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PLACE AND ROLE OF SOFT TISSUE ULTRASOUND EXAMINATION IN TOURNIQUET SYNDROME

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The purpose of the study was to demonstrate and analyze the possibilities of ultrasound diagnosis of tourniquet syndrome. All wounded were admitted at the Military Medical Clinical Center of the Northern Region of the Command of the Medical Forces of the Armed Forces of Ukraine from advanced surgical groups at different times from the wound with an existing tourniquet on the limb at different times after the tourniquet was placed (from 5 to 72 hours, on average 8.2±0.6). There were 32 male wounded. The average age of the wounded was 39.4±2.6 years. According to the location of the tourniquet, the wounded are distributed as follows: shoulder – 5 (15.6 %), thigh – 24 (75 %), leg – 3 (9.4 %) patients. All the wounded underwent an ultrasound and elastographic examinations. We used an average result after 12 measurements of each muscle group. When studying the data of muscle elastography against the background of the existing tourniquet, a significant difference in the elastography indicators of healthy superficial and deep muscles being under the tourniquet due to compression is noted. Elastography indicators in deep muscles are always higher than in superficial muscles. Changes in muscle elastography are localized by the location of the tourniquet. The use of ultrasound examination of soft tissues in tourniquet syndrome has an additional character. According to the data of elastography of soft tissues in the case of tourniquet syndrome, it is possible to determine the extent of soft tissue damage, which is important for determining the size of surgical intervention.

Key words: gunshot wounds of the limbs, tourniquet syndrome, soft tissue, elastography, ultrasound diagnostics

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МІСЦЕ ТА РОЛЬ УЛЬТРАЗВУКОВОГО ДОСЛІДЖЕННЯ М'ЯКИХ ТКАНИН ПРИ ТУРНІКЕТНОМУ СИНДРОМІ

Метою дослідження була демонстрація та аналіз можливостей ультразвукової діагностики турнікетного синдрому при вогнепальних пораненнях кінцівок. Всі поранені надходили до Військово-медичного клінічного центру Північного регіону Командування медичних Сил Збройних сил України з передових хірургічних груп в різні терміни від поранення з наявним турнікетом на кінцівці в різні терміни після постановки турнікету (від 5 до 72 годин, у середньому 8.2±0.6). Поранених було 32 пацієнти, всі – чоловічої статі. Середній вік поранених був 39.4±2.6 років. За локалізацією стояння турнікету поранені розподілені наступним чином: плече – 5 (15.6 %), стегно – 24 (75 %), гомілка – 3 (9.4 %) пацієнтів. Всі пораненим виконано ультразвукові та еластографічні дослідження. Фіксували середній результат після 12 вимірювань кожної групи м'язів. При вивченні даних еластографії м'язів на фоні наявного турнікету відмічали достовірну різницю в показниках еластографії здорових поверхневих та глибоких м'язів та м'язів, які знаходяться під турнікетом за рахунок здавлення. Показники еластографії в глибоких м'язах завжди більш ніж у поверхневих м'язах. Зміни еластографії м'язів локалізовані місцем стояння турнікету. Використання ультразвукового дослідження м'яких тканин при турнікетному синдромі має додатковий характер. За даними еластографії м'яких тканин при турнікетному синдромі можливо визначитися з обсягом ушкодження м'яких тканин, що важливо для визначення обсягу оперативного втручання.

Ключові слова: вогнепальні поранення кінцівок, турнікетний синдром, м'які тканини, еластографія, ультразвукова діагностика

The study is a fragment of the research project "Development of modern methods of diagnosis and treatment of purulentseptic complications in combat surgical trauma", state registration No 0120U101834.

Tourniquet syndrome is a condition that occurs when blood flow to a limb is blocked by a rigid object such as a tourniquet or belt. In general, the frequency of tourniquet syndrome in gunshot wounds of the extremities is about 10-20%. In some studies, the frequency was significantly higher, especially in combat conditions [3, 11, 12, 15].

In a study conducted in Ukraine during russia's large-scale aggression against Ukraine, the frequency of tourniquet syndrome in gunshot wounds to the extremities was 35%. In a study conducted in the USA, the frequency of tourniquet syndrome in gunshot wounds of the extremities was 12 % [4, 5, 10]. Tourniquet syndrome is more common in lower extremity injuries than in upper extremity injuries. This is due to the fact that the lower limbs have a larger volume of tissue and need more pressure to stop bleeding [7].

