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Endovascular interventions in technically challenging cases of post traumatic aneurysms and arteriovenous fistulas of limb arteries. Clinical cases

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Objective – to analyze current scientific data on the role of endovascular interventions in the management of technically challenging post-traumatic pseudoaneurysms (PTPA) and arteriovenous fistulas (AVF) of major extremity vessels resulting from gunshot wounds; to define the indications, benefits, and limitations of minimally invasive methods; to justify their role within hybrid strategies in comparison with conventional open reconstructions; and to present our case series of successful clinical observations.

Materials and methods. A systematic analysis of specialized literature dedicated to major extremity vessel injuries and their delayed complications was conducted. The review covers the experience of armed conflicts spanning from World War II to modern operations in Iraq and Afghanistan. We analyzed fundamental works (DeBakey, Rich), data from the Vietnam Vascular Registry involving 558 post-traumatic lesions, as well as contemporary epidemiological and multicenter studies (White, Clouse, DuBose) that highlight outcomes of endovascular management for vascular trauma. Special attention was paid to the comparative analysis of treatment strategies in anatomically complex (junctional) zones, where open surgery is associated with high operative trauma and increased risk of iatrogenic injuries.

Results. It was established that PTPAs and AVFs account for approximately 7 % of all vascular injuries within the structure of combat trauma. Open reconstruction (resection with autogenous vein grafting) remains the priority for contaminated wounds, infected PTPAs, and lesions located within flexion zones in young patients. It was found that in proximal segments not affected by infection, covered stent-graft implantation achieves a technical success rate of over 90 %, thereby radically minimizing dissection volume in anatomically complex zones. Embolization is positioned as an effective method for isolating branch lesions and providing adjuvant support for stenting. The main limitations of the endovascular approach include the risk of stent fracture in highly mobile segments and insufficient fixation zones. The feasibility of hybrid strategies in chronic high-flow AVFs with pronounced venous transformation is emphasized. The presented case series confirms the efficacy of the chosen algorithms in treating the consequences of gunshot wounds in both short- and mid-term periods.

Conclusions. Endovascular technologies are not a complete alternative to open vascular surgery, but they significantly expand the tactical arsenal in the management of extremity PTPAs and AVFs, particularly in cases of anatomically unfavorable lesion localization and high operative risk. The use of covered stent-grafts and selective embolization methods, with careful patient selection, ensures high technical success and stable clinical outcomes. The implementation of hybrid strategies allows for effective individualization of treatment tactics in the most complex cases with pronounced venous transformation. The choice of intervention (open, endovascular, or hybrid) must be based on a comprehensive assessment of the lesion's angioarchitecture, the presence of an infectious process, the biomechanical characteristics of the affected segment, and the patient's functional demands, which rules out the use of simplified, one-size-fits-all algorithms.

Keywords
extremity vascular trauma, post-traumatic pseudoaneurysm, arteriovenous fistula, covered stent-graft, embolization, endovascular treatment, hybrid interventions.

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Injuries to major limb vessels caused by gunshot and blast trauma continue to present significant challenges in both military and civilian vascular surgery. These injuries are characterized by high mortality rates, an elevated risk of limb loss, and substantial functional disability among survivors. Historical analysis shows a marked evolution in tactical approaches: whereas simple ligation of major arteries during World War II was associated with critically high amputation rates [8], the implementation of systematic vascular reconstruction during the Vietnam War substantially improved treatment outcomes [6].

Nevertheless, even with timely revascularization, a significant proportion of patients develop delayed complications – post traumatic pseudoaneurysms (PTPA) and arteriovenous fistulas (AVF). Data from the Vietnam Vascular Registry indicate that these lesions account for approximately 7 % of all vascular injuries [7]. Contemporary conflicts in Iraq and Afghanistan, as well as the experience of the full scale war in Ukraine, have demonstrated an increase in the number of complex combined injuries, particularly in proximal and junctional zones, which considerably complicates both diagnosis and surgical strategy [2, 3, 10].

Radical resection of the affected segment with open reconstruction (end to end anastomosis or autogenous vein interposition) is still the gold standard for treating PTPAs and AVFs [1, 8]. However, in cases of pronounced scarring, a developed collateral network, and close anatomical proximity to major nerve trunks, open surgery is associated with high morbidity, massive blood loss, and a risk of iatrogenic nerve injury [5].

Advancements in endovascular technologies, notably the introduction of covered stent grafts, have expanded treatment options for selected patient group. These methods reduce the extent of dissection and operative trauma [9]. Their use is nevertheless limited by factors such as localization in flexion zones, infection, and lack of adequate landing zones, requiring careful assessment of long term patency, especially in young patients who engage in high-intensity physical activity [4].

Objective – to analyze current scientific data on the role of endovascular interventions in the management of technically challenging post-traumatic pseudoaneurysms and arteriovenous fistulas of major extremity vessels resulting from gunshot wounds; to define the indications, benefits, and limitations of minimally invasive methods; to justify their role within hybrid strategies in comparison with conventional open reconstructions; and to present our case series of successful clinical observations.

