

EKSPERIMENTINIS TYRIMAS

The effect of passive foot flexion on blood circulation in sports and clinical medicine

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Key words: passive foot flexion; venous reserve volume; maximal venous emptying rate.

Summary. The aim of the study was to analyze the effect of the passive foot flexion on peripheral and systemic blood circulations in the state of rest of persons adapted to endurance physical loads, and on patients during surgery.

Methods. In the first series of experiments which included 16 males in recumbent supine position adapted to endurance physical loads, the effect of the passive foot flexion by applying a leg muscle activator on the systemic and peripheral blood circulations was analyzed. In the second series of experiments conducted with 6 males and 12 females, the passive foot flexion was aimed at preventing thromboembologenesis during the intraoperative period.

Results. After a session of the passive foot flexion applied to persons adapted to endurance physical loads, the venous reserve volume in them increased to 1.68 ± 0.3 mL/100 mL ($p < 0.05$). The maximal venous emptying rate increased to 48.3 ± 8.8 mL/100 mL/min ($p < 0.05$). After 15 min of the passive foot flexion, the indices of the systemic blood circulation were analogous to the ones before passive foot flexion. The maximal venous emptying rate in the calves of the left and right legs at the end of the surgery decreased to 59.7 ± 4.7 mL/100 mL/min ($p > 0.05$) and to 62.9 ± 4.0 mL/100 mL/min ($p > 0.05$), respectively.

Conclusions. The passive foot flexion applied to persons adapted to endurance physical loads increases venous reserve volume and maximal venous emptying rate. During the intraoperative period, the passive foot flexion increases maximal venous emptying rate from the triceps muscle of the calf thus decreasing the possible danger of thromboembologenesis.

Introduction

Complete recovery after physical loads undertaken and its stimulating by means of various methods are of special importance. New recovery means of local effect that contribute to decreasing the fatigue of muscle groups performing the work of the greatest intensity are applied ever more frequently. Various physiotherapeutic methods are applied widely (1–3). In our opinion, passive foot flexion is an effective modality. Blood flow in the muscles performing physical load is an important factor determining their working capacity. The intensity of blood flow in the muscles due to the effect of recovery means applied after intensive physical loads is associated with an increased blood flow and its distribution between more active and less active muscles. An increase in working capacity is made possible not only because of the improved cardiac function but also due to a suitable effect given to

the regulatory mechanisms of the peripheral blood circulation. The intensity of blood flow in the muscles of humans in the state of rest is subject to changes depending on their functional condition as well as due to the influence of external factors. It is of importance to find out in what way the passive foot flexion, applied as an additional means of recovery, affects the peripheral and the systemic blood circulations.

Additional means of recovery are applied in sports and clinical medicine. Means of recovery in sports activities are applied after intensive physical loads, e.g., the passive foot flexion is an effective means that helps to accelerate the processes of recovery of working capacity. However, any recovery procedure has its own specific effect on the body too. Each means of recovery subjects the human body to an additional load affecting its various functional systems (4). Continuous passive foot flexion undertaken for 60

seconds decreases rigidity in the ankle joint (5). Both passive and active flexions in the ankle joint increase blood flow rate in the muscles of the lower leg (6). Voluntary foot flexion and stretching movements increase the venous outflow rate from the muscles of the shank (7). The data on the effect of the passive foot flexion are scarce. Not always blood flow in the muscles is increased by passive movements, whereas active movements bring about work hyperemia (8). Hypokinesia during the intraoperative period is a factor of danger in clinical medicine since it can predispose the venous blood stasis and stimulate thromboembologenesis of deep veins in the lower leg. An analogous danger may arise due to traumas to the lower extremities or after the flight of long duration on the plane (9).

In special literature, we have not come across any research done in applying involuntary foot flexion aimed at improving the intensity of the peripheral and systemic blood circulations in healthy persons.

In modern medicine, in surgery, and in rehabilitation practice, the passive foot flexion is used for prevention of thromboembologenesis during the intraoperative period. This process in the physiological sense is the nearest to natural walking, and therefore it increases the venous outflow and decreases the probability of the venous blood stasis in the lower legs. On the other hand, skeletal muscles become as though resistant and insensitive to the "curare" effect of myorelaxants. All this ensures an optimum venous outflow from the most thromboembologenic areas, *i.e.*, the sural venous sinuses situated in the triceps muscle of the calf (10). If we believe in the probability of retention of the sensorimotor impulsation, then we will have a nearly complete picture of the effect produced by the "leg muscle activator," a mechanical device, that does the work of the skeletal muscle-venous blood pump in the triceps muscle of the calf.