In case of incorrect use of the tourniquet, you can expect more significant blood loss due to compression of the vein ("venous tourniquet"). Early medical reevaluation of the tourniquet is an important component at various levels of care. This includes reassessing the ability of the tourniquet to achieve hemostasis, the absence of pulses in the peripheral arteries, and the relevance of the tourniquet in general.

The widespread use of a tourniquet with its application as high as possible on the limb in accordance with Tactical Combat Casualty Care leads to a significant number of complications associated with local rhabdomyolysis. Hemorrhagic shock, a large number of sanitary casualties and tactical limitations often prevent timely conversion or repositioning of a tourniquet imposed under fire in the red zone of hostilities [8, 13].

Because of this, diagnostic measures aimed at determining the viability of soft tissues under the tourniquet are gaining considerable relevance. In this aspect, our attention was drawn to the technique of muscle elastography, which is a diagnostic method that uses ultrasound to measure muscle stiffness [2, 6, 12, 13]. he advantages of this method include that muscle elastography can be performed anywhere on the body where there are muscles. It is usually performed on the upper and lower extremities. The results can be used to diagnose muscle diseases, assess the severity of the disease and monitor the effectiveness of treatment.

The purpose of the study was to demonstrate and analyze the possibilities of ultrasound diagnosis of tourniquet syndrome.

Materials and methods. All the wounded were admitted to the Military Medical Clinical Centre of the Northern Region of the Command of the Medical Forces of the Armed Forces of Ukraine from the advanced surgical groups at different times from the wound with an existing tourniquet on the limb at different times after the tourniquet was placed (from 5 to 72 hrs, on average 8.2±0.6). There were 32 male wounded. The mean age of the wounded was 39.4±2.6 years.