Materials and methods

This systematic review examines the current literature on major limb vascular injuries, post traumatic pseudoaneurysms (PTPA), and arteriovenous fistulas (AVF). Emphasis was placed on analysis of case series from armed conflicts (World War II, the Vietnam War, Iraq, Afghanistan) and large civilian cohorts. Literature searches were performed in PubMed, Scopus, and Google Scholar for the period 1946–2024 using the following keywords: «traumatic pseudoaneurysm,» «arteriovenous fistula,» «endovascular,» «stent graft,» «embolization,» and «limb vascular trauma.»

Inclusion criteria: original clinical studies, case series, multicenter reports, and systematic reviews describing diagnostic strategies and treatment outcomes for traumatic vascular pathology of the extremities.

Exclusion criteria: experimental animal studies, isolated case reports without follow up analysis, and non-Englis publications lacking an English abstract or full translation.

A total of 17 articles met the inclusion criteria and were included in the analysis.

In addition to the theoretical analysis, this paper presents three retrospectively selected clinical cases managed at the National Military Medical Clinical Center «HVKOH.» The mechanisms of injury, diagnostic algorithms (physical examination, duplex ultrasound scanning, multislice CT angiography, selective arteriography), and the intervention technique – implantation of covered stent grafts – were analyzed. Immediate (up to 30 days), short and mid term follow up outcomes were evaluated. The study adhered to bioethical principles and patient data protection requirements in accordance with the Declaration of Helsinki.

Results

Analysis of gunshot injuries to major limb vessels shows that this pathology has historically represented one of the most complex challenges in combat surgery. The classic study by DeBakey and Simeone, which included 2,471 cases of arterial injuries during World War II, provided seminal evidence of the catastrophic consequences of major artery ligation, with amputation rates for femoral and popliteal artery injuries reaching 50 %. The doctrine shifted toward reconstruction during the Vietnam War. N. M. Rich et al. demonstrated that direct vascular repair and autogenous vein grafting dramatically reduced limb loss in a series of 1,000 acute injuries [6].

Despite successful primary management, analysis of delayed outcomes shows that late vascular

complications may still develop. The Vietnam Vascular Registry recorded 558 post traumatic pseudoaneurysms (PTPA) and arteriovenous fistulas (AVF) in 509 patients. These lesions accounted for about 7 % of all vascular injuries, with the vast majority (over 85 %) located in limb segments [7].

Experience from recent conflicts in Iraq and Afghanistan, analyzed by White and Clouse, indicates a change in injury patterns due to the widespread use of improvised explosive devices. This has led to an increase in complex combined injuries in which vascular damage is accompanied by massive soft tissue defects and multi fragment fractures [1, 10]. In such patients, PTPAs and AVFs often develop in anatomically difficult to access zones (subclavian axillary and ilio femoral segments), where traditional open resection per Rich is technically highly hazardous [3, 5, 7, 8].

In the setting of dense scarring and a hypertrophied collateral network characteristic of gunshot wounds, endovascular technologies (covered stent grafts and selective embolization) become a justified alternative. They reduce operative time and blood loss, which is critical for polytrauma patients [3]. Thus, current treatment tactics for complex post traumatic PTPAs and AVFs are shifting toward personalized selection between minimally invasive intervention and classical reconstruction, depending on anatomical considerations and the presence of infection [2].

A seminal analysis of the Vietnam Vascular Registry by Rich et al. found that of more than 7,000 vascular injuries, approximately 558 (≈7 %) were post traumatic AVFs and pseudoaneurysms. The vast majority of these lesions (> 85 %) were located in limb vessels, particularly the superficial femoral, popliteal, and tibial arteries. Contemporary conflict experience described by J. M. White et al. confirm that limb vessels remain the predominant injury site, with explosive mechanisms most often affecting the femoral and popliteal segments [10]. W. D. Clouse et al. emphasize that high energy fragment wounds are prone to delayed presentation of PTPAs and AVFs, especially in junctional zones, where acute-phase diagnosis is often technically limited [1].

Civilian case series (Hafez, Frykberg, and Topal) correlate with military data, identifying PTPAs and AVFs as major late complications of arterial trauma to the lower extremities [4, 5, 8]. Aggregated experience indicates that pseudoaneurysms typically present as a pulsatile mass and localized pain, whereas AVFs are classically associated with a systolic–diastolic «machinery» murmur and a palpable thrill over the vascular bundle [5]. Hemodynamic disturbances in the limb include progressive distal swelling, secondary varicose changes, and trophic skin disorders resulting from venous hypertension. Large, high flow fistulas can lead to high output heart failure.

Lesions in junctional zones, including subclavian, axillary, iliac, and proximal femoral arteries, represent a distinct category of complexity. Their deep anatomical location, proximity to neural plexuses, and propensity for pronounced scarring make these areas particularly suitable for endovascular and hybrid strategies that minimize surgical trauma when access is anatomically unfavorable.

