UDC 617.586-001.5-089
DOI http://doi.org/10.30978/GS-2025-1-15

ISSN 2786-5584 print
ISSN 2786-5592 online

Treatment of combat injuries to major arteries with extensive soft tissue defects

M. V. Shchepetov[1], K. V. Gumeniuk[1,2]

[1] National Military Medical Clinical Centre «The Main Military Clinical Hospital», Kyiv
[2] Ukrainian Military Medical Academy, Kyiv

✉ Mykola Shchepetov: shchepetov220@gmail.com

M. V. Shchepetov, http://orcid.org/0009-0007-2388-0943
K. V. Gumeniuk, http://orcid.org/0000-0001-8892-4061

Objective – to enhance the treatment outcomes of combat injuries to the lower extremities with damage to major arteries and extensive soft tissue defects by preventing complications and implementing an improved surgical algorithm.

Materials and methods. The study was conducted on a cohort of patients with gunshot and explosive wounds in the femoropopliteal segment of the lower extremities, affecting the major arteries. These patients sustained injuries during combat operations and received treatment at the National Military Medical Clinical Center «Main Military Clinical Hospital» between 2014 and 2024. The cohort was divided into two groups. The main group (n = 29) included patients who underwent treatment using an improved surgical algorithm that involved selective use of methods for extra-anatomic revascularization, ligation of the major arteries (in cases of complications in the reconstruction zone), and active application of rotational fasciocutaneous and muscle flaps to close soft tissue defects in the vascular reconstruction zone. The comparison group (n = 41) included patients who received treatment using standard methods that involved staged surgical debridement, NPWT, and staged wound closure. All patients were males aged between 23 and 57, with gunshot wounds to the lower extremities that caused damage to major arteries and extensive soft tissue defects.

Results. The improved surgical algorithm focused on patients with extensive soft tissue defects in the area of the reconstructed artery (> 100 cm^2), often accompanied by Gustilo-Anderson grade IIIC gunshot fractures. The treatment strategy included the following key components: 1) Early wound closure using rotational fasciocutaneous and muscle flaps to ensure reliable coverage of the neurovascular bundle. 2) Extra-anatomic bypass for complications such as erosion, thrombosis, or progression of infection in the reconstructed artery. 3) Ligation of major arteries followed by active monitoring of limb viability and delayed revascularization when feasible in cases of extra-anatomic vascular restoration failure. The main group (treated using the improved algorithm) had a significantly higher limb preservation rate than the comparison group (treated with conventional methods), with 82.8 % limb preservation and 17.2 % amputations versus 53.7 % limb preservation and 46.3 % amputations, respectively. Statistical analysis using the χ^2-test and Fisher's exact test confirmed the statistical significance of the improved surgical algorithm in amputation reduction rates (χ^2-test 5.16, p = 0.023; Fisher's exact test p = 0.02).

Conclusions. The implementation of an improved surgical algorithm for the treatment of gunshot wounds to major arteries in the lower extremities, accompanied by extensive soft tissue defects, significantly reduced the amputation rate in our study, from 46.3 % to 17.2 % (p = 0.02).

Keywords
gunshot wounds, gunshot and explosive injuries to the arteries of the lower extremities, extra-anatomical bypass surgery, revascularisation of the lower extremities, amputation, limb loss, limb preservation.

ARTICLE • Received 2025-01-25 • Received in revised form 2025-03-09

In modern warfare, the incidence of injuries involving major vascular damage has significantly increased compared to armed conflicts of the first half and middle of the 20th century [4, 8, 22]. According to numerous studies and reports, as well as our observations [4, 7, 10, 11, 22], most combat-related vascular injuries affect the lower extremity arteries, specifically the femoropopliteal segment. While limb salvage rates have improved significantly since previous wars, primarily due to successful arterial repair

at the second level of medical care [11, 22], successful revascularization does not guarantee a complication-free recovery for these severely injured patients. Various authors report complications in reconstructed arteries occurring in 6–30 % of cases [1, 3]. In comparison, secondary amputations after arterial reconstruction for combat-related injuries range from 8.5 % to 38 % [2, 4, 6], with the highest failure rates occurring in the femoropopliteal segment [4, 6]. Among early complications following revascularization for gunshot wounds to the lower limbs, arterial reconstruction failure leading to hemorrhage poses a direct threat to the patient's life, especially at the third and fourth levels of medical care [22]. Additional severe complications include thrombosis in the reconstructed artery and progressive necrosis of muscle groups despite maintained arterial perfusion, which may necessitate timely amputation to prevent acute renal failure [6, 7, 9, 10, 11].

Early research focused on the widespread use of the Mangled Extremity Severity Score (MESS), which was introduced in 1990 to assess extremity injuries and guide amputation decisions. This score initially suggested a near-certain probability of amputation when reaching 7 points or higher. However, recent studies and the European Society for Vascular Surgery (ESVS) 2025 Clinical Practice Guidelines on the Management of Vascular Trauma highlight that advancements in medical technology have diminished MESS's predictive accuracy for amputation [13]. Improvements in vascular reconstruction techniques, enhanced anesthesia and resuscitation protocols, principles of damage control surgery, and advanced fracture fixation methods have all contributed to this development [12]. The primary risk factors for limb loss in combat trauma, as noted by most authors, include the extent of soft tissue damage, the presence of associated gunshot fractures, the severity of compartment syndrome, and the time frame from injury to revascularization [2, 3, 8, 10]. This study aims to focus on this particularly challenging category of injured patients and improve treatment outcomes despite several adverse prognostic factors.

Objective – to enhance the treatment outcomes of combat injuries to the lower extremities with damage to major arteries and extensive soft tissue defects by preventing complications and implementing an improved surgical algorithm.

Materials and methods

We analyzed 209 medical records of patients treated at the National Military Medical Clinical Center «Main Military Clinical Hospital» for lower extremity combat injuries between 2014 and 2024. A cohort of 70 patients was identified as having damage to major arteries in the iliac and femoropopliteal segments, as well as extensive soft tissue defects and associated injuries. Patients were divided into two groups. The main group (Group O) included 29 patients who underwent treatment using an improved surgical algorithm. The comparison group (Group P) included 41 patients who received treatment using standard methods such as repeated staged surgical debridement, NPWT (negative pressure wound therapy), and staged wound closure.

The improved surgical algorithm for treating gunshot and explosive wounds to major arteries with extensive soft tissue defects included (Fig. 1):

1. Prompt use of rotational fasciocutaneous and muscle flaps to cover soft tissue defects in vascular reconstruction areas without viable muscles;

2. Implementation of methods for extra-anatomic revascularization to address complications or substantial contamination in initially reconstructed vessels in original vascular bundle sites.

3. Ligation of the major artery followed by dynamic limb monitoring when extra-anatomic revascularization was not feasible due to complications or its imminent risk. The major artery supply was progressively restored if ischemic tolerance persisted after the active infection was treated. For cases of extensive soft tissue necrosis, especially those involving muscle loss, amputation was recommended.

All patients in the study cohort were males aged between 23 and 57 years. The mean age in the main group was 37.4 ± 11.4 years, while in the comparison group, it was 34.2 ± 8.0 years ($p > 0.05$), indicating no statistically significant difference in age between the groups.

