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The Effectiveness of Intraoperative Ultrasound Navigation in the Removal of Soft Tissue Foreign Bodies Localized in Areas with Complex Surgical Anatomy After Gunshot Shrapnel Wounds

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RELEVANCE The greatest technical difficulties in the surgical removal of foreign bodies after gunshot shrapnel wounds (GSW) of soft tissues arise when fragments are deeply located near large vessels, nerve trunks, and in the area of the tendon-ligamentous apparatus of the extremities. At the moment, there is practically no information about the possibilities of removing soft tissue fragments localized in areas with complex surgical anatomy using intraoperative ultrasound navigation (IUN).

AIM OF THE STUDY To evaluate the effectiveness of the use of IUN in the removal of soft tissue foreign bodies localized in areas with complex surgical anatomy after GSW.

MATERIAL AND METHODS A comparative analysis of the outcomes of surgical treatment of 74 patients with GSW of soft tissues, in whom foreign bodies were localized in hard-to-reach anatomical zones near large vessels, nerve trunks, as well as in the thickness of the tendon-ligamentous apparatus of the extremities, was carried out. In 26 patients (group 1), foreign bodies were removed by a conventional surgical method. In 5 patients, a C-Arm X-ray machine was additionally used during the conventional procedure. In 48 patients (group 2), foreign bodies were removed using IUN.

RESULTS In 19.2% of group 1 patients, during the conventional surgical intervention, it was not possible to visualize and remove the foreign body. When removing soft tissue foreign bodies under conditions of additional use of X–ray scanning, we noted damage to large nerve trunks in 3 cases, and the intersection of tendons in various limb segments in 1 case. In 38.5% of patients, the operation was performed under anesthesia. The average length of the incision to remove the fragment was 18 cm (14; 21). The average duration of surgery was 150 minutes (90; 210). In group 1, 5 (19.2%) patients developed postoperative wound infectious complications. The average length of hospital stay was 10 days (7; 18). In patients of group 2, the use of IUN made it possible to clearly visualize the foreign body in soft tissues and nearby anatomically important structures, which ensured the safe performance of closed surgical manipulations in the wound during fragment extraction. In those patients, the operation was performed under local anesthesia. A positive result of the intervention (removal of the foreign body) was achieved in all the cases. The average length of the surgical incision was 1.5 cm (0.9; 2.1). The average duration of the intervention is 18 minutes (11; 24). In the 2-nd group of patients, there were no wound infectious complications in the postoperative period. The average length of hospital stay was 4 days (3; 5).

CONCLUSION The use of IUN in the removal of soft tissue foreign bodies localized in hard-to-reach and "dangerous" anatomical areas can significantly increase the effectiveness of surgical treatment of patients with GSW due to clear visualization of all stages of fragment extraction, optimization of surgical access and surgical technique, which significantly reduces the degree of surgical trauma and shortens the duration of surgery.

Keywords: gunshot shrapnel wounds, removal of soft tissue foreign bodies, complex surgical anatomy, intraoperative ultrasound control
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GSW – gunshot shrapnel wounds
IUN – intraoperative ultrasound navigation

INTRODUCTION

Modern local military conflicts are characterized by the widespread use of various explosive munitions with striking elements, the impact of which results in multiple shrapnel wounds of soft tissues in victims. According to statistics, during the military conflict in Donbass, the predominant part was made up of blind gunshot shrapnel wounds (GSWs) of soft tissues of various localizations, the share of which reached 80-85% of the total number of injuries [1]. In these conditions, the main task of the medical service at the stage of providing specialized surgical care is to optimize the methods and techniques of treatment that facilitate the rapid recovery of the wounded after gunshot shrapnel injuries.

The modern doctrine of combat surgical trauma treatment does not provide for primary surgical treatment of wounds in case of multiple small blind non-bleeding shrapnel wounds of soft tissues of any localization. According to the Main Military Medical Directorate of the Ministry of Defense of the Russian Federation, during modern military conflicts, primary surgical treatment of wounds is not indicated for 48% of wounded with soft tissue injuries. In this case, treatment is limited to wound care with subsequent observation of the tissue condition in the damaged area [2]. However, an unremoved fragment left in soft tissues is a risk factor for the development of serious wound infectious complications (including anaerobic infection, as well as secondary bleeding caused by a pressure ulcer, a foreign body, and (or) purulent melting of the vessel wall). In addition, fragments located near nerve trunks and in the thickness of the tendon-ligament apparatus provoke the formation of persistent pain syndrome, and neurological dysfunction of the injured limb [3].