The contemporary paradigm for treating technically challenging post traumatic pseudoaneurysms and arteriovenous fistulas has been substantially transformed by endovascular technologies. The use of covered stent grafts and selective embolization mitigates the principal drawbacks of open surgery in scar altered tissues and difficult anatomical locations. According to multicenter studies by DuBose and White, stent graft use for traumatic injuries of the subclavian axillary and ilio femoral segments shows high technical effectiveness exceeding 90 % [3, 9]. The authors justify endovascular intervention as a first line treatment in hemodynamically stable patients with adequate landing zones (i 10–15 mm) [3, 9]. The principal advantage of this approach is the avoidance of extensive dissection in junctional zones, which markedly reduces the risk of iatrogenic injury to adjacent neural structures and minimizes intraoperative blood loss [3, 9].

Alongside ligation or exclusion of major vessels, Topal and Clouse identify embolization as an independent definitive method for treating PTPAs of distal arterial branches and as an important adjunct in hybrid procedures [1, 8]. In cases of high flow AVFs, selective occlusion of feeding vessels or collaterals can stabilize regional hemodynamics and prevent recurrence (endoleaks) after stent graft implantation.

Despite clear advantages, the academic community – notably White J. M. and E. R. Frykberg – emphasizes the limitations of this method [4, 10]. The primary concern is the biomechanical instability of stents in active flexion zones, particularly the popliteal segment. The risk of fatigue fractures of the metal frame (stent fractures) and subsequent thrombosis limits the use of these devices in working age patients who engage in high-intensity physical activity. Additionally, the presence of perifocal infection is an absolute contraindication to endovascular prosthesis due to the risk of septic thrombosis and secondary arterial damage.

Chronic arteriovenous fistulas with pronounced venous aneurysmal transformation present particular scientific interest. In such clinical scenarios,

a staged hybrid approach is often most appropriate. The initial endovascular stage involves implantation of a stent graft to eliminate the pathological arteriovenous shunt and stabilize regional hemodynamics. The subsequent open stage consists of resecting the aneurysmally dilated veins and reconstructing venous outflow. Performing the open procedure after arterial flow has been restored allows dissection in a «dry» operative field, thereby substantially reducing the risk of uncontrolled hemorrhage and iatrogenic injury to adjacent structures.

Analysis of anatomic locations by DuBose and White indicates that the subclavian axillary and ilio femoral segments are the most favorable niches for endovascular exclusion of post traumatic lesions. In these zones, open surgery is traditionally associated with a high risk of injury to the brachial plexus or pelvic organs. By contrast, implantation of covered stent grafts via transfemoral or transbrachial access provides effective isolation of PTPAs and AVFs with minimal operative trauma.

The high effectiveness of this strategy is supported by multicenter studies. R. White et al. reported a technical success rate of 94 % for covered stent use in traumatic peripheral arterial injuries, with minimal periprocedural mortality [9]. J. J. DuBose et al. reported similar results for proximal upper limb segments, supporting the use of covered stents as a first line method in hemodynamically stable patients with suitable vascular anatomy [3].

Successful implementation of an endovascular strategy requires careful preoperative planning, in which the choice of vascular access determines precise device positioning. The standard approach involves retrograde access via the contralateral common femoral artery using a crossover technique. For lesions in the subclavian axillary region, however, an ipsilateral brachial access often provides better device control and higher accuracy in stent delivery. Inadequate selection of the puncture site or complex vessel tortuosity can significantly hinder navigation, leading to inaccurate graft deployment and unsatisfactory hemodynamic results [3].

The effectiveness of stent graft implantation directly depends on correct device sizing. The accepted standard is to choose a stent diameter 10–20 % larger than the reference arterial diameter (oversizing) to ensure secure fixation. The device length must cover the lesion and provide sealing (landing) zones of at least 10–15 mm proximally and distally relative to the healthy arterial wall [9]. In the ilio femoral and subclavian axillary segments, self expanding covered stents (e.g., Viabahn type) are generally preferred for their high flexibility [3, 9]. Although balloon expandable systems offer greater deployment precision, they are less resistant to external compression and deformation.

Analysis of common technical errors shows that the most critical issues are inadequate coverage of afferent or efferent flows, leading to persistent shunts (endoleaks), and inadvertent occlusion of functionally important branches, such as the vertebral, internal mammary, or profunda femoris arteries. The latter may precipitate acute ischemia or neurological deficit. Additionally, the risk of device migration and incomplete sealing increases substantially when working in heavily calcified or pathologically tortuous segments [9].

The popliteal artery represents a distinct «red zone» for endovascular interventions. Despite a high incidence of PTPAs and AVFs at this site, it is highly unfavorable for stenting because of specific biomechanics. Repeated knee flexion and extension impose critical loads on the stent's metal frame, inevitably leading to secondary deformation, fatigue fracture, and subsequent vessel thrombosis [4]. Therefore, for working age patients who engage in high-intensity physical activity, open autogenous vein reconstruction remains the treatment of choice [5]. Endovascular methods in this segment should be reserved for palliative care or as a last resort in patients with critically high surgical risk.