In the list of the abdominal surgeries, gastrofunduplications are likely to be the most thromboembologenic ones. Numerous factors predisposing thromboembologenesis, such as an increased pressure (12–14 mmHg) in the abdominal cavity, a negative effect of myorelaxants on the skeletal muscle–venous blood pump function, a vasodilating effect of analgetics, the reversed Trendelenburg position of the patient on the operating table, etc., are at work during surgery intervention. Postoperative continuous passive movements in the ankle joint performed with the help of a mechanical device increase venous outflow from the lower extremities (11).

After summarizing of the above-mentioned data, it was decided to improve venous outflow from the

most thromboembologenic areas, *i.e.*, the sural venous sinuses by making use of a mechanical foot flexion device during the intraoperative period of gastrofunduplications.

Therefore, the aim of the present study was to analyze the effect of the passive foot flexion on the indices of the peripheral and systemic blood circulations in the state of rest of persons adapted to endurance physical loads and in the patients at the beginning and at the end of surgery.

Methods

Two series of experiments were performed. In the first series of experiments, the effect of the passive foot flexion on the systemic (stroke volume, heart rate, and cardiac output) and on the peripheral blood circulations (venous reserve volume and maximal venous emptying rate in the calf of the leg) of healthy persons was analyzed. The sample consisted of 16 males (mean age 20.0 ± 0.3 years, height 182.5 ± 1.0 cm, weight 71.0 ± 1.7 kg) adapted to endurance physical loads. After a 20-minute adaptation in the state of rest in the recumbent supine position with the legs bent at the knees at the angle of 135° , changes at the systemic blood circulation were recorded applying the method of tetrapolar reography, and the indices of the peripheral blood circulation were registered with a venous occlusion plethysmograph. After a 15-minute session of the passive foot flexion, the indices of the systemic blood circulation and the peripheral blood circulation mentioned above were recorded again. The segment of the lower leg, the calf, was studied at the level of the heart.

For the second series of experiments, 6 male and 12 female patients (mean age 49.7 ± 3.6 years, height 171.6 ± 2.3 cm, weight 77.4 ± 2.9 kg) being prepared for gastrofunduplication surgery because of the hiatal hernia complicated by the gastroesophageal reflux were chosen randomly. The research protocol was estimated and approved by the Ethics Committee of Kaunas University of Medicine. To decrease the probability of thromboembologenesis, the employment of a leg muscle activator used for the passive foot flexion was chosen. The control of efficacy of the modality was performed making use of a venous occlusive plethysmograph *Periquant 850*. The venous hemodynamics of the triceps muscle of the calf, the maximal venous emptying rate, served as the object of the research. Measurements were made at the beginning and at the end of the surgery.

In both experiments, the passive foot flexion movements were performed using a leg muscle activator (10). The feet were attached to the pedals that were

moved by an electrical motor. The angle of pedal motion, as well as the amplitude of flexion and stretching movements was at 35°; the frequency, 30 foot movements per min. Separate sessions of the passive foot flexion for persons adapted to endurance physical loads revealed that the optimum duration of the session after which the highest work capacity was reached lasted 15 minutes (12).

The equality of averages of dependent samples was estimated with the help of Student's *t* test. The difference reliability was set at $p < 0.05$. Calculations were made using the statistical *Microsoft Excel* package and a specialized statistic program *Statistica*.

Results

In the first series of experiments before the passive foot flexion, when the pressure in the occlusive cuff was 30 mmHg, the venous reserve volume amounted to 1.14 ± 0.2 mL/100 mL. Values are means \pm SE (Fig. 1). After a session of involuntary foot flexion and stretching movements, the venous reserve volume increased to 1.68 ± 0.3 mL/100 mL ($p < 0.05$). Two hundred and twenty seconds later after the passive foot flexion, venous reserve volume in the calf remained increased, *i.e.*, 1.24 ± 0.2 mL/100 mL, whereas in the subsequent measurements (at the 364th, 518th, and 670th seconds) the venous reserve volume index was still but insignificantly higher, compared to the initial value.

After a session of the passive foot flexion, an increase in venous reserve volume in the calf was determined showing that venous blood vessels were emptied.