At the same time, during the primary surgical treatment of wounds, it is possible to remove a fragment from soft tissues only in 20% of cases. Therefore, fragments located deep in the thickness of large muscle masses (lumbar region, thigh, buttocks), as well as near the main vessels and nerve trunks (neck, inguinal, popliteal, axillary regions) are often not removed due to the increased risk of surgical intervention, and the high probability of an unsuccessful outcome of the operation [4]. Traditional surgeries for fragment extraction, especially in areas with complex surgical anatomy, in addition to technical difficulties and duration of surgical intervention, are also associated with anesthetic risks due to the administration of anesthesia. With conventional removal of foreign bodies from soft tissues, the percentage of unsuccessful operations ranges from 50 to 80% [5].

In recent years, data have appeared on the removal of soft tissue foreign bodies after GSWs using intraoperative fluoroscopic navigation [6]. However, high radiation exposure to the patient and medical personnel, as well as the lack of verification of radiolucent anatomical structures (vessels, nerves, tendon apparatus, etc.) during surgery significantly hinder the use of this method in everyday surgical practice. There are also some publications on the successful removal of soft tissue foreign bodies (including those not detected radiologically) under the control of intraoperative ultrasound scanning [7, 8]. And yet, at present there is no information at all about the possibilities of removing soft tissue foreign bodies localized in areas with complex surgical anatomy after gunshot fragmentation injuries using continuous intraoperative ultrasound navigation (IUN). Considering the potential of modern ultrasound imaging methods for complex anatomical structures in various soft tissue pathologies, the use of this technology at the stage of providing specialized surgical care to victims with a blind GSW can contribute to a significant improvement in the treatment outcomes for this category of patients.

The aim of the study was to evaluate the effectiveness of the use of IUN in the removal of soft tissue foreign bodies localized in areas with complex surgical anatomy after gunshot shrapnel wounds.

MATERIAL AND METHODS

Since June 2023 to the present, the surgical service of the N.A. Semashko Central City Hospital of the city of Rostov-on-Don has been operating in the hospital mode to provide specialized care to military personnel gunshot shrapnel wounded during the Special Military Operation. During this period, 1,658 victims with soft tissue GSWs of various localizations were treated in the medical facility, which amounted to 81.3% of the total number of wounded admitted.

As a rule, patients were admitted within the first 3 days after receiving the injury. At the time of hospitalization, patients underwent multiplanar radiography and ultrasound scanning with color Doppler mapping of the wound area. All foreign bodies were visualized as metal fragments from exploding shells.

In 74 victims (4.5%) with gunshot wounds to soft tissues, according to ultrasound scanning data, metal fragments were localized in hard-to-reach areas with fairly complex surgical anatomy, which created real technical difficulties if it was necessary to remove them using conventional surgical access. Thus, in 47 patients, the foreign body was located deep in the soft tissues in close proximity to large vessels: in 11 patients - in the area of the femoral vessels (in 8 - in the area of the Hunter's canal, and in 3 - in the inguinal area); in 9 patients - in the area of the shoulder vessels (in 5 patients - the brachial artery in the upper and middle third of the shoulder, in 4 patients - in the area of the brachial veins in the upper third of the shoulder); in 8 patients - in the area of the main vessels of the neck (common carotid artery, internal jugular vein); in 5 patients - in the area of the popliteal artery; in 3 - the axillary vessels, in 3 - in the area of the bifurcation of the brachial artery (in the area of the cubital fossa); in 3 patients - the radial artery (in the middle and upper third of the forearm); in 3 - the posterior tibial artery (in the middle and lower third of the shin); and in 1 patient - the lumbar artery (in the area of its origin from the aorta at the level of the lumbar vertebra L2). In 1 patient, the fragment was located near the facial artery in the area of the excretory duct of the submandibular salivary gland.

In 17 patients, the foreign body was located near large nerve trunks: in 6 patients, in the projection of the median nerve in the middle third of the forearm; in 5 cases - in the area of the deep peroneal nerve in the upper third of the shin; in 3 cases - in the area of the sciatic nerve in the upper third of the thigh; in 3 cases - in the area of the femoral nerve in the groin area.