Nevertheless, the limitations associated with stent graft use in highly mobile zones or in small diameter vessels have increased the role of transcatheter embolization, which is now regarded as far more than merely an adjunctive technique.

In modern interventions, embolization serves both as an independent definitive method and as an important component of combined therapy [8, 14]. Its main functions are the final isolation of pseudoaneurysms in second and third order arterial branches, occlusion of low flow arteriovenous fistulas fed by a limited number of feeders, and adjunctive support after stent graft implantation to eliminate residual shunting through the collateral network [8]. The effectiveness of this strategy depends directly on precise superselective catheterization of feeding vessels, which minimizes the risk of non target distal occlusion.

Selection of embolic material – metallic microcoils or liquid adhesive agents – must be strictly individualized to match local hemodynamics and lesion architecture. Achieving complete occlusion of the pathological focus is a critical success criterion, since even minimal residual flow is associated with a high rate of early recurrence. Furthermore, it is essential to consider potential risks, including incomplete exclusion of the pathological tract due to undiagnosed collaterals and the risk of distal migration

of embolic material with consequent ischemic complications in the target arterial territory [1, 8].

Despite the broad capabilities of modern techniques, there are certain clinical scenarios in which isolated open surgery or purely endovascular methods cannot achieve an optimal result. These scenarios include long standing high flow arteriovenous fistulas with critical aneurysmal venous transformation, cases with marked fibrosis after multiple prior interventions, and combined injuries with a hypertrophied collateral network [2, 7]. In such circumstances, a staged hybrid strategy that integrates the advantages of both approaches is considered the most rational option.

The initial endovascular stage of this strategy is aimed at implantation of a covered stent graft to exclude the arterial defect and, if necessary, selective embolization of dominant collateral branches. The primary objective of this stage is to achieve a radical reduction in pathological blood flow and stabilize the lesion's hemodynamics. The subsequent open stage involves limited resection of aneurysmally transformed venous segments and selective ligation of residual collaterals.

This sequence allows surgical dissection in a «dry» operative field, thereby markedly improving visualization of neurovascular structures and minimizing intraoperative trauma and blood loss. Although implementation of hybrid protocols requires a highly skilled operative team and appropriate technical resources, this approach provides the most predictable outcomes in the treatment of critically complex post traumatic lesions [5].

Despite technological progress, diagnosis and selection of treatment tactics for post traumatic vascular complications are accompanied by several objective difficulties. A major issue is delayed diagnostic confirmation, as chronic AVFs are often misinterpreted as isolated venous disease or heart failure of unclear etiology [1, 7, 8].

Accordingly, a thorough analysis of the trauma history and targeted auscultation to detect vascular bruit or a palpable thrill are essential [1, 7]. Another challenge is the presence of imaging artifacts on multislice CT angiography caused by metallic fragments in the wound area [2]. In such scenarios, catheter angiography remains indispensable for accurate assessment of lesion angioarchitecture and procedural planning [1].

The absence of universal treatment algorithms mandates an individualized approach that comprehensively considers infection risk, anatomical location of the defect, and the patient's age and physical activity level, rather than relying on simplified schemes [2].

A synthesis of international literature and our clinical observations highlights the following key points:

1. Epidemiology: PTPAs and AVFs account for approximately 7 % of all vascular trauma, with predominant localization in arterial segments of the extremities [7, 10].

2. Technical efficacy: The use of covered stent grafts for selected proximal lesions achieves technical success in over 90 % of cases [3, 9]. Transcatheter embolization shows high effectiveness both as a standalone method for small branch lesions and as an adjunct in combined procedures [4].

3. Limitations and risks: The primary limitations of endovascular methods are active flexion zones in the limbs and infection [5]. The issue of long term durability of metal frameworks in young patients remains unresolved and requires further investigation with extended follow up [1, 6].

Our clinical observations

To validate the theoretical positions presented and illustrate the tactical and technical aspects of treating post traumatic vascular pathology, we analyzed outcomes of three patients with PTPAs and AVFs of major limb arteries. In this series, lesions of the subclavian and femoral segments resulted from fragmentary gunshot and mine blast injuries sustained in combat.

These clinical cases demonstrate the variability of injury mechanisms and the complexity of anatomical localization in proximal zones. Each case confirms the appropriateness and high effectiveness of endovascular exclusion as the method of choice in technically challenging situations where open reconstruction poses excessive operative risk. The results indicate a stable hemodynamic effect and preservation of limb function in both the immediate and long term follow up.

Clinical case 1

Patient K., 48 years old. Admitted to the Vascular Surgery Clinic of the National Military Medical Clinical Center (NMMCC).

History and complaints: On 06/24/2024, the patient sustained a fragmentary gunshot injury to the right hemithorax. Primary surgical wound management was performed during medical evacuation. On day 4 post injury (06/28/2024), progressive pain and swelling of the right upper limb were noted. On physical examination, a pulsatile mass was found in the right supraclavicular region with a loud systolic bruit on auscultation. Distal pulses in the forearm arteries were preserved, and there were no signs of acute limb ischemia.

