbs in wounded servicemen with transtibial amputation and sarcopenia were significantly lower ($p < 0.05$) compared with those of apparently healthy men in the control group. The most pronounced strength deficit was observed in the muscles of the injured lower limb, particularly in the hip and knee flexors and extensors, confirming the negative impact of amputation and sarcopenia on the functional state of the muscular system.

3. The implemented 12-week comprehensive physical therapy program, which included therapeutic exercises of various orientations, gait training, stump preparation for prosthetic fitting, balance training, strengthening exercises for major muscle groups, and an educational component focused on lifestyle and nutritional modification, contributed to a significant improvement in muscular strength parameters in wounded servicemen. In particular, statistically significant increases ($p < 0.05$) were observed in handgrip strength, deadlift strength, isometric strength of the shoulder and elbow muscles, as well as the muscles of the hip and knee joints compared with baseline values.

4. Improvement in muscular strength characteristics was more pronounced in the group that underwent the comprehensive physical therapy program including sarcopenia-targeted interventions than in the group that received the standard rehabilitation program. This group demonstrated greater rates of recovery in upper limb muscle strength and a more pronounced increase in the strength of the injured lower limb muscles, which was confirmed by statistically significant between-group differences ($p < 0.05$) at the final stage of the study.

5. The obtained results indicate the necessity of incorporating specialized physical therapy interventions aimed at sarcopenia correction into rehabilitation programs for wounded servicemen with transtibial amputation. Comprehensive interventions combining resistance training, functional exercises, and educational measures contribute to more effective restoration of muscular strength potential, improvement of functional capacity, and increased effectiveness of the prosthetic rehabilitation process.

Conflict of Interest. None declared.

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