In 10 patients, the fragments were localized in the area of the tendon-ligament apparatus of the extremities: in 8 patients in the area of the wrist (in 3 - in the sheath of the ulnar synovial bursa, in 5 - in the median palmar space in the thickness of the long flexor tendons of the fingers); in 2 cases - in the thickness of the Achilles tendon in the area of fusion of the gastrocnemius and soleus aponeurosis).

Forty patients had a single fragment in soft tissue, 22 had up to 2–3 fragments within one anatomical region, and 12 patients had multiple residual foreign bodies (more than 10 fragments), including in several anatomical areas. The sizes of foreign bodies varied from 0.2 to 2.5 cm.

The main indication for the removal of foreign bodies from soft tissues was the localization of the fragment in close proximity to important anatomical structures — large vessels and nerve trunks, the tendon-ligament apparatus of the extremities — which created a real threat of their damage with the development of severe complications in the form of bleeding, neurological disorders, and impaired active motor movements of the limbs.

Depending on the method of foreign body removal, all patients were divided into two groups. Group 1 (comparison group) included 26 patients in whom foreign bodies were removed by a conventional surgical method. Of these, in 5 patients, due to the difficulty of finding a foreign body in soft tissues during conventional surgery, a C-arm (the Ziehm 8000 surgical fluoroscopic system) was additionally used to visualize the fragment. Given the small number of clinical

observations of additional use of the C-arm in the removal of soft tissue foreign bodies during conventional surgery, this study did not involve the allocation of a separate group for these patients. The Group 2 (the main group) included 48 patients who had foreign bodies removed from soft tissues under continuous intraoperative ultrasound visualization. The surgical intervention was performed using the RuScan 70P ultrasound diagnostic medical system. The linear high-frequency L12-3E sensor and the convex low-frequency C5-2 sensor were used. A comparative clinical analysis of the treatment outcomes of the patients in the study groups was conducted.

During statistical processing, the data were checked for compliance with the normal distribution based on the Kolmogorov–Smirnov test. The median (Me), 1st (Q1) and 3rd (Q3) quartiles were determined. The Wilcoxon test was used to assess differences between the two samples. Results with p values less than 0.05 were considered statistically significant.

RESULTS

In Group 1, conventional surgical intervention was performed in 10 patients (38.5%) under general anesthesia, in 9 patients (34.6%) — under conduction anesthesia, and in 7 patients (26.9%) — under epidural analgesia. At least two surgeons participated in the surgical intervention. To remove foreign bodies from soft tissues, incisions of 10 to 23 cm (Me – 18 (14; 21) cm) were made. This is stipulated in the methodological section. The duration of the surgical intervention varied from 40 to 280 minutes (Me – 150 (90; 210) minutes).

In Group 1, the surgery was unsuccessful in 5 patients (19.2%): foreign bodies could not be visualized and removed. The surgical intervention was completed by suturing and draining the surgical wound. In 4 patients (15.4%), serious intraoperative complications were observed during the removal of foreign bodies from the soft tissues of the extremities under additional fluoroscopic navigation: the deep peroneal nerve was damaged in 2 patients; the median nerve in the forearm was damaged in 1 patient; and in 1 patient, the tendon of the deep flexor of the second finger of the hand was transected.

In Group 1, 5 patients (19.2%) developed postoperative wound infectious and inflammatory complications that required additional prolonged treatment. In one patient with an unremoved foreign body from the wrist, a bedsore with erosion of the wall of the branch of the deep arterial palmar arch and the formation of a false aneurysm developed. This patient had several recurrent bleedings along the wound channel, which required repeated surgical intervention. In Group 1, the length of hospital stay varied from 7 to 22 days (Me – 10 (7; 18) days).

All the patients of Group 2 underwent surgery under local infiltration anesthesia using constant IUN. In this case, only one surgeon and a surgical nurse participated in the operation. The main surgical instruments used to remove foreign bodies were a Billroth straight serrated clamp and a standard mosquito clamp.