The study included patients with injuries extending from the external iliac artery to the tibioperoneal trunk. All patients presented with extensive soft tissue defects (> 100 cm^2) or Gustilo-Anderson grade IIIC gunshot fractures [10]. The soft tissue defects were deep, involving fascia, muscle, and bone tissue. In the main group, 26 patients had mine-blast or blast injuries, while 3 patients sustained gunshot bullet wounds. In the comparison group, 34 patients had mine-explosion injuries, and 7 had gunshot bullet wounds ($p > 0.05$).

All wounded individuals received staged medical care. At the second level of care (Role II), 70 % (n = 49) of patients had primary reconstructive arterial surgery. At the third level (Role III), 20 % (n = 14) underwent primary surgery on major arteries. At the fourth level (Role IV), 10 % (n = 7) had primary arterial reconstruction. The latter cases were associated with combat operations taking

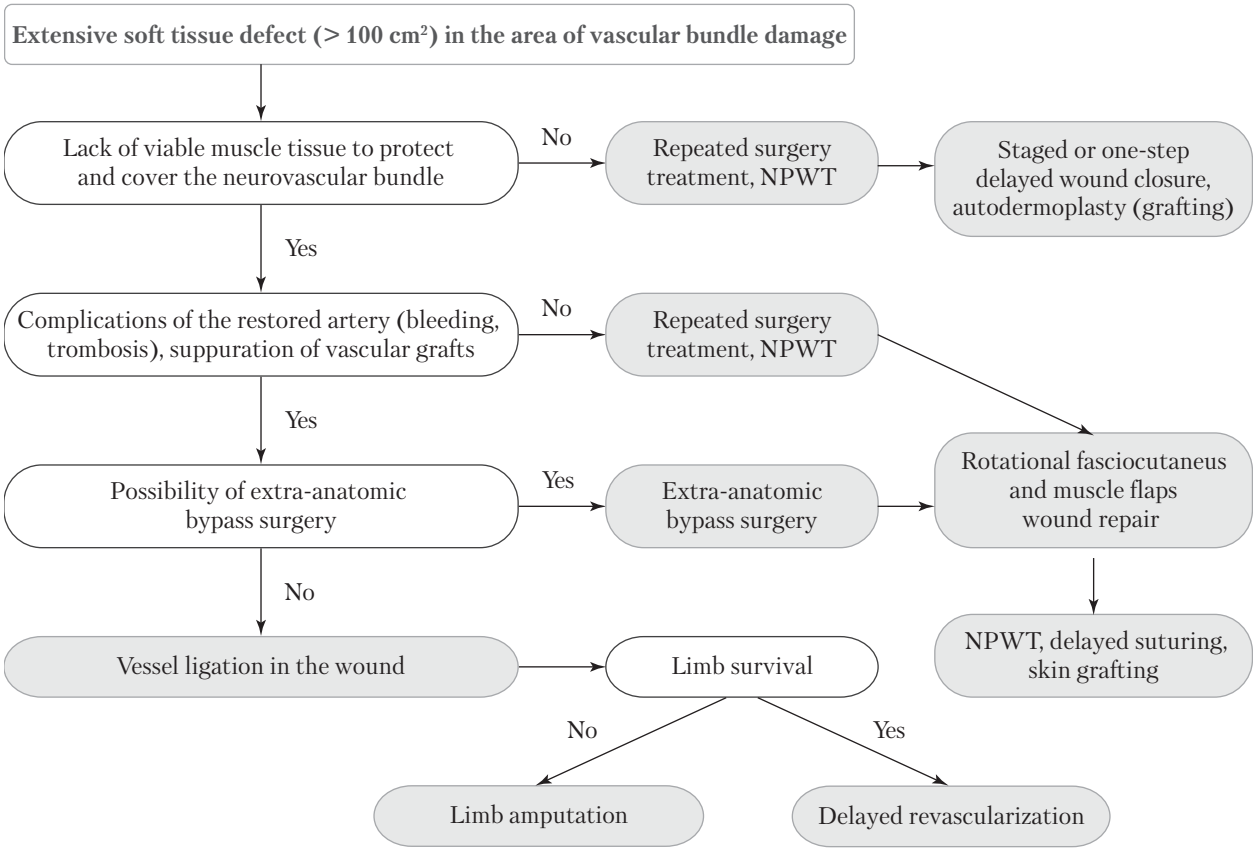


Figure 1. **Improved surgical algorithm for treating gunshot and explosive wounds to major arteries with extensive soft tissue defects**

place near Role IV medical facilities, which provided both second and third-level care. All repeated surgeries on major arteries and reconstructive-plastic interventions were conducted in Role IV medical facilities.

The most frequently affected area was the femoral segment (51 %, n = 36), followed by the popliteal segment (44 %, n = 31) and the external iliac artery (4 %, n = 3).

The study assessed both relative and absolute indicators of injury characteristics, primary and repeated surgical interventions, and treatment outcomes in both groups. The primary outcome measures were limb preservation (positive outcome) and amputation (negative outcome).

Statistical analysis was conducted using IBM SPSS Statistics, Version 22. Descriptive statistics were calculated. Mean values were presented as M ± SD, while relative values were expressed as n (%). A comparison of mean values of quantitative variables was performed using the Mann-Whitney U test or Student's t-test, depending on data distribution. A comparison of relative values was carried out using Pearson's χ^2 test and Fisher's exact test. The null hypothesis was rejected at $p < 0.05$.

Results

The study groups did not statistically differ in terms of the characteristics of gunshot wounds to the lower extremities involving major arteries ($p = 1.0$). The most common associated injuries were major venous damage and gunshot fractures (Table 1).

Table 1. **Characteristics of gunshot and explosive wounds of the lower extremities with damage to the arteries in the main and comparison groups**

Characteristic	Group M (n = 29)	Group C (n = 41)
Concomitant gunshot bone fracture in the area of injury	20 (69.0 %)	27 (65.9 %)
Concomitant damage to the main veins	24 (82.8 %)	34 (82.3 %)
Concomitant damage to the sciatic nerve or its branches	15 (51.7 %)	20 (48.8 %)
Compartment syndrome	26 (89.7 %)	37 (90,2 %)
Acute kidney injury	11 (37.9 %)	13 (31.7 %)
Multiple injury	10 (34.5 %)	16 (39.0 %)

All $p > 0.05$.

There were no significant differences in the primary surgical interventions between the two groups. The most common method for restoring the integrity of the damaged vessel was suturing the defect in the artery. Other methods of revascularization were end-to-end anastomosis and autogenous vein graft repair of the damaged artery. Prosthetic PTFE grafting was not a priority method for revascularization in the femoropopliteal segment. It was primarily used in cases where a suitable great saphenous vein was unavailable or for iliofemoral reconstructions [5, 16].

It is important to note that all patients underwent fasciotomy of the lower leg compartments during the primary arterial reconstruction stage (Table 2).

The structure of secondary surgical interventions varied considerably between the two groups. In the main group (Group M), extra-anatomic bypass was performed in 8 (27.6 %) patients, whereas no such cases were observed in the comparison group (Group C) (p = 0.0014). Additionally, wound reconstruction using muscle flaps, PFAP flaps (Profunda Femoris Artery Perforator), and autografting, was performed significantly more frequently in the main group (Table 3).