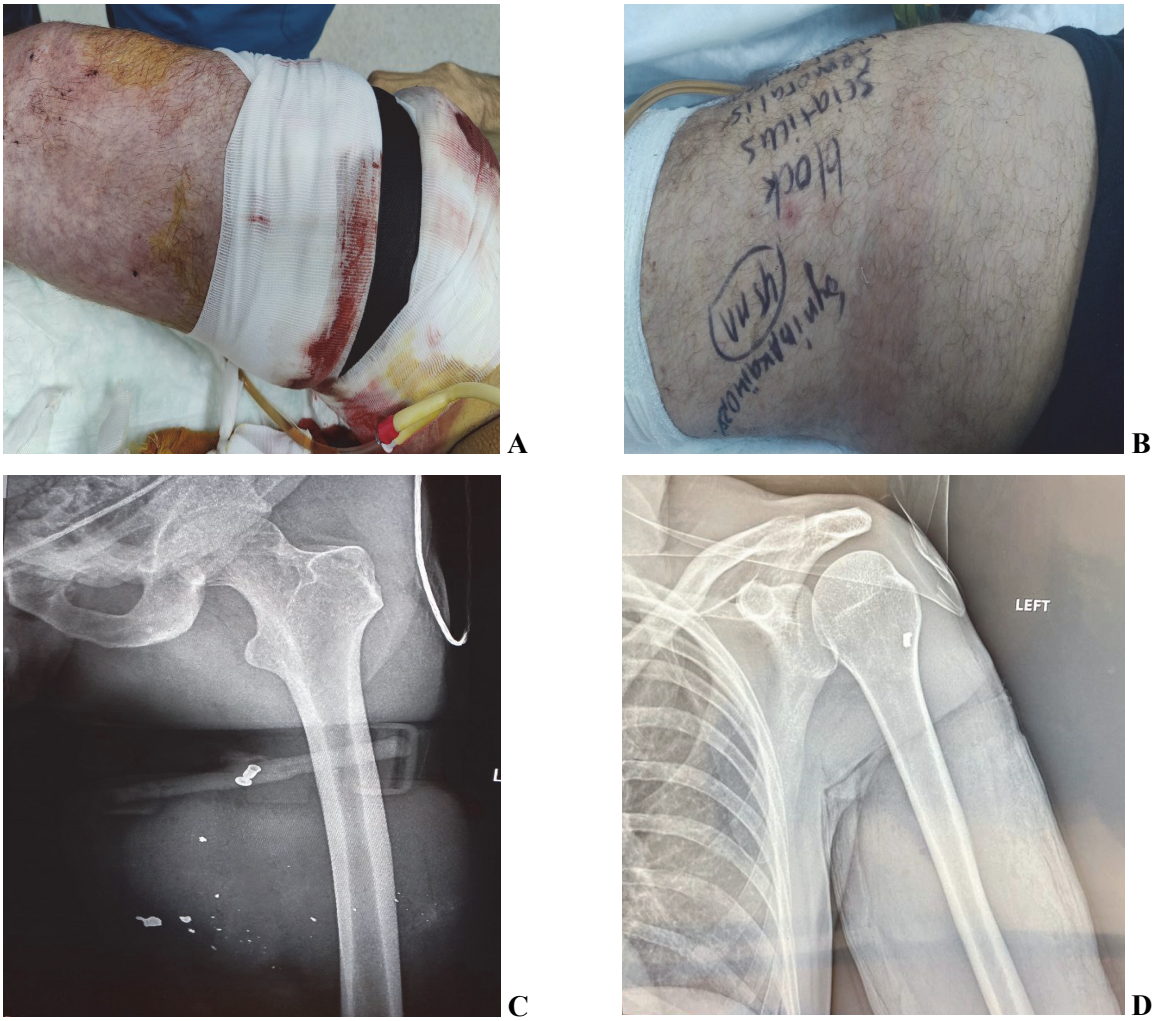

Fig. 1. Visual appearance and X-ray examination of tourrniquet syndrome. **A –** the presence of a tourniquet and bluish skin of the lower extremities at the level of the thigh below the tourniquet. **B –** a hyperemic strip of the skin of the lower limb at the place of the tourniquet. **C –** X-ray signs of tourniquet syndrome at the level of the upper third of the thigh. X-ray density decrease in the form of a circular band. Foreign bodies (metal fragments) of the left thigh soft tissues. **D** – X-ray signs of tourniquet syndrome at the level of the upper third of the shoulder. X-ray density decrease in the form of a circular band. A foreign body (metal fragment) around the head of the humerus soft tissues.

According to the location of the tourniquet, the wounded are distributed as follows: shoulder – 5 (15.6 %), thigh – 24 (75 %), leg – 3 (9.4 %) patients.

All the injured were subjected to biochemical blood analysis for urea, creatinine, creatine phosphokinase-MM using "Respons 920" (Germany), "Lab Analyt" (China), "HumaClot Duo Plus" (Germany), "Labline 40" and "Sunrise" (Austria) devices with additional BIORAD and BIOSAN equipment.

X-rays of the limbs were performed with the help of the complex X-ray diagnostic KRD-50 "INDIASCOP-01" (Ukraine).

For soft tissues ultrasound examination in case of tourniquet syndrome, a "Logiq P8P910" (USA) ultrasound device, with a linear L3-12 p sensor with a frequency of 3-12 MHz, and a shear wave elastography method was used. Elastographic studies were performed as follows: data were measured 12 times on superficial muscle groups, then on deep muscles of the front surface, then on deep muscles of the back surface, on symmetrical areas of a healthy limb. On the shoulder, the muscle was conditionally divided in half and measurements were taken. The mean result after 12 measurements of each muscle group was recorded.

The obtained results were calculated statistically using modern nonparametric and parametric criteria.

Results of the study and their discussion. The lower limb visual appearance in the case of tourniquet syndrome (fig. 1 A, B) and the X-ray data of the limbs with the available tourniquet (fig. 1 C, D) are shown lower.

We can see in details the healthy and affeected extremities muscles elastography registration (fig. 2).