Diagnostics: Selective direct angiography confirmed a pseudoaneurysm of segment II of the right subclavian artery (Fig. 1).

Figure 1. **Direct angiography. The arrow indicates the subclavian artery aneurysm**

Figure 2. **Direct angiography. The arrow indicates the implanted stent graft in the subclavian artery**

Surgical intervention: Given the technical difficulty of open exposure and the risk of injuring brachial plexus elements in the early post traumatic period, an endovascular approach was chosen. On 06/30/2024, a Gore Viabahn stent graft was implanted in the affected subclavian segment. After stent graft deployment, the aneurysmal sac was completely excluded, and the lumen contour of the parent vessel was restored (Fig. 2). No intraoperative complications occurred.

Postoperative course: Uneventful. The patient received standard antibiotic and infusion therapy. Dual antiplatelet therapy (aspirin + clopidogrel) was prescribed. At discharge, peripheral arterial pulses were palpable, and limb swelling had regressed. The patient was advised to undergo CT angiography in 3 months to assess stent graft patency and rule out endoleak.

Clinical case 2

Patient S., 36 years. Admitted to the clinic for elective surgical treatment of sequelae of a mine blast injury.

History and complaints: On 10/14/2024, he sustained a mine blast injury to the right thigh. Initial wound management and staged treatment were performed at the place of injury. Three months after the trauma, the patient noted progressive swelling of the right lower limb, a sensation of coldness in the foot, and calf pain on walking up to 100 meters (intermittent claudication, Fontaine Pokrovsky stage IIB).

Diagnostics: On 01/20/2025, the patient was admitted to NMMCC. Selective direct angiography revealed a large post traumatic pseudoaneurysm of the superficial femoral artery with significant mural thrombosis causing luminal narrowing of the parent vessel and distal embolization (Fig. 3).

Surgical intervention: Given the pronounced scarring in the injury zone and the risk of femoral nerve damage with open reconstruction, an endovascular approach was chosen. On 01/22/2025, a self expandable Gore Viabahn stent graft was implanted in the affected segment. Complete restoration of the arterial contour and exclusion of the aneurysmal sac from the circulation were achieved (Fig. 4). The procedure was completed without intraoperative complications.

Postoperative course: In the early postoperative period, the patient showed favorable dynamics: normalization of foot skin temperature, resolution of rest pain, and marked reduction in swelling. Pedal pulses were palpable. The patient was discharged in satisfactory condition on maintenance antiplatelet therapy. Follow up duplex ultrasound and CT angiography were recommended in 3 months to assess stent patency.