At the fourth level (Role 2) of care, additional fasciotomy was performed in 6 cases (20 %) in the main group and in 14 cases (34 %) in the comparison group.

The early closure of exposed arteries in gunshot wounds with viable muscle is well justified, as it directly influences the integrity of the vascular suture [11, 13, 16]. However, within the first week post-injury, achieving such an outcome is often challenging due to extensive wound contamination and the necessity for staged surgical debridement to remove devitalized tissues (Table 4).

Comparison of treatment approaches

Thus, the treatment of patients in the main group differed significantly from that in the comparison group. In the main group, wound closure was performed using rotational muscle flaps (Fig. 2) or fasciocutaneous flaps when an extensive tissue defect was present and it was impossible to cover the vascular bundle with viable muscles after a series of repeated staged surgical debridement combined with NPWT and targeted antibiotic therapy to reduce infection.

Management of complications and extra-anatomic bypass

When it was not possible to rapidly control the infection within the wound or in cases of complications arising from the reconstructed vessels (Fig. 3), the method of extra-anatomic bypass (Fig. 4, 5) was applied to restore blood supply to the limb. This was followed by subsequent staged surgical debridement and closure of the wound defect.

Table 2. **Characteristics of primary surgical interventions**

Type of intervention	Group M (n = 29)	Group C (n = 41)
Autogenous interposition vein grafting	8 (27.6 %)	8 (19.5 %)
PTFE- grafting	2 (6.9 %)	3 (7.3 %)
Arterial suture	9 (31.0 %)	15 (36.6 %)
End-to-end anastomosis	8 (27.6 %)	12 (29.3 %)
Main artery ligation	2 (7.00 %)	3 (7.3 %)
Fasciotomy of the lower leg	29 (100.0 %)	41 (100.0 %)
Bone fracture fixation	20 (69.0 %)	27 (65.9 %)

All p > 0.05.

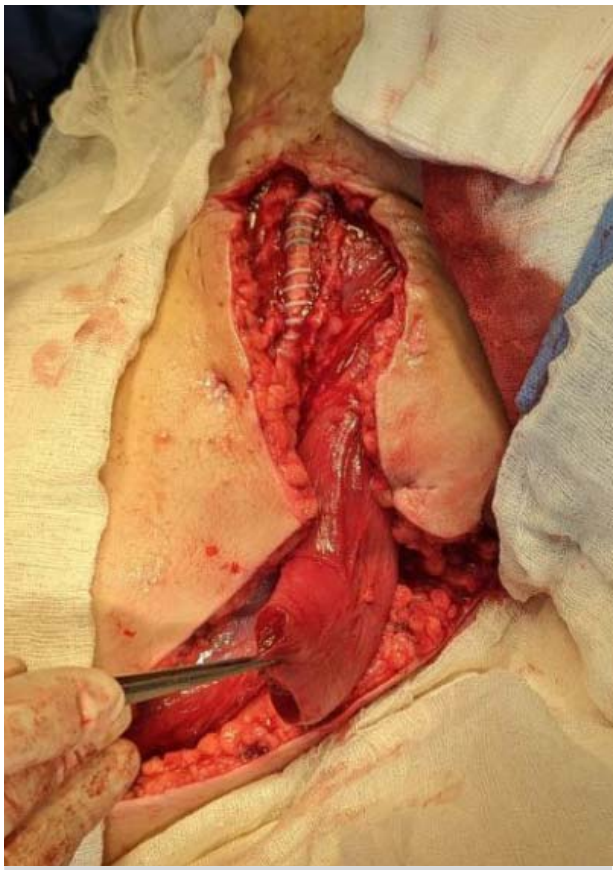
Table 3. **Characteristics of secondary surgical interventions**

Type of intervention	Group M (n = 29)	Group C (n = 41)
Autogenous interposition vein grafting	5 (17.2 %)	12 (29.3 %)
Extra-anatomic bypass	8 (27.6 %)	0*
M. gracilis rotation flap	6 (20.7 %)	2 (4.9 %)
M. gastrocnemius rotation flap	5 (17.2 %)	0*
M. sartorius rotation flap	4 (13.8 %)	0*
PFAP- flap	2 (6.9 %)	0
Main artery ligation	6 (20.7 %)	8 (19.5 %)
Staged repeated surgery treatment, NPWT	29 (100.0 %)	41 (100.0 %)
Wound suturing	11 (37.9 %)	20 (48.8 %)
Skin grafting	17 (58.6 %)	11 (26.8 %)*
Additional fasciotomies	6 (20.7 %)	14 (34.1 %)

The difference from the group M is statistically significant (p < 0.05).

Table 4. **The terms of reconstructive and plastic interventions in the wounded patients from the main group**

Intervention	Time since injury, days		
	4–7	8–11	12–15
Gastrocnemius muscle flap	–	4	1
Gracilis muscle flap	2	3	1
Sartorius muscle flap	1	1	2
PFAP-flap		1	1



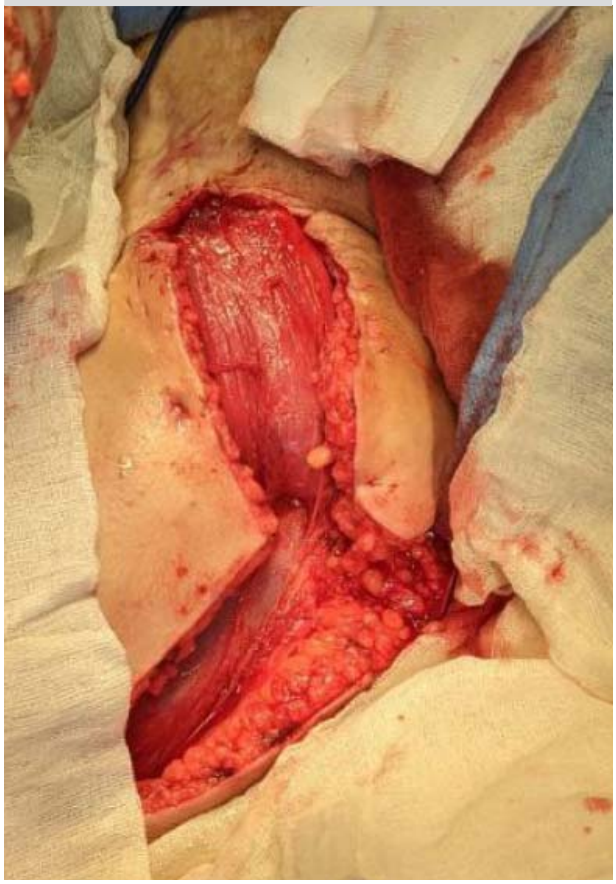


Figure 2. **Coverage of the iliofemoral PTFE-graft in the upper third of the right thigh with a m. gracilis flap**

