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POST-TRAUMATIC VASCULAR RECONSTRUCTION: NEW TECHNIQUES, REHABILITATION, AND TRANSLATIONAL PERSPECTIVES

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Abstract: Traumatic vascular injury is a major cause of morbidity and mortality in emergency services, requiring rapid and effective approaches to preserve life and limbs. This study aims to review innovations in vascular reconstructive surgery, post-trauma rehabilitation, and new techniques aimed at functional recovery. The methodology adopted consisted of an integrative literature review, covering scientific articles published between 2020 and 2025. The results show that the combination of technical advances, such as microsurgery and perforating flaps; endovascular innovations, including covered stents and hybrid techniques; and advances in preoperative planning with angiotomography and 3D mapping have significantly expanded the available therapeutic arsenal. These strategies, when applied in an integrated and multidisciplinary manner, contribute to reduced ischemia time, lower operative morbidity, and a higher probability of limb salvage, especially in centers that have hybrid rooms and well-structured protocols. It can be concluded that post-traumatic vascular reconstruction has become more effective and multifaceted in the last decade, driven by more precise microsurgical techniques, advanced endovascular approaches, and the emergence of bioengineered solutions. However, the consolidation of these innovations in global clinical practice requires robust evidence, investments in infrastructure, and standardized protocols.
Keywords: Reconstructive surgery. Vascular surgery. Microsurgery

INTRODUCTION

Traumatic vascular injury is a significant cause of morbidity and mortality in emergency and trauma services , where the immediate consequences range from exsanguination to distal ischemia and functional loss, and initial decisions regarding hemorrhage control and revascularization are critical for patient survival and limb preservation (Magee *et al.*, 2022).

In recent decades, the field of post-traumatic reconstructive vascular surgery has undergone numerous technological and organizational transformations that have changed therapeutic paradigms from the predominance of classic open repair to a more integrated strategy that includes endovascular approaches, hybrid rooms, advanced microvascular techniques, and time-buying interventions such as REBOA (*Resuscitative Endovascular Balloon Occlusion of the Aorta)*. (Holmberg *et al.,* 2025).

These innovations do not replace open surgery, but they expand the therapeutic arsenal and require selection protocols based on the anatomy of the injury, degree of contamination, hemodynamics, and local resources.

From an epidemiological and organizational standpoint, contemporary management of vascular trauma requires multidisciplinary integration (vascular surgeons, trauma surgeons, interventional radiologists, microsurgery and rehabilitation teams) and dedicated infrastructure. The spread of hybrid rooms (operating rooms with integrated high-resolution imaging) has enabled the sequential and immediate performance of endovascular procedures and open repairs without the need for intra-hospital transfers, reducing the time between diagnosis and intervention and potentially decreasing losses due to transit and therapeutic delay (Palacios-Rodríguez *et al.*, 2021).

Studies such as that by Qi et al. (2025) describe a favorable operational impact and reduction in procedure time in series of abdominal-pelvic and vascular trauma, although their implementation requires logistical planning, training, and high costs.

Thus, in reconstructive microsurgery—notably flow-through flaps (such as variants of the anterolateral thigh flap)—it has been possible, in a single procedure, to cover soft tissues and restore the distal arterial axis, which is crucial in attempts to save limbs with significant arterial loss associated with soft tissue defects . These techniques, documented in case series and small cohorts, have shown good flap survival rates and acceptable limb salvage rates when applied in specialized centers; however, they are more technically complex and require re-exploration compared to elective procedures (Prichayudh *et al.,* 2023).

In addition to surgical techniques, translational fields are simultaneously emerging that may redefine long-term reconstruction: Vascularized Composite Allotransplantation (VCA) and approaches to immune tolerance induction or tissue engineering (biofabricated grafts), which promise alternatives to conventional salvage in irreparable injuries. Despite scientific progress, widespread clinical applications remain limited by immunological issues, risks of chronic immunosuppression, and ethical criteria/patient selection (Ribeiro Junior *et al.*, 2024).

Given this, this study aims to develop a study on reconstructive surgery and innovations in post-trauma rehabilitation and new techniques for reconstruction and functional recovery in the vascular area.

METHODOLOGY

This is an integrative literature review study with a qualitative approach, whose objective is to identify, analyze, and synthesize scientific evidence published between 2020 and 2025 on technical innovations and rehabilitation strategies in post-traumatic vascular reconstructive surgery. The integrative review was chosen because it allows the inclusion of studies with different designs (clinical trials, cohorts, case series, and systematic reviews), enabling a comprehensive analysis of the topic.

The articles were searched in the following scientific databases: PubMed/MEDLINE; LILACS (Latin American and Caribbean Health Sciences Literature) and SciELO (Scientific Electronic Library Online). Health science descriptors (Decs) in Portuguese and English were used, combined by Boolean operators (AND, OR).