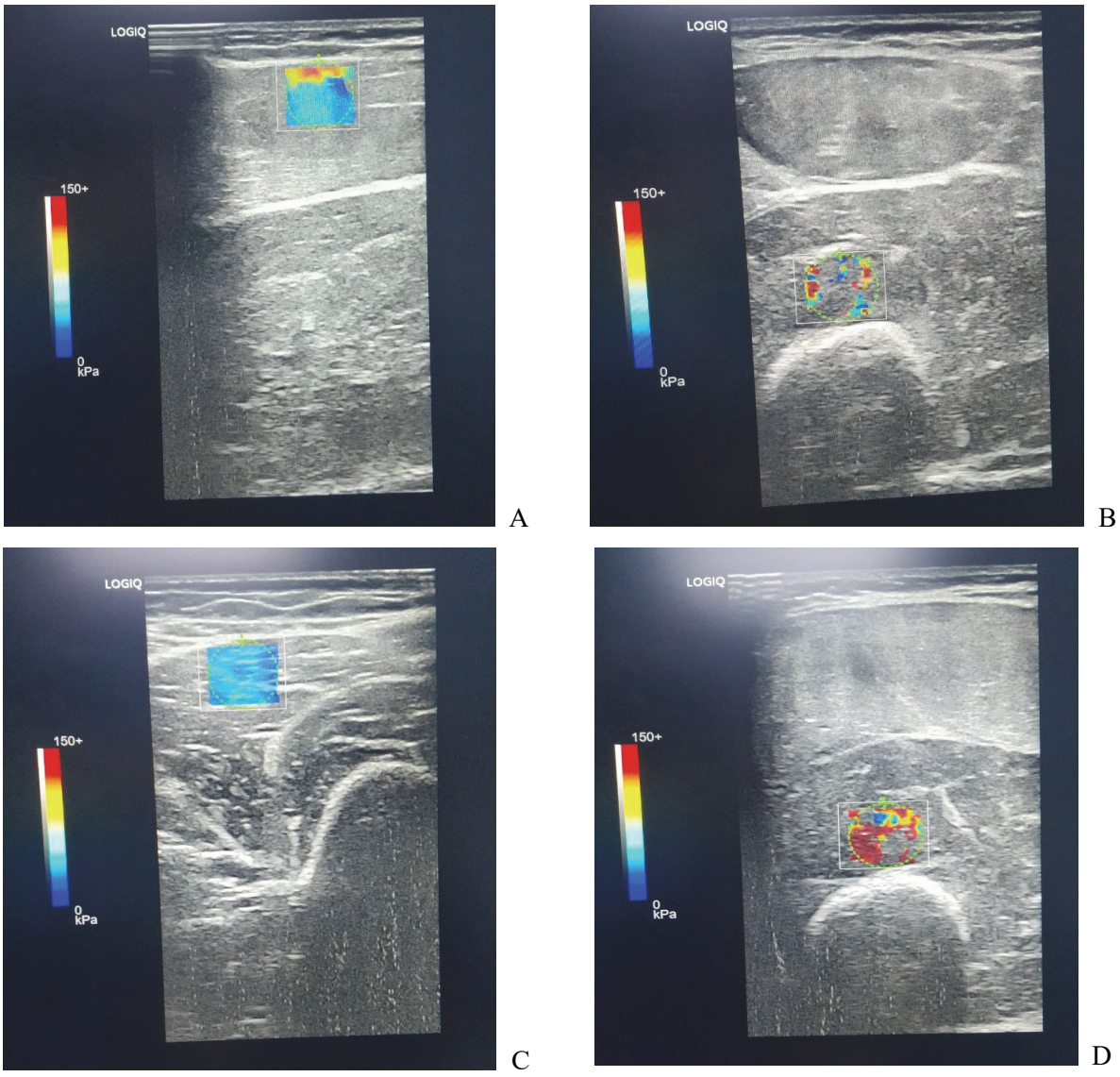

Fig. 2. Ultrasound scans of the thigh superficial and deep muscles soft tissues. A and B – of the affected extremity. C and D – of the contralateral extremity without pathology.

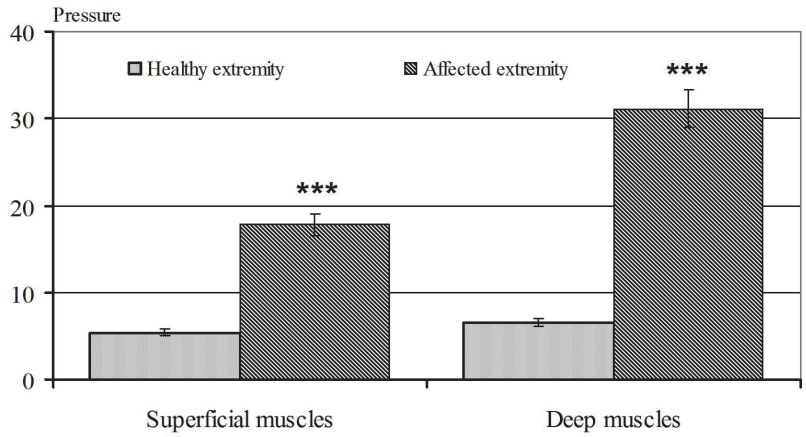

Fig. 3. The data of muscle pressure in healthy and affected extremity registered at elastography

Note: *** – P<0.001 – statistical differences of the investigated parameters compared with the same in healthy extremity (ANOVA + Newmann Keuls criteria)

The changes in muscle elastography are localized by the tourniquet location. We performed muscle elastography in 32 wounded which results evidently show the increase in superficial muscles pressure in 3.3 times in affected extremity vs the same index in healthy extremity ($p<0.001$; fig. 3). One could see those deep muscles pressure in affected extremity registered at muscle elastography in 4.8 times higher vs the same control index in healthy extremity ($p<0.001$).