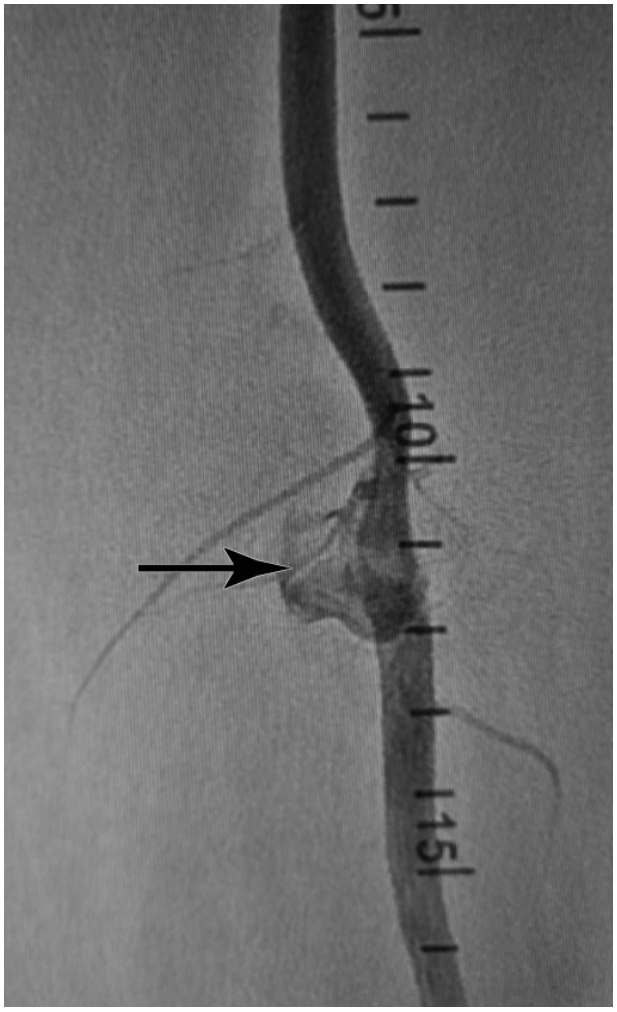


Figure 3. **Direct angiography. Aneurysm of the superficial femoral artery**

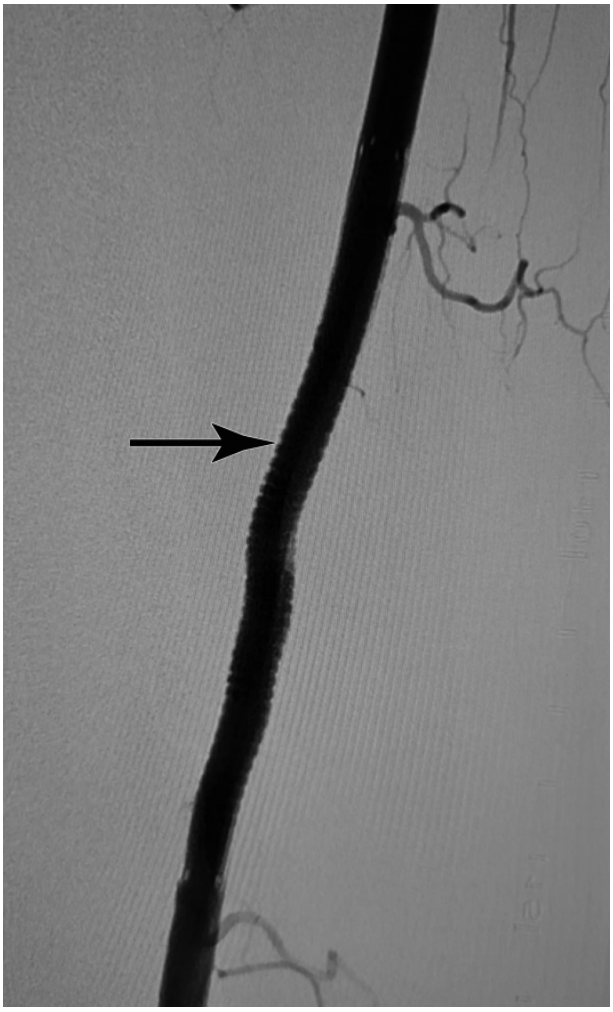


Figure 4. **Direct angiography. The arrow indicates the implanted stent graft in the superficial femoral artery**

Clinical case 3

Patient L., 43 years old. Admitted to the Vascular Surgery Clinic of the NMMCC for treatment of a chronic post traumatic arteriovenous fistula.

History and complaints: On 09/05/2018, he sustained a severe combined mine blast injury. Injury pattern included multiple fragment wounds of the lower limbs, a comminuted fracture of the right tibia with soft tissue defect, perineal injury with rectal damage, and a pubic bone fracture. At initial levels of care, the patient underwent loop colostomy formation and application of an external fixator to the right tibia.

Clinical status: On examination at our center, the main vascular pathology was identified as a persistent post traumatic arteriovenous fistula (AVF) between the superficial femoral artery (SFA) and the corresponding vein. Clinically, this presented with marked limb swelling, dilated superficial veins, and a characteristic palpable thrill («purring») over the vascular bundle projection.

Diagnostics: Multislice CT angiography and selective direct catheter angiography confirmed a functioning AVF between the SFA and the femoral vein with evidence of significant blood shunting into the arterialized venous circulation (Fig. 5, *6*).

Surgical intervention: Given the severity of the combined injury, the presence of an AVF, and substantial soft tissue defects–making open reconstruction high risk for infectious complications–an endovascular approach was chosen. On 01/18/2019, endovascular exclusion of the fistula was performed by implanting a stent graft in the affected femoral artery segment. Control angiography confirmed complete cessation of the pathological shunt with preservation of main arterial flow (Fig. 7).

Outcomes: In the postoperative period, there was a rapid reduction in swelling and normalization of venous pressure in the limb. The patient was discharged in satisfactory condition with recommendations for antiplatelet therapy and duplex ultrasound follow up at 1, 3, and 6 months.