Prior to the passive foot flexion, when the pressure

in the cuff was 30 mmHg, maximal venous emptying rate amounted to 36.4 ± 6.6 mL/100 mL/min (Fig. 2). At the 79th second after a session of the passive foot flexion, the maximal venous emptying rate increased insignificantly, *i.e.*, to 40.9 ± 8.3 mL/100 mL/min ($p > 0.05$). The greatest increase in the maximal venous emptying rate was reached at the 364th and at the 518th seconds and it amounted to 48.3 ± 8.8 mL/100 mL/min ($p < 0.05$) and 49.5 ± 10.1 mL/100 mL/min ($p < 0.05$), respectively, whereas at the 670th second of the recording, the maximal venous emptying rate was significantly smaller, compared to its initial value.

After a session of the passive foot flexion, an increase in maximal venous emptying rate took place.

The ratio of the maximal venous emptying rate to the venous reserve volume, when the pressure in the cuff was 30 mmHg, amounted to 0.53 ± 0.04 s⁻¹ (Fig. 3). Due to the effect of a session of the passive foot flexion applied, the maximal venous emptying rate and the venous reserve volume ratio decreased to 0.42 ± 0.06 s⁻¹ ($p > 0.05$). In subsequent measurements, *e.g.*, at the 364th second of recording, it increased significantly – to 0.77 ± 0.08 s⁻¹, whereas later, *i.e.*, at the 518th and the 670th seconds, it decreased and was still but insignificantly greater, compared to the initial level.

The passive foot flexion exerted a positive influence on the ratio of the maximal venous emptying rate to the venous reserve volume, which after a session of the passive foot flexion had a character of two phases, *i.e.*, a decrease in the first phase and a significant increase, compared to the initial level, with a subsequent return to the initial value, in the second phase.

In the recumbent supine persons adapted to endu-

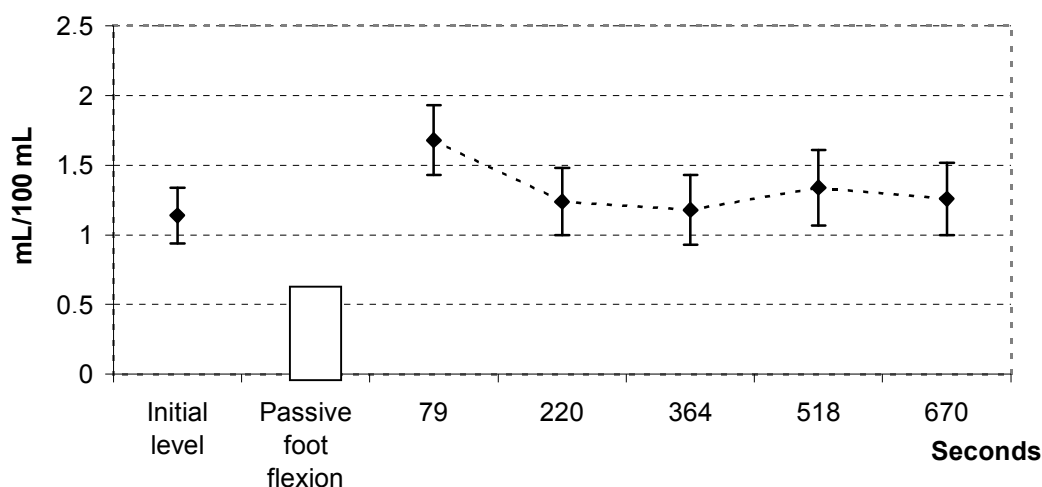


Fig. 1. Changes in venous reserve volume (mL/100 mL) after a session of passive foot flexion

Values are means \pm SE.