Thus, the main descriptors used were: *"Vascular reconstructive surgery"* OR *"reconstructive vascular surgery"; "vascular trauma"* AND *"post-trauma rehabilitation"*; *"endovascular techniques"* AND *"limb salvage"*; *"flow-through flap"* AND *"microsurgery"*; *"Resuscitative Endovascular Balloon Occlusion of the Aorta"* OR "*REBOA"; "hybrid operating room*" AND "*vascular injury*"; and "*vascularized composite allotransplantation*" AND "*tissue engineering.*"

Articles were included that addressed post-trauma vascular reconstructive surgery techniques, with a description of innovations or rehabilitation strategies; were published between 2020 and 2025; were available in full in Portuguese, English, or Spanish; and presented original data (clinical trials, observational studies, case series) or systematic reviews with or without meta-analysis. Articles that exclusively addressed non-vascular reconstructive techniques; dealt only with pediatric populations without correlation with adults; were conference abstracts, letters to the editor, editorials, or studies with unexplained methodology; and were duplicated in more than one database were excluded.

Screening was performed in three stages: reading titles and abstracts for initial exclusion of articles outside the scope; reading potentially eligible articles in full to confirm inclusion criteria; and standardized data extraction.

Given this, a comparative analysis was performed between the studies to identify trends, benefits, limitations, and gaps in evidence. Whenever possible, differences in results between older studies were highlighted to assess technical evolution and the consolidation of practices.

As this study was based exclusively on data publicly available in the scientific literature, there was no need to submit it to the Research Ethics Committee, following the guidelines of CNS Resolution No. 510/2016.

RESULTS AND DISCUSSION

Post-trauma reconstruction in the vascular area involves not only restoration of arterial and venous perfusion, but also tissue coverage, restoration of function, and prevention of complications such as infection and limb loss. In recent decades, Breuer *et al.* (2023) highlighted that there have been significant advances on three major fronts: (1) micro and supermicroscopic techniques applied to revascularization and tissue grafting, (2) greater integration of endovascular and hybrid approaches for traumatic vascular injuries, and (3) innovations in tissue engineering, bioartificial grafts, and cell therapies aimed at vascular regeneration and functional integration.

According to Lim *et al.* (2023), traumatic arterial injuries were traditionally treated by open repair (suture, autologous vein interposition, bypass), but in the last 10 years there has been rapid adoption of endovascular techniques (covered stents, fenestrated stent-grafts, angioplasty, catheter thrombectomy), including in traumatic contexts when the anatomy allows it.

Current evidence indicates that, in various scenarios of arterial trauma to the limbs, endovascular treatment has comparable or higher survival rates than open surgery, in addition to being associated with shorter hospital stays, less blood loss, and a lower risk of iatrogenic injuries to adjacent tissues. However, the therapeutic decision must be individualized, considering factors such as wound contamination, extent of injury, and availability of appropriate devices. In these situations, especially in cases of extensively contaminated wounds or significant loss of arterial wall, open repair with autologous vein remains the option of choice (Qi et al., 2025).

Studies such as that by Ozawa *et al.* (2024) suggest that integration in a hybrid room (open surgery + endovascular capacity) optimizes results in complex injuries: it allows rapid revascularization, real-time imaging, and, when necessary, immediate conversion to open surgery. The combination of techniques (e.g., angioplasty followed by local grafting or flap transfer) has been shown to reduce amputations in patients with acute traumatic ischemia (Ozawa *et al.*, 2024).

Post-traumatic vascular reconstruction requires conduits with good patency, mechanical strength, and low thrombogenicity, in which autologous grafts (saphenous vein) remain the gold standard but are limited when the donor vessel is unavailable, diseased, or when the defect is extensive. Therefore, tissue engineering seeks to produce Tissue-Engineered Vascular Grafts (TEVGs) and acellular/bioartificial grafts that offer patency and tissue integration comparable to autologous grafts, with a lower risk of infection than synthetic prostheses in contaminated wounds (Kang; Yang, 2024).

As demonstrated by Di Francesco et al. (2023), recent reviews show that acellular vascular grafts have the ability to be rapidly repopulated by host cells, evolving into functionally viable structures with active endothelium and progressive remodeling. This process promotes tissue integration, reduces thrombogenicity, and improves medium-term patency , making it a promising alternative to traditional synthetic grafts in trauma or contamination scenarios.

Breuer *et al.* (2023) demonstrated the relevance of in vivo recellularization in humans and evolution to living vessels in hemodialysis patients; these results motivated clinical trials and initial regulatory approvals for limited applications in trauma. Comparatively, decellularized grafts have better biocompatibility and less inflammatory response than synthetic prostheses (e.g., PTFE) in contaminated environments, but long-term durability and behavior under high flow are still under study.