We saw visually during surgery that muscles are viscid, thickened, pale, do not contract, do not bleed, loose, destroyed by compression, sometimes with hemorrhages (fig. 4).

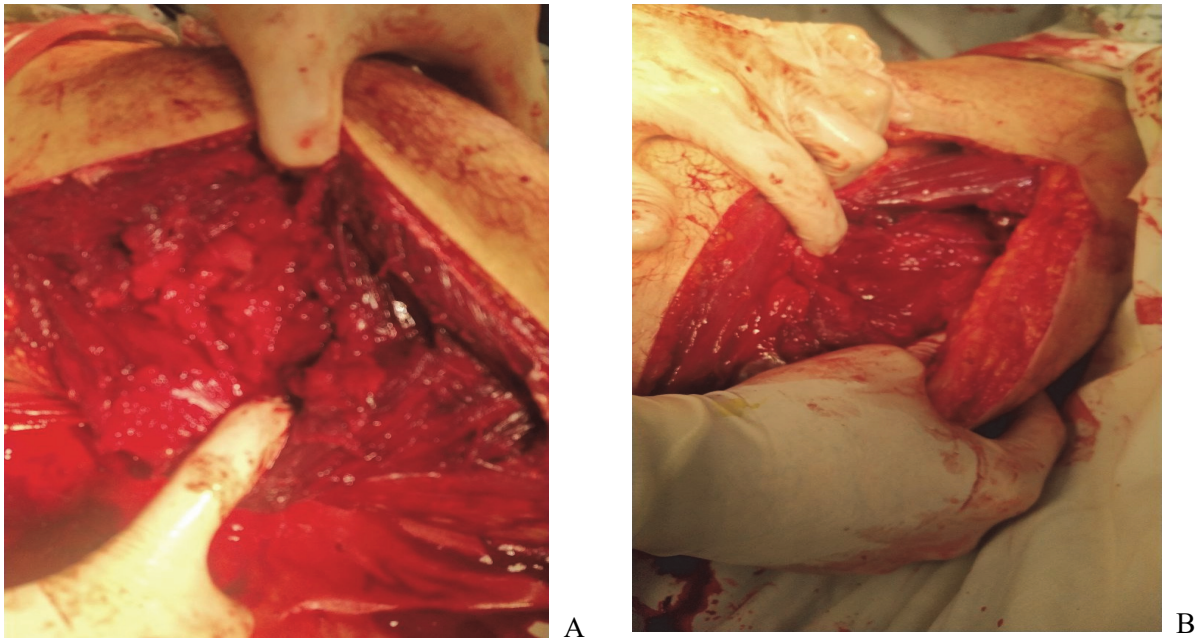

Fig. 4. Intraoperative view of soft tissues during fasciotomy. A – fasciotomy from the thigh lateral surface, muscle revision. B – fasciotomy from the thigh medial surface, muscle revision.

According to the sequence of necrotic changes development inside the soft tissues one could reveal the following their distribution: firstly, pathological changes are observed in the medial group of muscles (especially on the thigh), then they appeared in the deep muscles that are adjacent to the bones, and after all - in the superficial muscles and inside the subcutaneous tissue and skin which are more resistant to compression. These necrotic changes are directly related to the force of compression and the time of tourniquet duration, so they are the amount of soft tissue damage which determined the size of surgical intervention. Therefore, the use of additional methods, i.e. soft tissues ultrasound examination, allows to visualize the soft tissues changes in case of tourniquet syndrome before surgical intervention. It is clear that in this case the surgeon and the operating team will significantly gain time, which significantly improves the results of the surgical intervention with the subsequent positive results of each wounded person restorative treatment and/or rehabilitation.