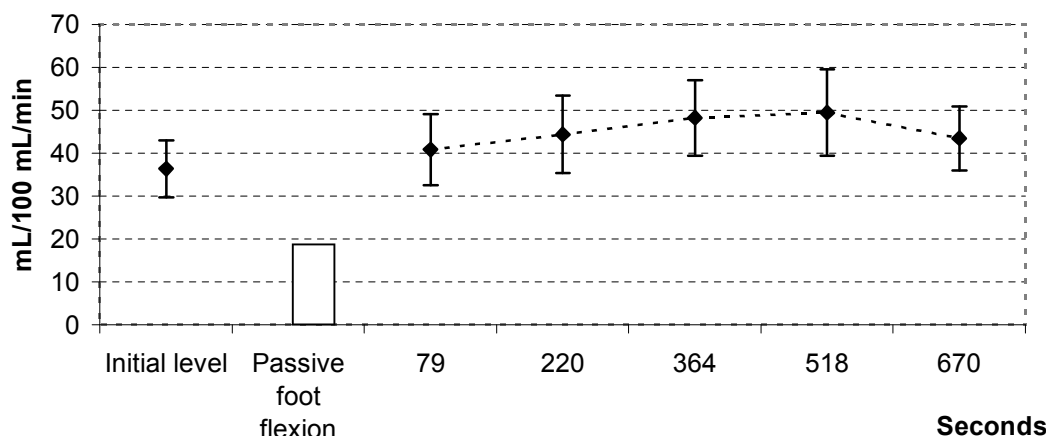


Fig. 2. Maximal venous emptying rate (mL/100 mL/min) after a session of passive foot flexion
Values are means \pm SE.

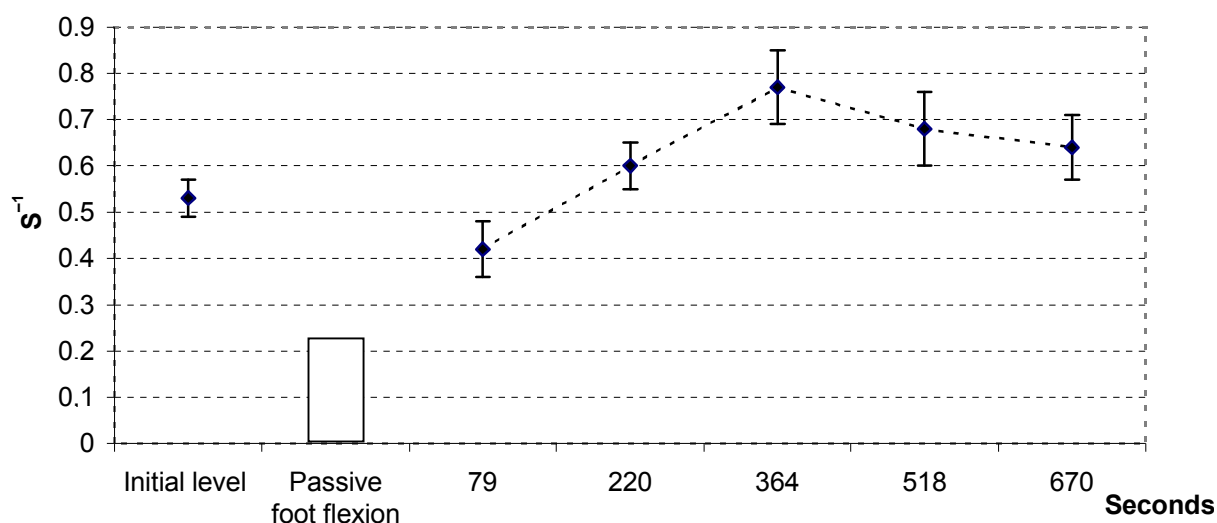


Fig. 3. The effect of passive foot flexion on the ratio of the maximal venous emptying rate to the venous reserve volume (s⁻¹)
Values are means \pm SE.

rance physical loads, the indices of systemic blood flow, *i.e.*, stroke volume, heart rate, and cardiac output, before a session of the passive foot flexion movements were 86.7 ± 3.4 mL, 57.5 ± 2.2 beats/min and 5.0 ± 0.3 L/min, accordingly. After a 15-min session of the passive foot flexion, the indices of systemic blood circulation were analogous to the values determined before the session.

In the second series of experiments, the indices of the maximal venous emptying at the beginning of the surgery were 65.5 ± 5.0 mL/100 mL/min (Fig. 4) in the calf of the left leg and 70.0 ± 5.9 mL/100 mL/min in the calf of the right leg, whereas at the end of the surgery these indices decreased to 59.7 ± 4.7 mL/100 mL/min ($p > 0.05$) and to 62.9 ± 4.0 mL/100 mL/min ($p > 0.05$), respectively.

At the end of the surgery, performed together with

the passive foot flexion, just an insignificant decrease in maximal venous emptying rate was observed.

No changes in the indices of systemic blood circulation of the patients studied during the intraoperative period were determined.