Authors such as Kirkton *et al.* (2020) describe the evolution of *Bioengineered Human Acellular Vessels* (HAV). These acellular conduits derived from human cells have been implanted in humans (initial indications: hemodialysis and, recently, trauma/vascular applications) and have shown cell repopulation and evolution to "living vessels" after implantation, with acceptable patency in short- to medium-term follow-up.

This case illustrates that some technologies have already passed the preclinical phase and reached controlled human application, while others (bioprinting, complex scaffolds) remain in the translational phase (Kirkton *et al.*, 2020).

According to Kirkton et al. (2020), they discuss whether the priority is currently to treat vascular trauma with *off-the-shelf* material: commercially developed acellular grafts (e.g., HAV) show viability in selected applications and may be preferable when autologous vein is not available and the risk of infection makes synthetic prostheses inadvisable.

However, if the priority is innovation for complex cases with time for planning (delayed reconstruction), recellularized scaffolds and 3D bioprinting allow for customized reconstructions, especially for extensive defects or when donor morbidity is to be minimized (Abdollahi *et al.*, 2020). While adjuvant therapies (exosomes/MSCs) are useful for promoting microvascularization of the recipient bed and potentially increasing the survival of compromised flaps, their clinical use in trauma requires further randomized trials (Tan *et al.,* 2024).

In the context of practical recommendations for trauma centers, Wahlgren et al. (2025) emphasize the need for integrated multidisciplinary teams, including a vascular surgeon/trauma surgeon or orthopedist, microsurgeon/plastic surgeon, interventional radiologist, anesthesiologist experienced in massive hemorrhage, perioperative nursing staff, and perfusionist or specialized technological support. In addition, early team activation has proven to be essential in reducing diagnostic and therapeutic delays, contributing to better clinical outcomes.

In contrast, Holmberg *et al*. (2025) emphasize that, whenever possible, access to a hybrid room (angiography + surgical capacity) or a rapid transfer plan to it should be available. The hybrid room allows for immediate endovascular action, conversion to open surgery, and reduces transit time, which is crucial in patients with active bleeding. Studies such as those by the authors above observe gains in efficiency and less blood loss in centers with THOR/hybrid OR.

Prichayudh *et al*. (2023) highlight that the use of emerging technologies (acellular grafts/HAV, biofunctionalized scaffolds) can be considered in centers with experience and in research/compassionate use protocols; in acute trauma, many technologies require logistics (preparation time) that limit immediate use, however, some off-the-shelf options (HAV) have already begun to appear in selected applications. Because of this, teams need to maintain links with research centers and ethics committees to participate in clinical studies (Prichayudh *et al.,* 2023).

Technological and conceptual advances, including supermicrosurgery, endovascular and hybrid approaches, three-dimensional planning, and tissue engineering strategies, have already promoted significant changes in post-traumatic vascular reconstruction, reflected in higher limb salvage rates and better functional outcomes. However, the consolidation of these innovations still depends on the production of high-quality evidence, especially through prospective studies and randomized clinical trials in traumatic settings, in order to establish robust and standardized clinical guidelines (Qi et al., 2024).

Therefore, multidisciplinary integration, investment in microsurgical training, monitoring, and hybrid infrastructure are immediate measures that can optimize outcomes. In the medium and long term, bioartificial grafts and immune tolerance induction strategies may further expand reconstructive options, reducing dependence on autologous grafts and decreasing donor morbidity.

Although it provides a comprehensive and up-to-date overview of innovations in post-traumatic vascular reconstructive surgery, this study has some limitations. Many of the studies available in the literature are case series, observational studies, or early-phase trials, which limits the strength of the evidence and may lead to undue generalizations. Another relevant aspect is that some of the technologies discussed (such as bioartificial grafts, bioprinting, and cell therapies) are still in the experimental or translational phase, restricting their immediate applicability to clinical practice. Finally, regional and economic barriers related to the implementation of these innovations in different health contexts were not explored, which may impact the external validity and applicability of the findings in resource-limited settings. Thus, further studies should be conducted to elucidate these points.

CONCLUSION

The last decade has consolidated technological and conceptual advances in post-traumatic vascular reconstruction, with the integration of supermicrosurgery, perforating flaps, endovascular techniques, hybrid approaches, and 3D planning, which have expanded therapeutic options and favored better outcomes, especially in centers with specialized infrastructure. At the same time, translational innovations such as bioengineered grafts, bioprinting, and cell therapies signal a promising future, although they still lack robust clinical evidence and standardization for widespread use. Thus, current practice is already more effective and multifaceted than it was ten years ago, but its consolidation depends on the efficient integration of available tools, the strengthening of multidisciplinary teams, and engagement in research that validates sustainable long-term gains.

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