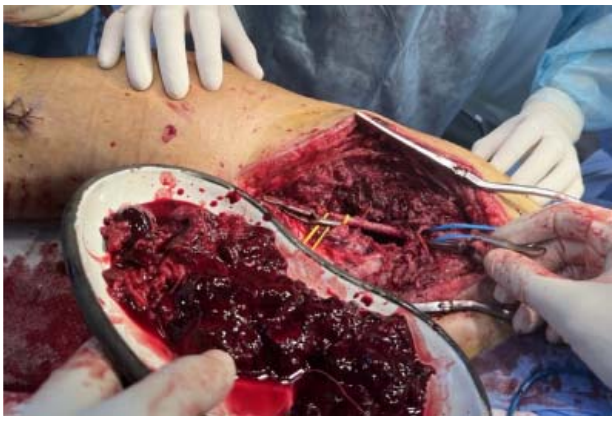


Figure 3. **Erosive bleeding after primary reconstruction from the SFA suture area. The wounded patient sustained an explosive shrapnel injury to the right thigh, causing damage to both the superficial femoral artery and vein. The patient presented with hectic fever, elevated C-reactive protein levels (190–230 mg/L), and a significant left shift in the leukocyte formula. Extensive necrosis of the adductor muscles and partial involvement of m. vastus intermedius were observed in the wound. The artery was exposed and unprotected, located within a purulent-necrotic focus**

Illustrative case and vascular reconstruction technique

For example, Fig. 5 illustrates a treatment stage for a patient in the main group. In this case, a combined injury involving the sigmoid colon and external iliac artery was managed with an extra-anatomic crossover iliofemoral PTFE bypass to prevent contamination of the vascular reconstruction site.

When extra-anatomic bypass was technically unfeasible or in cases of complications involving the reconstructed vessel (Fig. 6, 7) and progressive necrotic-infectious processes in the affected zone, ligation of the major artery (typically the superficial femoral artery in the upper and middle thirds of the thigh) was performed.

Management of arterial ligation and ischemic complications

Surgical interventions involving ligation of major arteries in the femoral segment required careful postoperative monitoring of the patient's condition. If the limb exhibited good tolerance to ischemia, vascular reconstruction was performed on a delayed basis following wound decontamination or even complete healing. However, if ischemia of the distal muscle groups progressed – evidenced by elevated creatine phosphokinase (CPK) levels, increased pain syndrome, and signs of ischemic neuropathy – a decision was made to proceed with limb amputation.

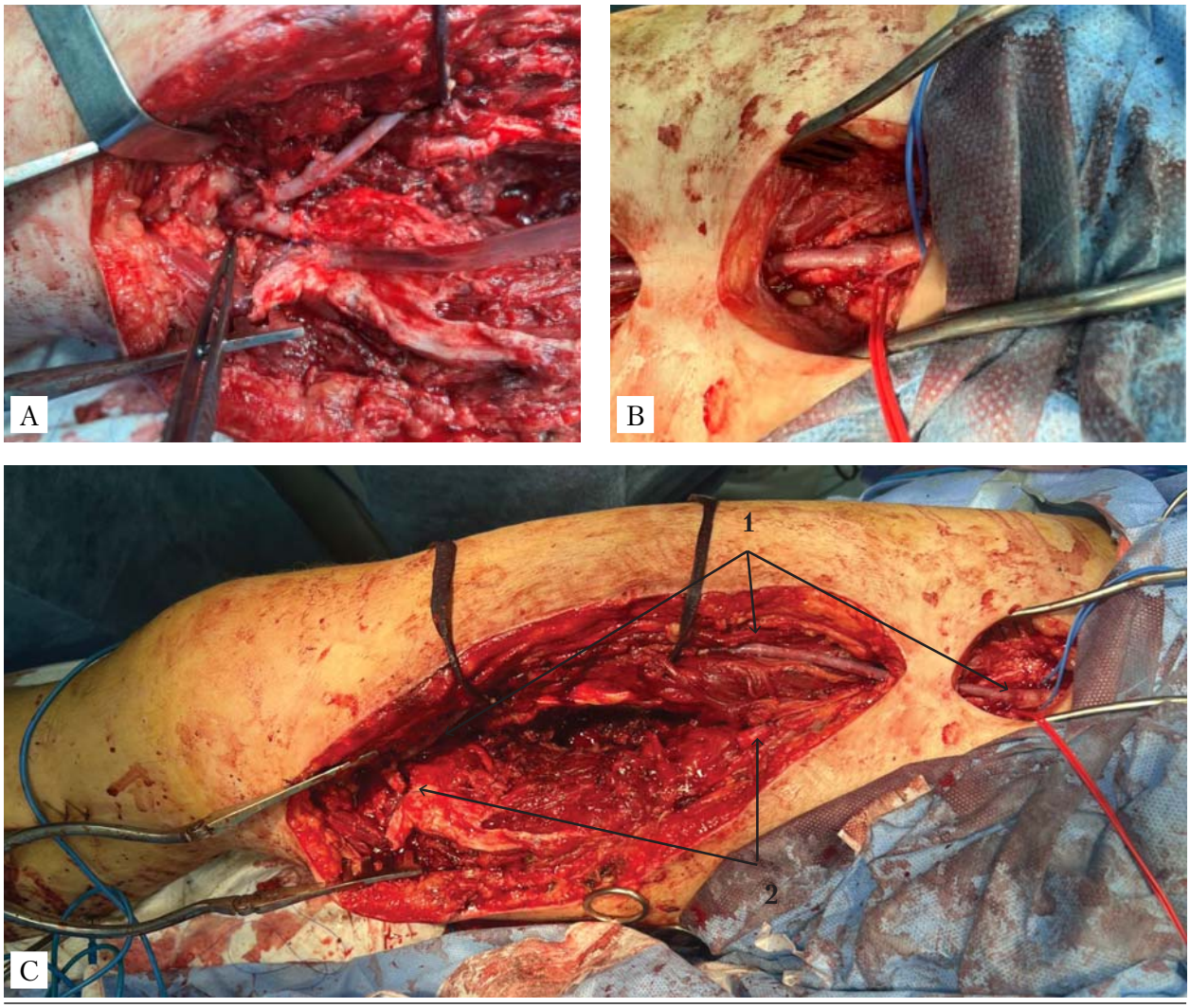


Figure 4. **Restoration of blood flow in the extremity via extra-anatomic femoropopliteal bypass using autogenous vein graft through the space between the rectus femoris and vastus intermedius muscles. The purulent-necrotic area is centrally located after debridement and preparation for NPWT system application.** Distal, above the knee (A), and proximal (B) anastomoses. Extraanatomic femoro-politeal bypass (C): 1 – femoropopliteal bypass; 2 – stumps of the ligated superficial femoral artery

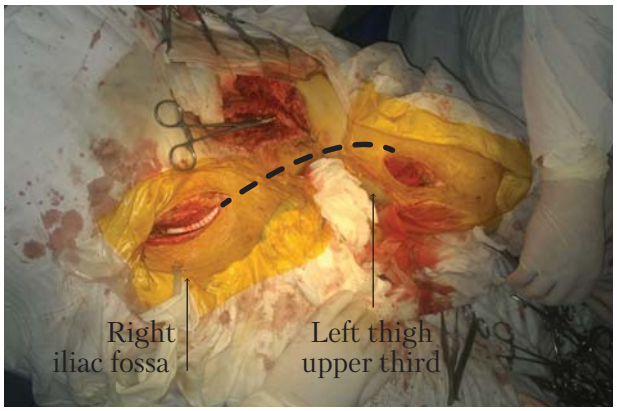


Figure 5. **Injury to the left iliac fossa with damage to the external iliac artery, combined with a penetrating abdominal wound involving the sigmoid colon. Due to failure of the primary ilio-femoral bypass, extra-anatomic crossover ilio-femoral PTFE-bypass was performed from right to left to achieve revascularization.**

Comparison group treatment approach

Patients in the comparison group were managed using staged repeated surgical debridement with NPWT and subsequent staged wound closure. Complications associated with vascular reconstruction, such as erosive bleeding, thrombosis, and progression of necrotic-infectious processes, were treated through repeated arterial defect suturing, bypass with autogenous vein grafts (interposition), thrombectomy, or arterial ligation with continued monitoring. In cases of progressive limb ischemia or recurrent vascular graft erosions, amputation was performed.