Discussion

The passive foot flexion increases venous reserve volume in the calf in the persons adapted to endurance physical loads. In this case, a greater venous outflow from the venous blood vessels takes place, as the passive foot flexion performs contraction – stretching and relaxation of the calf muscles. This assertion is confirmed by the increased period of time during which the plethysmogram curve reaches its maximum level showing to what extent the veins have been emptied. The results of our previous researches have shown that

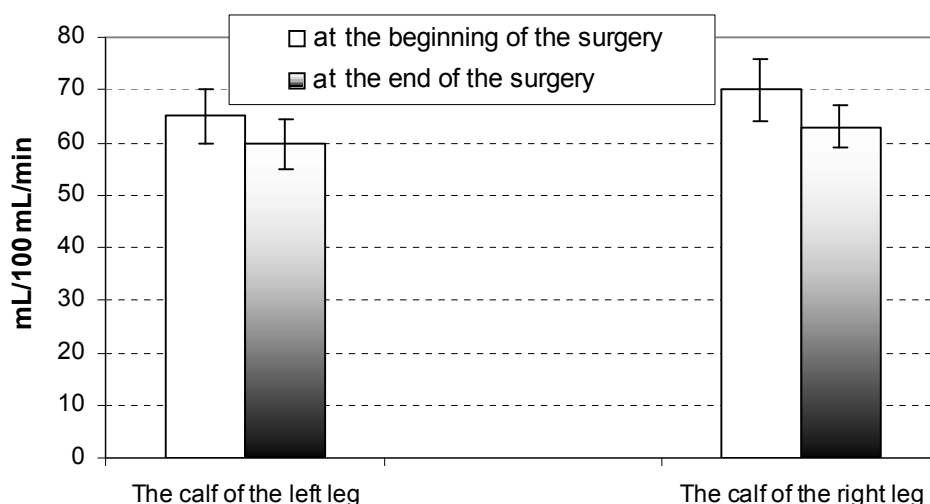


Fig. 4. Maximal venous emptying rate (mL/100 mL/min) at the beginning and the end of the surgery
Values are means \pm SE.

after the passive foot flexion, there occurs a decrease in the initial blood supply volume to the lower extremity, confirmed by a diminished girth (maximal circumference) of the calf (12).

Immediately after the passive foot flexion, a slight increase in the maximal venous emptying rate is determined. After a session of the passive foot flexion with an increase in venous reserve volume, the volume of the calf of the leg decreases. After a session of the passive foot flexion, calf muscles contract no longer, whereas the veins are emptied due to involuntary muscle contractions. After applying the passive foot flexion, more time is required for refilling the veins with blood for the pressure in the lower leg tissues to become the same as in the venous occlusion cuff (compared to the pressure that was prior to the session of the passive foot flexion applied). Until the veins are filled with blood, a slight increase in the maximal venous emptying rate takes place, whereas the ratio of the maximal venous emptying rate to venous reserve volume decreases by $25.0 \pm 10.3\%$. The changes in this ratio are caused by the increased venous reserve volume. Subsequently, *i.e.*, at the 220th recording second, a significant increase in the maximal venous emptying rate is determined. This is a proof of the fact that the passive foot flexion decreases the venous blood volume, what is evident from the increased maximal venous emptying rate. It should be noted that the estimation of the maximal venous emptying rate, determined by a venous occlusion plethysmograph, depends on the pressure in the occlusion cuff. The additional information on the blood flow in veins is provided by the ratio of the maximal venous emptying rate to venous reserve volume, which does not depend upon

the occlusion cuff pressure (13). After the passive foot flexion session, a decrease in the maximal venous emptying rate was recorded, since in this case the increased venous reserve volume considerably exceeds venous emptying rate in the calf. The increased venous reserve volume shows the emptied venous blood vessels to be a result of the passive foot flexion. There should be also a decrease in the venous pressure resulting the increased venous outflow (14). Consequently, a decrease in the ratio of the maximal venous emptying rate to the venous reserve volume can be explained by the effect produced by the passive foot flexion. Afterwards, the filling up of the venous blood vessels takes place, the venous reserve volume decreases, and the increased venous pressure is a consequence of the process. Due to the increased venous pressure, the veins dilate, and thus venous reserve volume is increased. The position of the foot affects venous outflow rate too. P. Fleming *et al.* (15) have shown that placing an individual in the 25 degrees foot-down position consistently produces a significantly higher rise in the venous blood velocity when the venous pump is used than in the horizontal and foot-up position. They believed that increasing the volume of blood in the venous plexus of the foot by placing the feet in a dependent position should lead to a more efficient pumping mechanism.