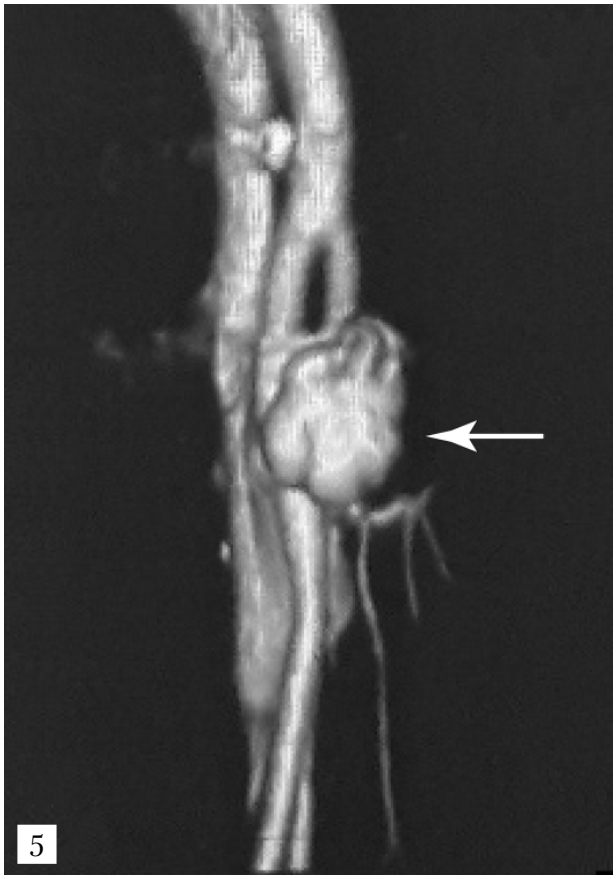
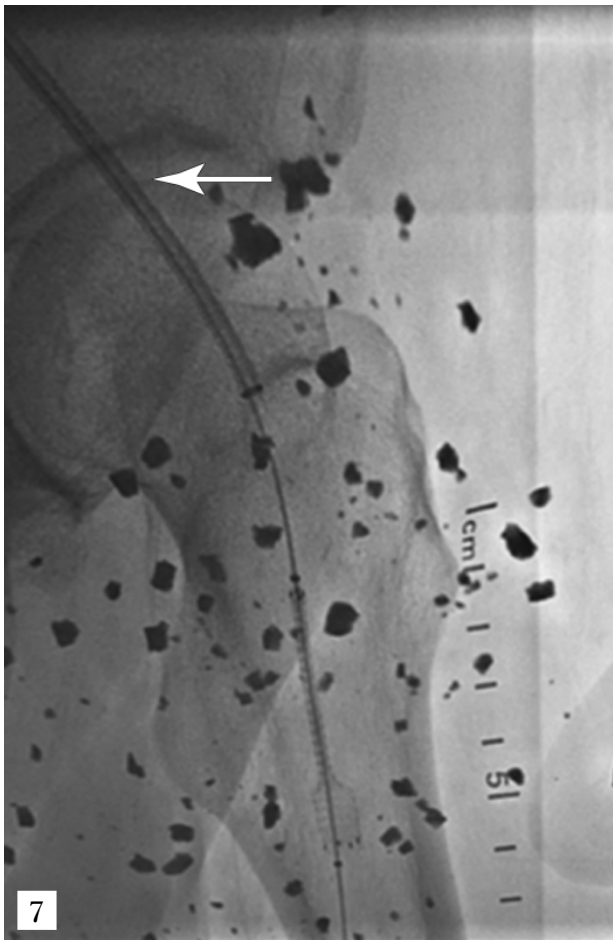


Figure 5. **Multislice CT angiography. The arrow indicates the arteriovenous fistula between the femoral artery and vein and the post traumatic aneurysm**

Figure 6. **Direct angiography in the same patient. The arrow shows contrast jetting into the arteriovenous fistula between the femoral artery and vein**

Figure 7. **Same patient. Multiple fragments. A stent graft was also implanted in the common femoral artery; no visualization of the post traumatic aneurysm or arteriovenous fistula**



effectiveness of covered stent grafts (over 90 %) in proximal locations such as the subclavian axillary and ilio femoral segments [3, 9]. The authors advocate for an endovascular first line approach in stable patients, emphasizing the marked reduction in operative trauma. However, the success of this strategy directly depends on careful planning of landing zones for device fixation.

Complementing this arsenal, A. E. Topal et al., W. D. Clouse et al., and J. M. White et al. define the role of embolization as both a definitive treatment for small branch pseudoaneurysms and low flow AVFs, and as an effective adjunct for eliminating collateral flow (endoleaks) after stent graft implantation [4, 8, 10].

There is consensus in the scientific community on clear limitations of the endovascular method. These limitations include reduced stent durability in high mobility zones (notably the popliteal segment) due to the risk of fractures and thrombosis, unsuitability for infected lesions, and anatomical constraints that preclude reliable graft fixation. Thus, the choice between open and endovascular reconstruction must be individualized, based on lesion location and the risk of infectious complications.

Analysis of current literature clearly delineates two complementary strategies: classical open reconstruction [2, 4, 6, 7], which remains the priority for infected, distal, and flexion zone lesions; and endovascular/hybrid methods [3, 9, 10], which are appropriate for proximal, anatomically favorable injuries and aimed at minimizing surgical trauma.

Based on our experience, we align with the views of classical authors that open reconstruction is the treatment of choice for infected lesions, extensive segmental vessel wall damage, and injuries located in active flexion zones in young patients [2, 4, 5].

At the same time, we support and implement an endovascular exclusion strategy using covered stent grafts for stable proximal lesions in the subclavian axillary and ilio femoral segments [3, 9]. Our study confirms that, in the absence of infection and with adequate landing zones (≥ 10–15 mm), the endovascular approach markedly reduces surgical trauma and blood loss while providing high technical effectiveness.

These approaches have been successfully implemented at our center for the treatment of PTPAs and AVFs in patients with gunshot injuries. The results confirm the high efficacy and reliability of the chosen tactics during short and mid term follow up [1].

Conclusions

Expansion of the tactical arsenal. Endovascular interventions do not completely replace classical vascular surgery, but they substantially expand the tactical options for treating post traumatic aneurysms and arteriovenous fistulas (AVF). This is particularly relevant for lesions located in anatomically challenging zones (notably the subclavian segment) and for patients with high operative risk.