During the surgical intervention using IUN, in all cases, the individual features of the complex topography of foreign bodies in relation to nearby anatomical structures, as well as the absence of a straight wound channel, and the possibility of partial displacement of the fragment relative to the tissues during infiltration anesthesia were taken into account. Particular attention was paid to patients with foreign bodies located in close proximity to major vessels and large nerve trunks; the possible risk of their damage during surgical extraction of fragments was assessed.

To demonstrate the possibilities of IUN in removing soft tissue foreign bodies localized in areas with complex surgical anatomy, we present clinical examples illustrating the specifics of diagnosis and individual stages of extraction of fragments located in close proximity to the main vessels of the neck, upper and lower extremities (Fig. 1–8).

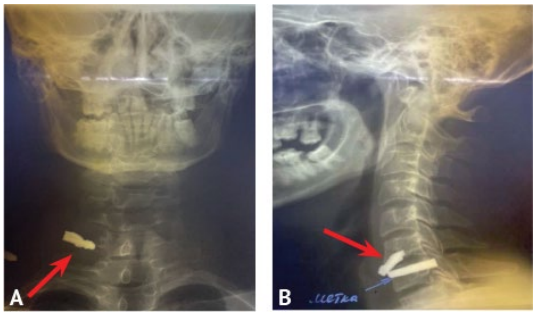

Fig. 1. Radiograph of patient M. with a gunshot shrapnel wound to the soft tissues of the neck. A — direct projection; B — lateral projection with an X-ray topographic marker (indicated by arrow). Foreign body located in the area of the common carotid artery (indicated by arrow)

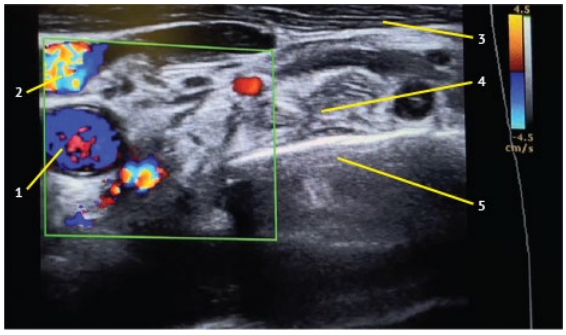

Fig. 2. Ultrasound scan of soft tissues of the neck in color Doppler mapping mode of patient M. with a gunshot shrapnel wound to the neck. Foreign body located in the area of the common carotid artery. Arrows indicate: 1 — common carotid artery; 2 — internal jugular vein; 3 — sternocleidomastoid muscle; 4 — scalene muscles; 5 — foreign body

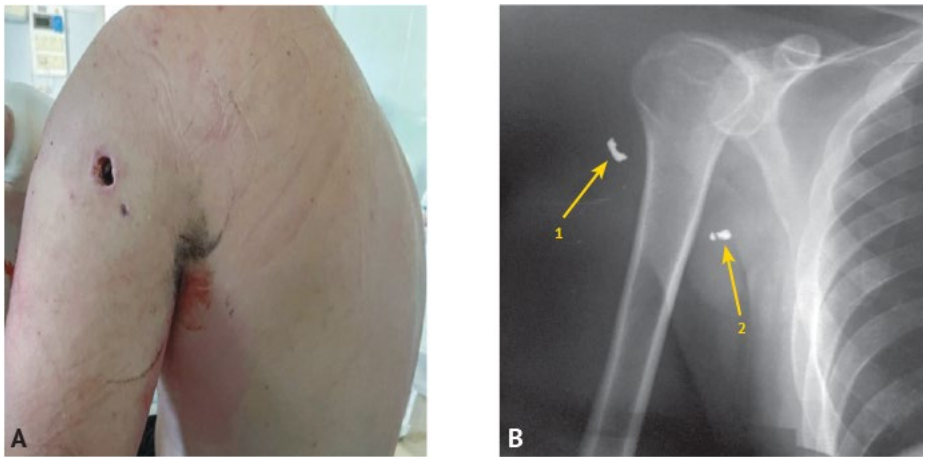

Fig. 3. Patient R. with a gunshot shrapnel wound to the soft tissues of the left shoulder region. A — entrance hole of the gunshot wound; B — radiograph of the left shoulder region (direct projection). Foreign bodies located in soft tissues are indicated by arrows: 1 — in the deltoid muscle; 2 — in the region of the brachial vein