It is important to note that both groups initially received empirical antibiotic therapy, which was later adjusted to targeted antibacterial treatment based on bacteriological culture results. The spectrum of wound infection pathogens did not show significant differences between groups ($p > 0.05$, Table 5).

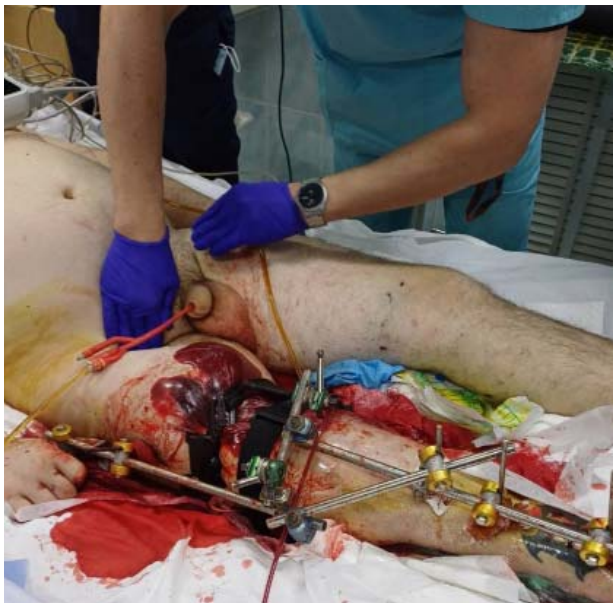


Figure 6. **Erosive bleeding in a patient with an extensive soft tissue defect and a gunshot comminuted femoral fracture on day 8 of treatment following thrombectomy of the superficial femoral artery for post-traumatic thrombosis. NPWT was applied. The hemorrhage occurred due to arterial erosion in the setting of inflammatory changes, distal to the arteriotomy site. Direct compression was applied at the projection of the common femoral artery**

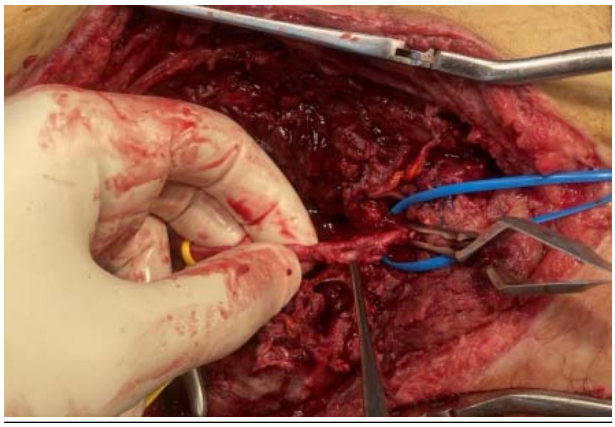


Figure 7. **The forceps indicate the site of vascular suture rupture**

Complications associated with vascular reconstruction

Wounds characterized by extensive soft tissue defects and gunshot fractures carry a high risk of complications involving reconstructed vessels [1, 3, 7, 9]. In both study groups, cases of erosive hemorrhages were observed, resulting from either suture line failure, arterial wall destruction, or graft erosion. Additionally, thrombosis of the reconstructed arterial segment and suppuration of the vascular bundle area were reported.

Table 5. **Characteristics of wounded patients depending on the predominant wound microflora**

Microorganism	Group M (n = 29)	Group C (n = 41)
Klebsiela pneumoniae	17 (58.6 %)	28 (68.3 %)
Acinetobacter spp., *baumanii*	10 (34.5 %)	21 (51.2 %)
Proteus mirabilis	4 (13.8 %)	8 (19.5 %)
Staphlococcus aureus	4 (13.8 %)	1 (2.4 %)
Enterococcus faecium	5 (17.2 %)	6 (14.6 %)
Pseudomonas aeruginosa	9 (31.0 %)	17 (41.4 %)
Staphilococcus haemoliticus (в крові)	5 (17.2 %)	3 (7.3 %)
E. coli	6 (20.7 %)	5 (12.2 %)

All p > 0.05.

Table 6. **Complications of the restored arteries**

Complications	Group M (n = 29)	Group C (n = 41)
Erosive bleeding	5 (17.2 %)	6 (14.6 %)
Reconstruction segment thrombosis	3 (10.3 %)	7 (17.1 %)
Infection, suppuration in the area of restored vessels	11 (37.9 %)	19 (46.3 %)

All p > 0.05.

There were no significant differences in the complication spectrum between Group M and Group C (Table 6).

Complications of vascular reconstruction

In the main group (Group M), the complications associated with reconstructed arteries were as follows: erosive bleeding – 5 cases (see Fig. 6), thrombosis of the reconstructed segment – 3 cases, and infection (suppuration) in the vascular reconstruction area – 11 cases. In the comparison group (Group C), the complications associated with reconstructed arteries were as follows: erosive bleeding – 6 cases, thrombosis of the reconstructed segment – 7 cases (Fig. 8), and infection and suppuration in the reconstructed vascular area – 19 cases.

Secondary amputations peaked in both groups during the second week of treatment (Table 7).

Treatment Outcomes and Statistical Analysis

The treatment outcomes in the main and comparison groups exhibited significant differences (Table 8).