We also consider the additional use of elastography to determine the volume of affected soft tissues in tourniquet syndrome to be important. The significantly different results were obtained while analyzing the data of elastography of the upper and lower extremities muscles in wounded in the visual absence of pathology in our clinical measurements. The index investigated was less in the upper limbs vs the same in the lower limbs which we suppose is related to both the muscles thickness and load. Elastography data

revealed even higher in sportsmen patients than in the non-exercising patients [14]. These we also analyzed during the elastography data evaluation.

Therefore, the data obtained are in favour of the ultrasound method use reasonability in the wounded with applied tourniquet. It's clear that our proposed and carefully researched the soft tissues ultrasound examination in tourniquet syndrome application has an additional character to the general comprehensive examination of the affected extremity of the wounded. Together with ultrasound examination we considered important the soft tissue elastography in tourniquet syndrome use to determine the extent of soft tissue damage in case of tourniquet application, which is extremely important for saving life and a healthy limb in the future.

With the aim of discussion we allow to judge the main aspects of tourniquet syndrome and ultrasound examination.

Tourniquet syndrome in our clinical observations is more common in lower extremity injuries which are also consistent with known data [7]. Tourniquet is widely used in tactical combat assistance to the wounded militaries despite long misundestandings and controversial concepts of its use in caser of combat trauma. Tourniquet widespread use showed its prominent advantage during the recent military conflicts in Iraq and Afghanistan [4, 10].

Tactical combat assistance to the wounded is performed on the front line, and the leading point for saving the life of the wounded is the blood circulation restoration [3, 12]. A tourniquet is a simple and effective tool for this aim [10]. But despite the real advantages of this procedure, it is important to weigh all the benefits and risks.

The main complications resulting from tourniquet use, in order of frequency, are the following: amputation, compartment syndrome, neurological disorders, vascular thrombosis, muscle necrosis, acute renal failure, acute pain, limb numbness and joint contracture. These complications depend on the tourniquet duration of use. Its use more than 3 hrs increases the frequency of complications and mortality [10].

A compressive-crush injury that occurs in case of a tourniquet incorrect use is characterized by a severe specific traumatic injury in the form of a combination of destruction of limbs' soft tissues, vascular and nervous structures with their prolonged compression, which during reperfusion leads to a critical disorder of hemodynamics and kidney function failure due to endotoxicosis.

A tourniquet use should be accompanied by an affected extremity systematic re-evaluation, especially with long-term use. The frontline medical team should take into account the time of medical evacuation after the use of a tourniquet to reduce the incidence of complications and mortality. Re-evaluation must be performed as early as possible.

The extremities ultrasound examination is performed to estimate the great vessels patency, the presence of nerve damage, and to determine the location of a foreign body in soft tissues [1, 9].

Tourniquet syndrome ultrasound diagnosis has its own peculiarities. When a wounded person is placed with a tourniquet and irreversible ischemia is detected, the tourniquet is not removed from the limb [3, 10]. All changes recorded during muscles ultrasonic monitoring are associated with obvious tissue compression and soft tissues changes under the tourniquet. We should estimate the degree of compression by comparison the data obtained from both the wounded and healthy extremity.

Therefore, taking into account the expressed functional and dynamic changes in the muscles during the tourniquet syndrome and the prevalence of changes in the limbs' deep muscles, we consider the use of ultrasound and elastographic methods of investigation from the diagnostic aim to be fundamentally and clinically justified, since it makes possible to objectify the limbs' soft tissues damage degree in tourniquet syndrome.

Conclusions

1. The frequency of tourniquet syndrome, which most often occurs during the current military situation with injuries of the lower extremities, is 35 %.

2. The tourniquet widespread use leads to a significant number of complications, that's why the diagnostic measures aimed at determining the viability of soft tissues under the tourniquet are gaining high relevance.

3. An ultrasound method of research is reasonable to use in case of tourniquet syndrome from the diagnostic point of view. It allows to visualize the soft tissue changes in case of tourniquet syndrome before surgical intervention. Important that soft tissues ultrasound examination has an additional character to the general comprehensive examination of the injured limb.

4. According to data of soft tissues elastography in the case of tourniquet syndrome, it is possible to determine the degree of soft tissue damage, which is important for determining the size of surgical intervention.

Prospects for further research include a time-dependent postoperative treatment analysis of the extremity's soft tissues' functional state evaluation efficacy under a tourniquet in wounded patients during the process of their restoration or rehabilitative observation. The soft tissues ultrasound and elastographic examination diagnostic value should also be comprehensively assessed to maximize their use during the patients' preoperative examination.

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