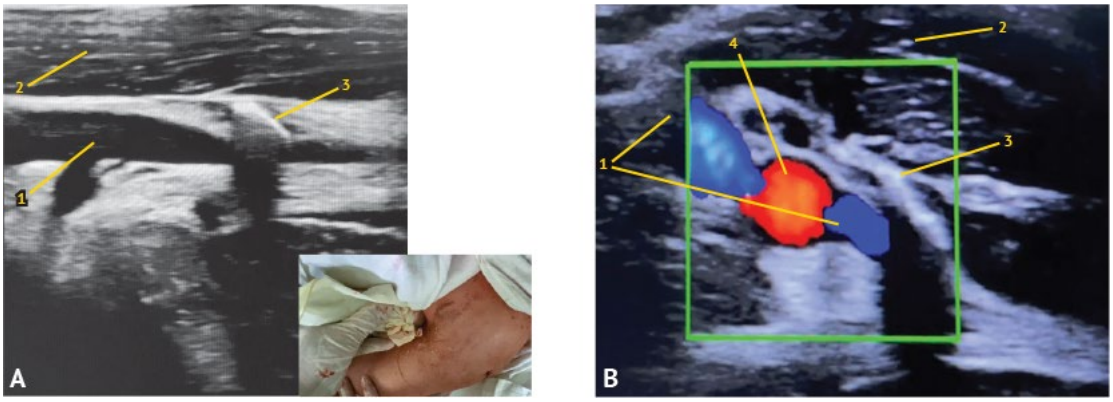

Fig. 4. Ultrasound scan of soft tissues of the left shoulder of patient R. with a gunshot shrapnel wound. A — longitudinal scanning in B-mode; B — transverse scanning in color Doppler mapping mode. Foreign body located in the area of the brachial vein. Arrows indicate: 1 — brachial vein; 2 — biceps brachii; 3 — foreign body; 4 — brachial artery

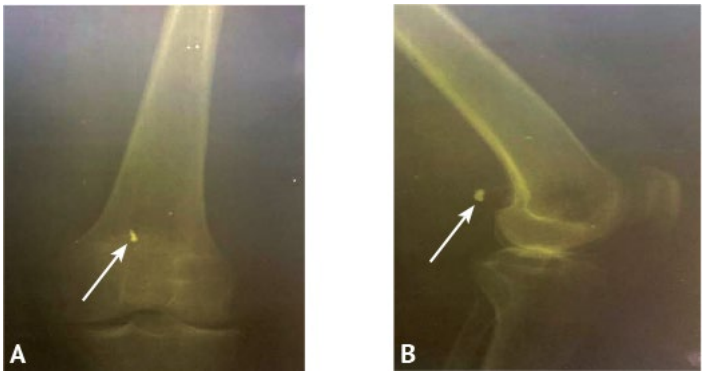

Fig. 5. Radiograph of patient K. with a gunshot shrapnel wound to the soft tissues of the left popliteal region. A — direct projection; B — lateral projection. Foreign body located in the region of the popliteal artery (indicated by arrow)

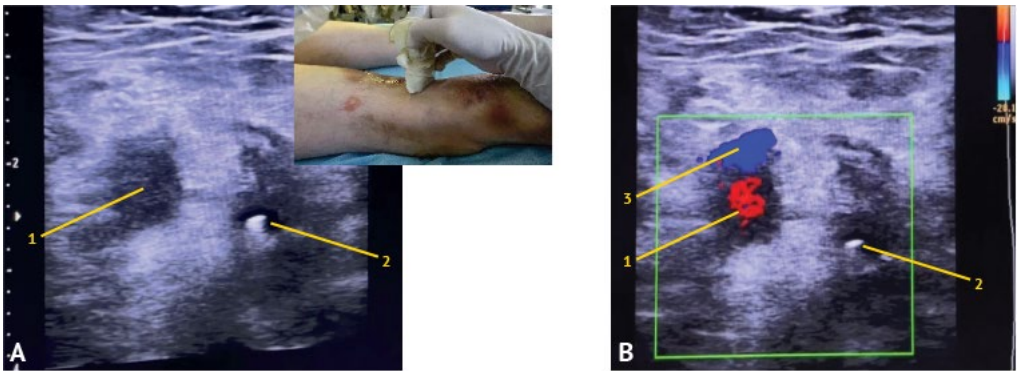

Fig. 6. Ultrasound scan of soft tissues of the left popliteal region of patient K. with a gunshot shrapnel wound. A — longitudinal scanning in B-mode; B — transverse scanning in color Doppler mapping mode. Foreign body located in the area of the popliteal artery. Arrows indicate: 1 — popliteal artery; 2 — foreign body; 3 — popliteal vein