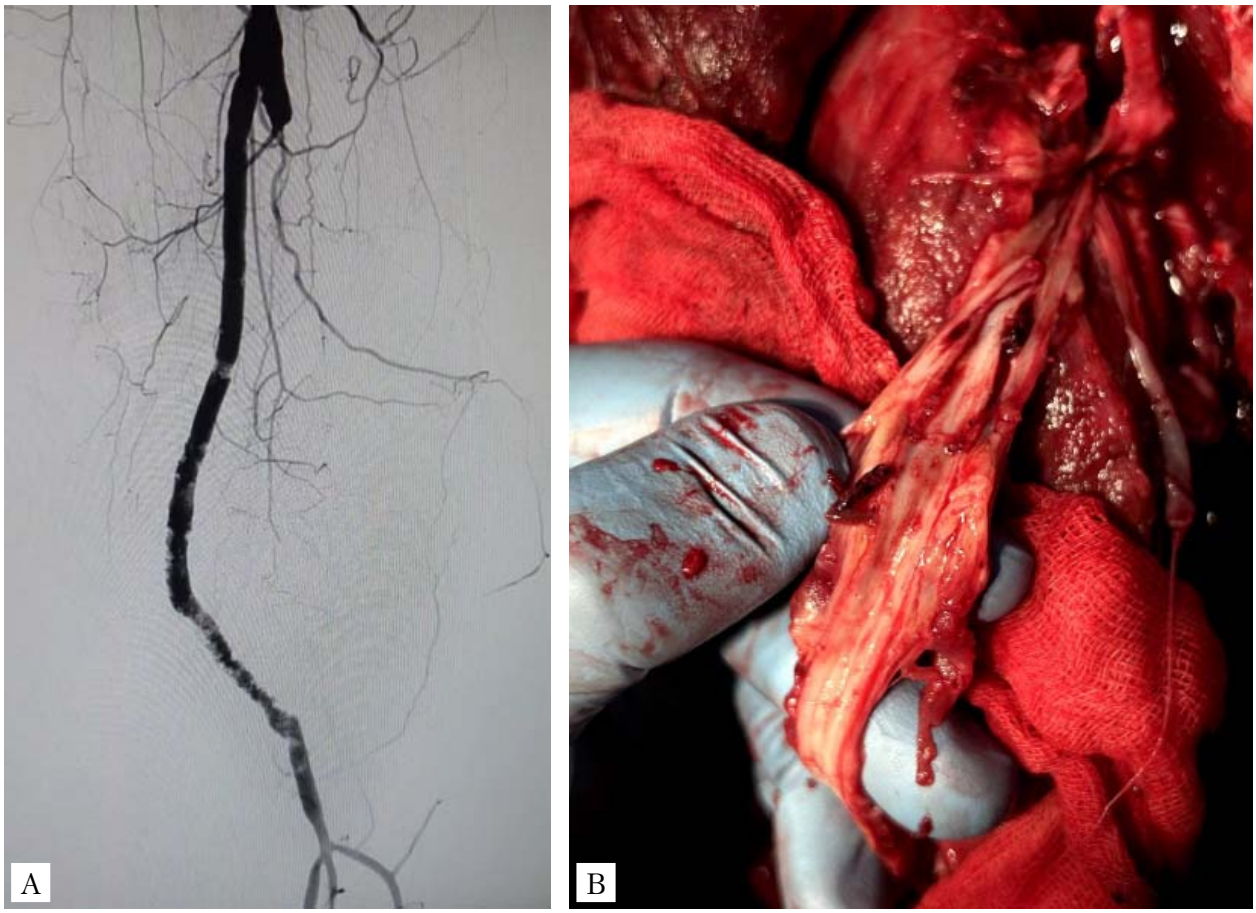


Figure 8. **Recurrent thrombosis of the femoropopliteal bypass using an autogenous vein graft in a patient with an explosive shrapnel wound to the left lower limb involving injury to the distal portion of the superficial femoral artery. Chronology of secondary surgical interventions: 1) GSV graft thrombectomy, 2) re-bypass procedure, 3) thrombectomy, 4) revision of tibial arteries, 5) amputation at the mid-thigh level. Angoigraphic picture GSV graft thrombosis (A). Longitudinally dissected autogenous vein graft with thrombotic masses (B)**

Table 7. **Terms of amputations**

Group	Time since injury, days			
	3–6	7–10	11–14	15–20
Main	–	3	2	–
Comparison	2	8	7	2

Table 8. **Treatment outcomes in the groups**

Treatment outcome	Group M (n = 29)	Group C (n = 41)
Limb preservation	24 (82.8 %)	22 (53.7 %)*
Amputation (within 4 weeks from the start of treatment)	5 (17.2 %)	19 (46.3 %)*
Referred to the orthopedic department after wound healing to change the method of bone fixation	14 (48.3 %)	15 (36.6 %)

The difference from the group M is statistically significant ($p < 0.05$).

The limb preservation rate was significantly higher in the main group, with 17.2 % amputations and 82.8 % limb salvage, compared to the comparison group, where 46.3 % of patients required amputations, leaving only 53.7 % with preserved limbs. Statistical analysis using the χ^2 test and Fisher's exact test demonstrated the statistical significance of the improved surgical algorithm in reducing amputation rates ($\chi^2 = 5.16$; $p = 0.023$; Fisher's exact test, $p = 0.02$).

Discussion

The wounded patients in this study cohort were characterized by extensive soft tissue defects and gunshot fractures. Numerous studies analyzing predictors of poor outcomes in vascular trauma have highlighted the presence of extensive soft tissue defects and concomitant fractures as key factors contributing to higher secondary amputation rates [1, 2, 7, 10]. This study aimed to improve treatment outcomes specifically for this high-risk patient category.

Lauren T. Greer et al. conducted a single-center study on vascular graft failures in combat casualties transferred to a tertiary hospital in the continental United States. The study included patients who had undergone limb vascular reconstruction in Iraq or Afghanistan and later experienced graft rupture. Among 10 secondary complications, 4 (40 %) cases were erosive hemorrhages, which the authors associated with concomitant gunshot fractures, soft tissue defects, and infection [2].

The original MESS (Mangled Extremity Severity Score) study (1990) concluded that a score above 7 strongly predicted the need for amputation. All patients in our study cohort had MESS scores exceeding 7. However, recent studies have shown that advancements in technology have reduced the accuracy of MESS in predicting amputations. This improvement is attributed to modern vascular reconstruction techniques, enhanced resuscitation and anesthesia protocols, and advanced fracture fixation methods [12]. Other studies suggest that while MESS is useful for outcome prediction, it is not sufficiently precise to be relied upon exclusively [11]. Our findings support this view, as all patients in our cohort exceeded a MESS score of 7. We aimed to demonstrate the technical possibilities of limb preservation, following careful evaluation of the patient's general condition and the functional capacity of the preserved limb in the future.

According to literature data, the most common early complications in the treatment of gunshot wounds to the lower limbs with arterial injuries are recurrent thrombosis in the reconstructed segment, accounting for 72–80 % of vascular graft complications [2, 4, 6]. Bleeding due to graft or anastomosis failure are the second most frequent complication. Our study, however, found a higher proportion of secondary hemorrhages (48 % thrombosis vs. 52 % bleedings). The higher rate of hemorrhages may be attributed to infection activity and wound necrosis expansion rather than purely surgical technique limitations. The first one can be both a consequence of imperfect surgical technique and progression of the infectious process in the wound. Secondary bleeding can be caused exclusively by the progression of infection activity and the expansion of necrosis in the radial tissue displacement area produced by the temporary cavity.

In our study cohort, the overall amputation rate was 34 %, with 66 % of limbs preserved. However, it is essential to note that our cohort consisted exclusively of severe injuries with extensive tissue loss and associated trauma. In contrast, Amila Sanjiva Ratnayake et al. analyzed risk factors for failed arterial reconstruction based on data from 129 combat casualties in Sri Lanka, reporting an amputation rate of 20 % following failed vascular reconstruction [1]. Similarly, Robert B. Laverty et al. studied vascular reconstruction outcomes in military trauma, describing secondary amputations in 23 % of patients who had undergone femoropopliteal segment vascular repair [6].

Difficulties in treating these patients arise at the stage when the infectious process actively progresses within the wound, and the vascular bundle or graft is either surrounded by infected tissues or completely exposed over a large area, with no viable tissue available for coverage. This condition significantly increases the risk of multiple complications.