Technical efficacy. The use of covered stent grafts and embolization techniques demonstrates a high technical success rate and satisfactory clinical outcomes. Achieving optimal results requires careful preoperative patient selection and strict adherence to established intraoperative control protocols.

Role of hybrid technologies. In the most complex clinical situations where a single approach (open or minimally invasive) is insufficient, hybrid techniques ensure individualized treatment and reliable reconstruction of the vascular conduit.

Priority of individualized approach. Selection of the optimal strategy (open, endovascular, or hybrid) should be based on a comprehensive assessment, including precise anatomical verification of the injured segment, identification of concomitant infection, evaluation of soft tissue damage, and consideration of the patient's overall condition. This personalized approach is preferable to rigid, universal algorithms.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval and written informed consent statements

Ethics committee approval was not required for this study as it is a retrospective report of clinical cases and contains no identifiable patient data. However, written informed consent for the clinical procedures, data analysis, and publication of these case reports, including any accompanying clinical images, was obtained from all individual participants in accordance with the Declaration of Helsinki. Patient anonymity has been strictly preserved.

Authors contributions

Conception and design, critical revision of the article — Y. M. Susak, K. V. Humeniuk; acquisition of data, analysis and interpretation of data, drafting the article — Y. V. Nahaliuk.

Statement on the use of generative artificial intelligence

The authors did not use generative AI or AI-assisted technologies in the writing process of this manuscript.

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Ендоваскулярні методи лікування технічно складних посттравматичних аневризм та артеріовенозних фістул кінцівок: аналіз серії клінічних випадків

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Мета — проаналізувати сучасні наукові дані щодо ролі ендоваскулярних втручань у лікуванні технічно складних посттравматичних псевдоаневризм (ПТПА) та артеріовенозних фістул (АВФ) магістральних судин кінцівок унаслідок вогнепальних поранень, визначити показання, переваги та обмеження малоінвазивних методів, обґрунтувати їхнє місце в складі гібридних стратегій порівняно з класичними відкритими реконструкціями, а також представити власну серію успішних клінічних спостережень.

Матеріали та методи. Проведено систематичний аналіз профільної літератури, присвяченої травмам магістральних судин кінцівок та їхнім відстроченим ускладненням. Огляд охоплює досвід збройних конфліктів від Другої світової війни до сучасних операцій в Іраку та Афганістані. Проаналізовано фундаментальні праці (DeBakey, Rich), дані Vietnam Vascular Registry щодо 558 посттравматичних уражень, а також сучасні епідеміологічні та мультицентрові дослідження (White, Clouse, DuBose), що висвітлюють результати ендоваскулярного лікування судинної травми. Особливу увагу приділено порівняльному аналізу тактик лікування в анатомічно складних («junctional») зонах, в яких відкрита хірургія асоціюється з високим рівнем операційної травматичності й ризиком ятрогенних ушкоджень.

Результати. Установлено, що на частку ПТПА й АВФ припадає близько 7 % від усіх судинних ушкоджень у структурі бойової травми. Відкрита реконструкція (резекція з автовенозною пластикою) залишається пріоритетною при контамінованих пораненнях, інфікованих ПТПА та ураженнях зон згину (flexion zones) у молодих пацієнтів. З'ясовано, що в проксимальних сегментах за відсутності інфекції імплантація покритих стент-графтів забезпечує технічний успіх у понад 90 % випадків, радикально мінімізуючи обсяг дисекції в анатомічно складних зонах. Емболізація позиціонується як ефективний метод для ізоляції гілкових уражень й ад'ювантної підтримки стентування. Основними обмеженнями ендоваскулярного підходу вважають ризик механічної деструкції стенту в мобільних сегментах і дефіцит зон фіксації. Наголошено на доцільності гібридних стратегій при хронічних високопотокових АВФ із виразною венозною трансформацією. Представлені власні клінічні спостереження підтверджують ефективність обраних алгоритмів у лікуванні наслідків вогнепальних поранень у короткостроковому та середньостроковому періодах.

Висновки. Ендоваскулярні технології не є повною альтернативою відкритій судинній хірургії, але вони суттєво розширюють тактичний арсенал при лікуванні ПТПА й АВФ кінцівок, особливо в разі анатомічно несприятливої локалізації уражень і високого операційного ризику. Використання покритих стент-графтів та методів селективної емболізації, за умови прецизійного відбору пацієнтів, забезпечує високу технічну успішність і стабільні клінічні результати. Упровадження гібридних стратегій дає змогу ефективно індивідуалізувати лікувальну тактику в найскладніших випадках із виразною венозною трансформацією. Вибір втручання (відкрите, ендоваскулярне чи гібридне) має ґрунтуватися на комплексній оцінці ангіоархітектоніки ураження, наявності інфекційного процесу, біомеханічних особливостях ураженого сегмента та функціональних запитах пацієнта, що виключає застосування спрощених універсальних алгоритмів.

Ключові слова: травма судин кінцівок, посттравматична псевдоаневризма, артеріовенозна фістула, покритий стент-графт, емболізація, ендоваскулярне лікування, гібридні втручання.

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