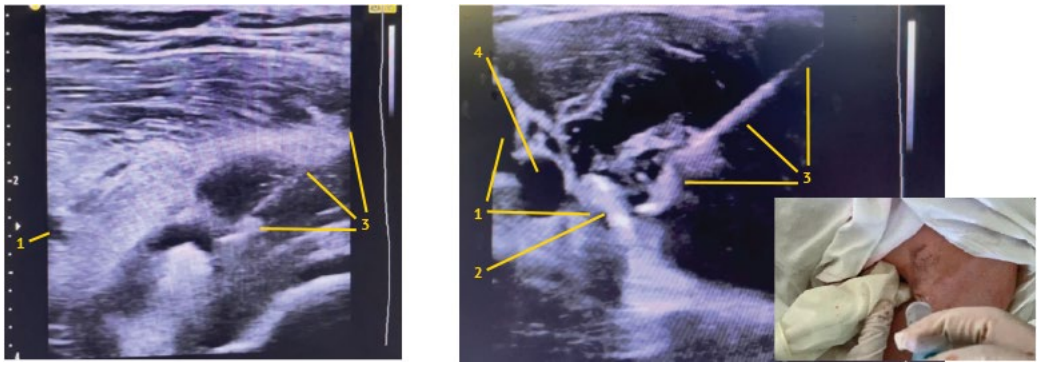

Fig. 7. Ultrasound scan of soft tissues of the left popliteal region (A) and left shoulder (B) of patients with gunshot shrapnel wounds at the stage of local infiltration anesthesia during surgical extraction of foreign bodies located in the area of the main vessels. The arrows indicate: A: 1 — popliteal artery (partially); 2 — foreign body; 3 — injection needle. B: 1 — brachial veins; 2 — foreign body; 3 — injection needle; 4 — brachial arter

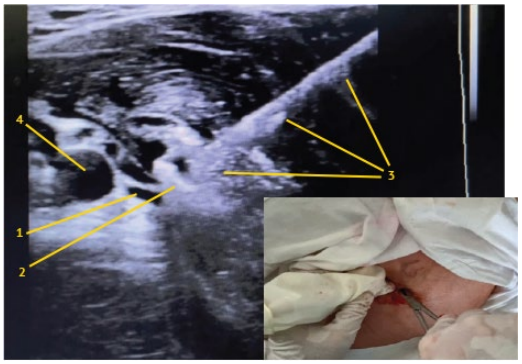

Fig. 8. Ultrasound scan of soft tissues of the left shoulder of patient R. with a gunshot shrapnel wound at the stage of removing the foreign body located in the area of the brachial vein. Arrows indicate: 1 — brachial vein; 2 — foreign body; 3 — clamp branches; 4 — brachial artery

After ultrasound visualization of the foreign body in the soft tissues, it was removed in two ways: through the wound channel with subsequent surgical treatment of the wound or through a separate minimal incision directly above the fragment, since the latter was located at a fairly large distance from the place of its entry into the skin. In this case, the dimensions of the surgical access were, as a rule, comparable with the diameter of the foreign body being removed, and varied from 0.5 to 2.5 cm (Me – 1.5 (0.9; 2.1) cm) (Fig. 9). The duration of the surgical intervention ranged from 3 to 35 minutes (Me – 18 (11; 24) minutes).