Continuous passive movements in the ankle joint performed with the help of a mechanical device can improve the venous outflow from the lower extremities after surgery (11). Due to performing a passive compression in the sole veins, venous blood circulation changes insignificantly. A voluntary muscle activation yields better results than a passive compression

of the veins. In clinical situations, the conscious post-operative patients should be advised to perform the flexions instead of applying just the intermittent pneumatic compression stockings (16, 17). Both passive and active foot flexion movements increase the average and peak venous outflow rates; however, greater positive changes are brought about by the active flexion movements (6).

The passive foot flexion applied to the recumbent supine subjects adapted to endurance physical loads had no essential effect on the indices of their systemic blood circulation (stroke volume, heart rate, and cardiac output).

There was determined an insignificant decrease ($p > 0.05$) in the maximal venous emptying rate at the end of the surgery. This finding shows a positive effect of the muscle activator applied during the intraoperative period, as it activates the capacity of the leg muscle venous blood pump. As a consequence of the process described above, there occurs a decrease in venous blood stasis in the lower legs. Therefore, a smaller venous outflow was recorded at the end of the surgery than at its beginning. The results obtained have con-

firmed the work hypothesis that a leg muscle activator improves the venous blood outflow from the most thromboembolic areas, *i.e.*, the triceps muscle of the calf. The indices of the systemic hemodynamics remain practically unchanged throughout the surgery. The data of our study are in accord with the assertions of other authors concerning the positive effect of the passive foot flexion on the venous hemodynamics (6, 11, 17)

Conclusions

1. In the recumbent supine persons adapted to endurance physical loads, the employment of passive foot flexion increases the venous reserve volume and the maximal venous emptying rate.

2. During the intraoperative period, the passive foot flexion improves the rate of venous outflow from the triceps muscle of the calf thus decreasing the probability of thromboembologenesis.

3. We recommend the passive foot flexion to be applied in order to increase the venous blood outflow from the lower extremities in the conditions of hypokinesia.

Pėdų pasyvaus lankstymo poveikis kraujotakai sporto ir klinikinėje medicinoje

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Raktažodžiai: pasyvus pėdų lankstymas, rezervinė venų talpa, maksimalus venų tuštėjimo greitis.

Santrauka. *Tikslas.* Išanalizuoti asmenų, adaptuotų prie ištvermės fizinių krūvių, pasyvaus pėdų lankstymo poveikį periferinei ir sistemei kraujotakai ramybės būsenoje ir ligonių operacijų metu.

Tirtųjų kontingentas ir tyrimo metodika. Pirmoje tyrimų serijoje ($n=16$), ligoniams gulint, kojų raumenų aktyvatoriumi buvo tiriamas pasyvaus pėdų lankstymo poveikis vyrų, adaptuotų prie ištvermės fizinių krūvių, sistemei ir periferinei kraujotakai. Antroje tyrimų serijoje šešiams ligoniams vyrams ir dvylikai ligonių moterų operacijos metu tromboembologenezės tikimybei mažinti buvo atliekamas pasyvus pėdų lankstymas.

Rezultatai. Po pasyvaus pėdų lankstymo seanso, asmenų, adaptuotų prie ištvermės fizinių krūvių, rezervinė venų talpa padidėjo iki $1,68 \pm 0,3$ mL/100 mL ($p < 0,05$). Maksimalus venų tuštėjimo greitis padidėjo iki $48,3 \pm 8,8$ mL/100 mL/min. ($p < 0,05$). Po 15 min. pasyvaus pėdų lankstymo sisteminės kraujotakos rodikliai buvo analogiški buvusiems iki seanso. Maksimalus venų tuštėjimo greitis kairės ir dešinės kojų blauzdos operacijos pabaigoje nežymiai sumažėjo, atitinkamai – $59,7 \pm 4,7$ mL/100 mL/min. ($p > 0,05$) ir $62,9 \pm 4,0$ mL/100 mL/min. ($p > 0,05$).

Išvados. Pasyvaus pėdų lankstymo judesiai asmenims, adaptuotiems prie ištvermės fizinių krūvių, didina rezervinę venų talpą ir maksimalų venų tuštėjimo greitį. Pasyvus pėdų lankstymas operacijos metu pagerino veninio kraujo ištekėjimo greitį iš trigalvio blauzdos raumens, taip mažindamas galimą tromboembologenezės pavojų.

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