An effective strategy for limb salvage in cases of early complications (such as thrombosis and erosive bleeding) is extra-anatomic bypass. This technique involves placing the vascular graft and anastomoses within relatively healthy tissues, away from necrotic zones [2, 4, 13, 15]. This method is particularly justified in cases where the graft cannot be covered with viable tissues, either due to initial massive soft tissue loss or subsequent extensive necrectomies during wound debridement. Furthermore, placing a graft within the original vascular bundle site becomes impossible when infection-induced hemorrhage develops at the reconstruction site [13, 14]. In such cases, extra-anatomic bypass remains the only viable option for limb salvage [13, 14].

According to David Feliciano, the indications for extra-anatomic shunting in vascular trauma include: 1) extensive soft tissue loss over the injured vessel, 2) incisional infection with blowout of an underlying vascular repair, and 3) simultaneous infections in soft tissue and underlying native vessel secondary to injection of illicit drugs.

For lower limb explosive and gunshot wounds with major arterial injuries, the most commonly performed extra-anatomic bypass procedures include 1) crossover femoro-femoral bypass, 2) ilio-femoral bypass (see Fig. 6, 8), 3) ilio-popliteal bypass through the obturator foramen or lacuna musculorum, 4) femoro-anterior tibial (or peroneal) bypass along the lateral leg surface, and 5) femoropopliteal bypass between the quadriceps muscle layers (see Fig. 5) [13, 14].

However, not all vascular injuries can be managed with extra-anatomic bypass. Extensive soft tissue defects in the popliteal fossa, which prevent coverage of the exposed vascular reconstruction site, pose a major challenge. In such cases, immediate wound closure with musculocutaneous or muscle flaps may prevent limb loss, but only if infection control is concurrently achieved. Conversely, David Feliciano warns against over-reliance on plastic surgery

techniques in such complex injuries, particularly in cases of gunshot wounds or severe infections from illicit intravenous drug use. The combination of extensive vascular damage, soft tissue loss, and deep muscle cavitation complicates reconstruction. Feliciano notes that rotational muscle flaps may be ineffective due to multiple metallic foreign bodies, local edema, and large wound cavities [22].

Limb amputation in cases of vascular reconstruction failure should only be considered after thorough revision of the major arteries, muscle compartments, and the patient's overall condition, particularly when multiple injuries are present [8, 11, 12]. If severe vascular complications render safe revascularization impossible and fasciotomy reveals extensive muscle necrosis, amputation may be required. However, if muscle viability persists and some tissue responsiveness remains, limb salvage should be attempted through continued staged treatment.

In cases of complex polytrauma, such as chest, abdominal, pelvic, or severe cranial injuries, life-saving interventions must take priority over limb preservation. In such scenarios, timely amputation of a severely damaged limb may improve the overall prognosis and redirect trauma recovery towards survival.

Conclusions

The implementation of an improved surgical algorithm for the treatment of gunshot injuries to major arteries in the lower extremities, accompanied by extensive soft tissue defects, significantly reduced the amputation rate in our study, from 46.3 % to 17.2 % ($p = 0.02$).

Declaration of interests

The authors declare that they have no conflicts of interest.

Authors contributions

Conception and design — K. V. Gumeniuk; data collection, critical revision of the article, analysis and interpretation of data, drafting the article – M. V. Shchepetov.

References

1. Гуменюк КВ, Король СО, Гибало РВ. Настанови з військово-польової хірургії. Київ; 2024:470-487.
2. Кутовий ОБ, Люлько ІВ, Сергєєв ОО, та ін. Досвід лікування вогнепальних поранень магістральних судин на етапах евакуації. КЗ «Дніпропетровська обласна клінічна лікарня ім. І. І. Мечникова», ДЗ «Дніпропетровська медична академія МОЗ України». Доповідь на конференції; 2015. Доступно за посиланням: http://repo.dma.dp.ua/id/eprint/324.
3. Лябах АП, Деркач РВ, Костогриз ОА. Шкала MESS при бойовій травмі кінцівок: ампутація чи збереження? Вісник ортопедії, травматології та протезування. 2022;(3):15-20. doi: 10.37647/0132-2486-2022-114-3-15-20.
4. Роговський ВМ, Віхляєв СМ, Коваль БМ, Родіонов ОС, Щепетов МВ, Борківець ОМ, Голінко ВМ. Досвід виконання екстраанатомічних шунтувань при гнійно-некротичних ускладненнях після реконструктивних операцій на магістральних артеріях. Проблеми військової охорони здоров'я. Київ; с.399-402.
5. Роговський ВМ, Щепетов МВ. Лікування вогнепальних поранень магістральних артерій. Київ: Книга плюс; 2022:119. ISBN:978-966-460-153-2.
6. Тертишний С, Хоменко І, Гуменюк К, Король С, Цема Є, Дубенко Д, Михайлусов Р, Гринчук М, Попова О. Метааналіз класифікацій дефектів м'яких тканин та обґрунтування оптимального об'єму та методу хірургічної реконструкції. Ukrainian Scientific Medical Youth Journal. 2021;(1(121)):112-123. doi: 10.32345/USMYJ.1.2021.112-123.
7. Щепетов МВ. Причини незадовільних результатів лікування вогнепальних поранень магістральних артерій кінцівок. Хірургія України. 2019;(3):38-45. doi: 10.30978/SU2019-3-38.
8. Almadwahi NY, Al-Hodiafy HZ, Al-Shuja'a MA, Alammari SA, Jowah HM. Penetrating Femoropopliteal Vascular Damage in Yemen War: Prompt Management. Results and Risk Variables for Limb Loss and Mortality. Mathews J Surg. 2024. 7(1):26. doi: 10.30654/MJS.10026.
9. Barros D'Sa AA, Harkin DW, Blair PH, Hood JM, McIlrath E. The Belfast approach to managing complex lower limb vascular injuries. Eur J Vasc Endovasc Surg. 2006 Sep;32(3):246-56. doi: 10.1016/j.ejvs.2006.02.004. Epub 2006 Apr 18.
10. Brown KV, Ramasamy A, Tai N, MacLeod J, Midwinter M, Clasper JC. Complications of extremity vascular injuries in conflict. J Trauma. 2009 Apr;66(suppl. 4):S145-9. doi: 10.1097/TA.0b013e31819cdd82. PMID: 19359958.
11. Feliciano DV. Pitfalls in the management of peripheral vascular injuries. Trauma Surg Acute Care Open. 2017 Aug 28;2(1):e000110. doi: 10.1136/tsaco-2017-000110. PMID: 29766105; PMCID: PMC5877918.
12. Greer LT, Patel B, Via KC, Bowman JN, Weber MA, Fox CJ. Management of secondary hemorrhage from early graft failure in military extremity wounds. J Trauma Acute Care Surg. 2012 Oct;73(4):818-24. doi: 10.1097/TA.0b013e3182587f32. PMID: 22835998..1097/TA.0b013e3182587f32.
13. Hafez HM, Woolgar J, Robbs JV. Lower extremity arterial injury: results of 550 cases and review of risk factors associated with limb loss. J Vasc Surg. 2001 Jun;33(6):1212-9. doi: 10.1067/mva.2001.113982. PMID: 11389420.
14. Jawas A, Abbas AK, Nazzal M, Albader M, Abu-Zidan FM. Management of war-related vascular injuries: experience from the second gulf war. World J Emerg Surg. 2013 Jul 1;8(1):22. doi: 10.1186/1749-7922-8-22. PMID: 23816260; PMCID: PMC3700839.
15. Laverty RB, Brock SG, Walters TJ, Kauvar DS. Outcomes of Arterial Grafts for the Reconstruction of Military Lower Extremity Arterial Injuries. Ann Vasc Surg. 2021 Oct;76:59-65. doi: 10.1016/j.avsg.2021.03.006. Epub 2021 Apr 5. PMID: 33831531.
16. Loja MN, Sammann A, DuBose J, Li CS, Liu Y, Savage S, Scalea T, Holcomb JB, Rasmussen TE, Knudson MM; AAST PROOVIT Study Group. The mangled extremity score and amputation: Time for a revision. J Trauma Acute Care Surg. 2017 Mar;82(3):518-523. doi: 10.1097/TA.0000000000001339.
17. O'Sullivan ST, O'Sullivan M, Pasha N, O'Shaughnessy M, O'Connor TP. Is it possible to predict limb viability in complex Gustilo IIIB and IIIC tibial fractures? A comparison of two predictive indices. Injury. 1997 Nov-Dec;28(9-10):639-42. doi: 10.1016/s0020-1383(97)00134-4. PMID: 9624343.
18. Ratnayake AS, Bala M, Howard R, Rajapakse K, Samarasinghe B, Worlton TJ. Identification of risk factors for arterial repair failures and lessons learned: Experiences from managing 129 combat vascular extremity wounds in the Sri Lankan War. J Trauma Acute Care Surg. 2019 Jul;87(1S Suppl 1):S178-S183. doi: 10.1097/TA.0000000000002260. PMID: 31246924.
19. Sharrock AE, Tai N, Perkins Z, White JM, Remick KN, Rickard RF, Rasmussen TE. Management and outcome of 597 wartime penetrating lower extremity arterial injuries from an international military cohort. J Vasc Surg. 2019 Jul;70(1):224-232. doi: 10.1016/j.jvs.2018.11.024. Epub 2019 Feb 18. PMID: 30786987.
20. Stain SC, Weaver FA, Yellin AE. Extra-anatomic bypass of failed traumatic arterial repairs. J Trauma. 1991 Apr;31(4):575-8. doi: 10.1097/00005373-199104000-00019. PMID: 2020044.
21. Wahlgren CM, Aylwin C, Davenport RA, et al.; Document Reviewers; Blair P, Civil IDS, Engelhardt M, Mitchell EL, Piffaretti G, Wipper S. Editor's Choice – European Society for Vascular Surgery (ESVS) 2025 Clinical Practice Guidelines on the Management of Vascular Trauma. Eur J Vasc Endovasc Surg. 2025 Feb;69(2):179-237. doi: 10.1016/j.ejvs.2024.12.018. Epub 2025 Jan 13.
22. Woodward EB, Clouse WD, Eliason JL, Peck MA, Bowser AN, Cox MW, Jones WT, Rasmussen TE. Penetrating femoropopliteal injury during modern warfare: experience of the Balad Vascular Registry. J Vasc Surg. 2008 Jun;47(6):1259-64; discussion 1264-5. doi: 10.1016/j.jvs.2008.01.052. Epub 2008 Apr 14.