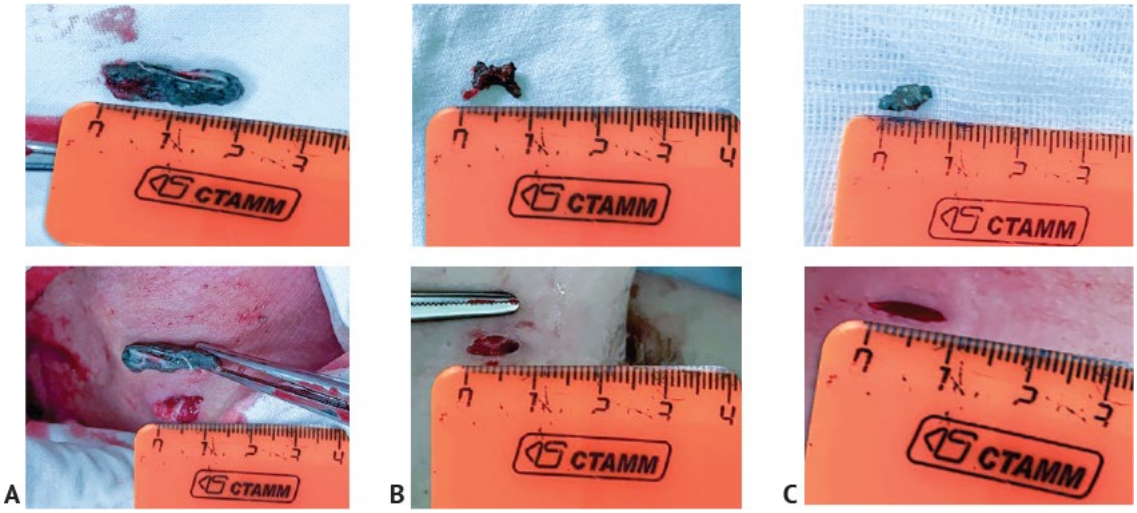

Fig. 9. Top: Removed foreign bodies located in the area of the common carotid artery (A), brachial vein (B), and popliteal artery (C). Bottom: The corresponding surgical approaches used to remove these foreign bodies under intraoperative ultrasound navigation

In Group 2 patients, no wound infectious complications were observed in the postoperative period. All the patients were discharged in satisfactory condition on the 3rd–5th day after surgery (Me – 4 (3; 5) days).

DISCUSSION

The presented data largely reflect a clear evolution of the surgeons' approach to choosing the optimal method for removing foreign bodies from soft tissues in patients with GSWs. This tendency is especially clearly revealed in a comparative analysis of treatment outcomes of patients with soft tissue foreign bodies localized in areas with complex surgical anatomy, using various methods of removing fragments.

The use of conventional surgical techniques without any intraoperative radiation visualization of a foreign body significantly complicated its search in soft tissues; in more than a third of cases it led to the refusal to perform surgery under local anesthesia, and forced to resort to combined anesthesia, inevitably accompanied by an increase in the size and degree of traumatization of the surgical access, and also significantly increased the duration of the intervention. Moreover, in 19.2% of cases, it was not possible to visualize and remove a foreign body from soft tissues, despite a significant expansion of surgical access. Additional use of fluoroscopic navigation using a C-arm during conventional surgical intervention allowed surgeons to improve the technical conditions of its

performance to a certain extent due to intraoperative visualization of the foreign body in soft tissues. At the same time, this method did not allow visualization of radiolucent important anatomical structures, such as large vessels, nerve trunks and tendons, which created a real risk of their damage when performing closed surgical manipulations in the wound during the operation. Thus, in Group 1 patients, during the removal of soft tissue foreign bodies with the additional use of a C-arm, damage to large nerves and tendons on the upper and lower extremities was noted in 4 cases. Moreover, when performing surgical interventions under constant fluoroscopic navigation, there was an additional radiation load on the patient and medical staff.

The high level of trauma and longer duration of surgical intervention in Group 1 patients largely predetermined the development of a fairly large number of postoperative wound infectious complications, which was accompanied by an increase in the length of their hospital stay.

The analysis of the use of IUN in the removal of foreign bodies from soft tissues revealed significant advantages of this method compared to standard techniques, especially in cases of fragments' localization in close proximity to large vessels, nerve trunks and tendon-ligament apparatus. Thus, the use of intraoperative ultrasound scanning in continuous mode during the removal of a foreign body – in contrast to performing this surgical procedure using a C-arm – in addition to the absence of radiation exposure, made it possible to accurately determine the localization of the fragment in soft tissues, and assess its relationship with the surrounding anatomical structures, including blood vessels, nerve trunks and tendons. This helped determine the most optimal surgical approach for removing a foreign body, completely visually control the performance of all closed manipulations with surgical instruments in the wound, which virtually eliminated the risk of damaging anatomically important structures. In all the cases, it was possible to perform surgical intervention under local anesthesia, and minimize surgical trauma by reducing surgical access and significantly shortening the time of surgery. All this allowed Group 2 patients to achieve the desired surgical result (removal of the foreign body), avoid the development of postoperative wound infectious complications, and reduce the length of their hospital stay by 2.5 times compared to Group 1 patients.