Лікування вогнепальних поранень магістральних артерій із масивними дефектами м'яких тканин

М. В. Щепетов [1], К. В. Гуменюк [1, 2]

[1] Національний військово-медичний клінічний центр «Головний військовий клінічний госпіталь», Київ

[2] Українська військово-медична академія, кафедра військової хірургії, Київ

Мета — поліпшити результати лікування вогнепальних поранень нижніх кінцівок із ушкодженням магістральних артерій і масивними дефектами м'яких тканин шляхом профілактики ускладнень та впровадження активної хірургічної тактики за вдосконаленим алгоритмом.

Матеріали та методи. Проведено аналіз когорти пацієнтів із вогнепальними пораненнями стегново-підколінного сегмента нижніх кінцівок із пошкодженням магістральних артерій і великим дефектом м'яких тканин, які отримали поранення в результаті бойових дій та проходили лікування в Національному військово-медичному клінічному центрі «Головний військовий клінічний госпіталь» у 2014—2024 рр. Пацієнтів розподілили на дві групи. В основній групі (n = 29) пацієнтів лікували з використанням удосконаленого хірургічного алгоритму (з вибірковим застосуванням екстраанатомічних методів відновлення кровотоку, перев'язки магістральних артерій (зона реконструкції яких мала ускладнення) і активним використанням ротаційних шкірно-фасціальних та м'язових клаптів для закриття дефектів м'яких тканин у зоні судинної реконструкції), у групі порівняння (n = 41) пацієнти отримували лікування за стандартною методикою (етапні хірургічні обробки, NPWT-терапія, етапне ушивання ран). Усі пацієнти — чоловіки віком від 23 до 57 років.

Результати. Основними принципами вдосконаленого алгоритму є відбір пацієнтів із масивним дефектом м'яких тканин у зоні відновленої артерії (> 100 см^2), зокрема із супутнім вогнепальним переломом кістки IIIc типу за класифікацією Gustilo-Anderson, якомога раніше закриття рани з використанням ротаційних шкірно-фасціальних і м'язових клаптів, що забезпечує надійне укриття судинно-нервового пучка, при ускладненнях у відновленій артерії (арозія, тромбоз, прогресування інфекційного процесу) — застосування методів екстраанатомічного шунтування, за неможливості екстраанатомічного відновлення кровопостачання — перев'язка магістральної артерії з динамічним спостереженням за станом кінцівки і пацієнта. При задовільній толерантності до ішемії після завершення активного інфекційного процесу — відтерміноване відновлення магістрального кровопостачання, при прогресуванні ішемії на тлі лігованої артерії та загибелі м'язів — ампутація кінцівки. Установлено, що частота збереження кінцівки була значно вищою в основній групі: 17,2 % ампутацій і 82,8 % збережених кінцівок, тоді як у групі порівняння — 46,3 та 53,7 % відповідно. Статистичний аналіз отриманих даних виявив статистичну значущість удосконаленого алгоритму хірургічного лікування цієї когорти поранених для збереження кінцівок ($\chi^2 = 5{,}16$; $p = 0{,}023$, точний тест Фішера $p = 0{,}02$).

Висновки. Упровадження вдосконаленого хірургічного алгоритму в лікування вогнепальних поранень магістральних артерій нижніх кінцівок із масивними дефектами м'яких тканин дало змогу знизити частоту ампутацій при цих тяжких видах бойової травми з 46,3 до 17,2 % ($p = 0{,}02$).

Ключові слова: вогнепальні поранення, вогнепальні та вибухові пошкодження артерій нижніх кінцівок, екстраанатомічне шунтування, реваскуляризація нижніх кінцівок, ампутація, втрата кінцівок, збереження кінцівок.

FOR CITATION

Shchepetov M.V., Gumeniuk K.V. Treatment of combat injuries to major arteries with extensive soft tissue defects. General Surgery (Ukraine). 2025; (1); 15-25. http://doi.org/10.30978/GS-2025-1-15.