CONCLUSION

Our clinical analysis revealed obvious advantages of using intraoperative ultrasound navigation in removing soft tissue foreign bodies in patients with gunshot shrapnel wounds compared to conventional surgery, including a hybrid version of surgery using a C-arm. The greatest advantages of intraoperative ultrasound scanning are revealed when removing soft tissue foreign bodies located near the main vessels, large nerve trunks, as well as tendon-ligament structures of the extremities and not visualized under fluoroscopic control, which create a real risk of damage when performing closed surgical manipulations. The main advantages of using intraoperative ultrasound navigation in the removal of soft tissue foreign bodies compared to conventional surgical intervention include the following:

1) clear visualization of a foreign body relative to radiolucent anatomical structures (vessels, nerve trunks, tendon-ligament apparatus), which allows full control over all closed surgical manipulations in the wound and guarantees their safety;

2) the possibility of performing surgical intervention under local infiltration anesthesia;

3) minimization of surgical trauma due to a significant reduction in the size of the surgical access (1.5 cm versus 18 cm; $p<0.05$), and the duration of the surgical intervention (18 minutes versus 150 minutes; $p<0.05$).

The use of intraoperative ultrasound navigation in the removal of soft tissue foreign bodies localized in areas with complex surgical anatomy after gunshot shrapnel wounds made it possible to completely avoid the development of wound infectious complications, and significantly reduce the length of hospital stay compared to the group of patients who underwent conventional surgery (4 days versus 10 days; $p<0.05$).

FINDINGS

1. In 4.5% of victims with gunshot shrapnel wounds to soft tissues, foreign bodies are localized in areas with a fairly complex surgical anatomy (near large vessels, nerve trunks, as well as in the thickness of the tendon-ligament apparatus), which creates real technical difficulties in the case of their removal by the conventional surgical method. According to ultrasound scanning, such “dangerous” localization of foreign bodies is most often detected in the area of important anatomical structures of the upper and lower extremities, as well as the neck.

2. The use of the conventional surgical method for removing the foreign body localized in a "dangerous" anatomical zone significantly complicates its search in soft tissues, is accompanied by an increase in the size and degree of trauma of the surgical access, and also significantly prolongs operative time. Moreover, in 19.2% of cases, surgical intervention is unsuccessful due to the impossibility of visualizing and removing the foreign body from soft tissues, despite a significant expansion of the surgical access.

3. Additional use of intraoperative fluoroscopic navigation during the conventional surgical intervention does not allow visualization of anatomically important radiolucent structures (vessels, nerve trunks, tendons) located near the foreign body, which significantly increases the risk of their damage during removal of the fragment from soft tissues.

4. Intraoperative ultrasound scanning allows for precise visualization of the foreign body in soft tissues and adjacent anatomical structures (vessels, nerves, tendons), as well as the surgeon's working instruments during surgery, which guarantees the safety of all closed surgical manipulations in the wound during fragment extraction.

5. The use of intraoperative ultrasound navigation in the removal of foreign bodies from soft tissues can significantly increase the effectiveness of surgical treatment of patients with gunshot shrapnel wounds compared to the conventional surgical intervention. A positive result of surgical treatment in this case is achieved, first of all, due to constant and clear ultrasound visualization of all stages of foreign body removal from soft tissues, optimization of surgical access and surgical technique. This notably reduces the degree of trauma of surgical intervention due to a significant reduction in the size of the surgical access (Me - 1.5 cm versus Me - 18 cm; $p < 0.05$) and the duration of surgery (Me - 18 minutes versus Me - 150 minutes; $p < 0.05$).

6. The use of intraoperative ultrasound navigation during the removal of foreign bodies from soft tissues, compared to the conventional surgical intervention, allows avoiding the development of postoperative wound infectious complications, which significantly reduces the hospitalization period for patients with gunshot shrapnel wounds (Me – 4 days versus Me – 10 days; $p<0.05$) and contributes to their faster rehabilitation.

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