European Journal of Clinical Pharmacy
Print ISSN: 2385-409X **Online ISSN**: 3105-0409
Website: https://farmclin.com/

Original Research Article

Modern Aspects of Vascular and Endovascular Surgery

Article History:

Name of Author:
Borisov Yaroslav Sergeevich[1], Prikhodko Ekaterina Olegovna[2], Gamzaev Ramazan-Ali Salmanovich[3], Kalinchenko Nina Vadimovna[4], Magomedov Murad Badirkhanovich[5], Sharifov Shikhemil Khanpashevich[6], Magomedov Vagid Abdulbasirovich[7] and Nasekina Avelina Andreevna[8]

Affiliation: *[1]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Borisov Ya.S.)*
[2]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Prikhodko E.O.)
[3]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Gamzaev R.-A.S.)
[4]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Kalinchenko N.V.)
[5]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Magomedov M.B.)
[6]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Sharifov. Sh.Kh)
[7]Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Magomedov V.A.)
8Student, Institute of Medicine and Health Preservation named after G. R. Derzhavin, Russian Federation, Tambov (Nasekina A.A.)
Corresponding Author:

Abstract: Vascular diseases are highly prevalent, and population aging significantly increases the relevance of vascular pathology. At the same time, the demand for vascular surgical services has been rising, as such interventions markedly improve both quality of life and life expectancy. This trend stimulates the development and implementation of innovations in the field of vascular medicine. In recent decades, the armamentarium of vascular surgeons has expanded to include robotic platforms, artificial intelligence systems, advanced 3D visualization, and telemedicine technologies. The aim of this article is to analyze current trends in innovations emerging in vascular surgery.

Keywords: endovascular intervention, stents, robot, artificial intelligence, telemedicine.

Borisov Yaroslav Sergeevich

Received: 28-11-2025
Revised: 05-12-2025
Accepted: 12-01-2026
Published: 28-01-2026

INTRODUCTION

Cardiovascular diseases (CVDs) are highly prevalent and affect more than 230 million people worldwide. The number of CVD cases is projected to increase substantially over the next 30 years. Traditional risk factors for CVD include diabetes, smoking, and advanced age. CVDs are associated with peripheral arterial disease due to shared pathogenetic mechanisms such as dyslipidemia, inflammation, and thrombosis. Many of these pathological processes may lead to vascular obstruction, including occlusion of the coronary arteries and lower-limb vessels [1, 2]. Acute occlusion often presents as a life-threatening condition and requires urgent surgical intervention.

Vascular surgery has demonstrated remarkable progress in recent decades, largely attributable to advances in technology and the introduction of new therapeutic approaches. Vascular surgeons frequently manage terminal stages of atherosclerosis and diabetes; however, access to vascular surgical care remains uneven across countries, populations, and social groups, which significantly limits the dissemination of the most advanced practices [3]. Moreover, despite the growing demand for vascular procedures, there is a shortage of qualified vascular surgeons, including in European countries [4]. These challenges have partly driven the emergence of technological innovations and improvements in vascular surgery training systems worldwide. These developments require further investigation and analysis.

The relevance of this article is determined by the high prevalence of cardiovascular pathology, the technological advances accumulating in vascular surgery, and the evolving training systems for specialists in this field in recent decades.

The aim of this study is to examine and analyze contemporary achievements and innovations in vascular surgery.

MATERIALS AND METHODS

A literature search was conducted in the KyberLeninka, PubMed, and Google Scholar databases using the following key terms: “vascular surgery,” “vascular stenting,” “endovascular surgery,” and “history of vascular surgery.”

Preference was given to publications from recent decades; however, earlier works were included for topics related to the history of vascular surgery. Articles were selected if they were open-access and relevant to the subject of this study. The filtering process was performed in several stages: by article title, by abstract analysis, and by full-text review.

RESULTS

Vascular Surgery: Retrospective and Contemporary Perspectives

The history of vascular surgery dates back to ancient times, largely due to the high rates of trauma accompanying early stages of human development. The earliest methods of controlling vascular bleeding included cauterization, compression (with bandages, straps, or cords), and the application of plant-based mixtures. Although vessel ligation was first proposed by Aulus Cornelius Celsus two thousand years ago, it was forgotten for nearly fifteen centuries until it was reintroduced in 1552 by Ambroise Paré. Subsequent progress was directed toward improving vessel ligation techniques and developing hemostatic forceps, clamps, hooks, and methods of compression hemostasis.

The first lateral vascular suture, used to preserve the vessel and the limb, was performed in the second half of the 18th century by Richard Lambert. However, widespread adoption of such sutures occurred only 130 years later. In the late 19th century, Mathieu Jaboulay proposed a circular anastomotic suture in which the apposed vessel edges contacted only at the intimal surface, which minimized thrombosis. Further efforts of surgeons focused on developing new methods of surgical hemostasis, creating patterns for anastomoses, designing biological and synthetic grafts, and improving surgical instrumentation [5].

A significant contribution to the development of vascular surgery was made by F.W. Blaisdell (Frank William Blaisdell). He performed the first axillofemoral bypass for acute occlusion of an aortofemoral graft, first described the role of cerebrospinal fluid pressure changes in spinal cord ischemia after temporary thoracic aortic occlusion, and contributed substantially to defining the role of carotid endarterectomy (stroke reduction and other outcomes) as well as advancing the understanding of coagulation [6].

The initial phase of vascular surgery is considered to have concluded around the 1970s with the invention of Gore-Tex, which was later used in the production of vascular prostheses [5]. The subsequent development of vascular surgery is characterized by a transition from open procedures to minimally invasive laparoscopic and endovascular operations. A major step toward laparoscopic vascular surgery was taken in 1993, when Y.M. Dion performed a laparoscopically assisted aortobifemoral bypass. Since then, various endoscopic techniques have been developed to treat aneurysms and occlusions of the aortoiliac segment. The number of endovascular procedures continues to increase, supported by the integration of robotic platforms [7].

Dotter C.T. and Judkins M.P. were the first to report eleven cases of endovascular procedures on lower-extremity vessels in 1964. According to the authors, "percutaneous transfemoral catheter dilatation of the segmental femoral artery was performed within minutes." However, several cases were complicated by thrombosis, which led to amputation [8]. Over time, the practice of endovascular interventions expanded to other regions of the circulatory system, including the coronary arteries.

It is noteworthy that vascular procedures are not performed exclusively by vascular surgeons in all countries, and the organization of care for patients with vascular pathology varies considerably. Advanced endovascular procedures are typically carried out in large academic centers. In most vascular centers in Canada, peripheral endovascular interventions and endovascular aneurysm repair are routinely performed. Procedures involving the ascending aorta or aortic arch are conducted by cardiac surgeons, whereas interventions on the descending aorta are performed by vascular surgeons and/or cardiac surgeons. Carotid artery stenting is performed by interventional surgeons or neurosurgeons, while carotid endarterectomy is carried out by vascular surgeons. Venous stripping and sclerotherapy of the lower extremities are reimbursed by the public healthcare system. Endovenous treatment is generally available in private clinics in Canada [9].

In Colombia, despite economic challenges, more than 96% of the population is covered by the national health insurance system, and vascular procedures are included in the coverage. Unlike Canada, carotid stenting in Colombia is performed by neurointerventional radiologists. Decisions regarding the type of intervention are made through multidisciplinary discussion. Endovascular repair of abdominal aortic aneurysm is performed by vascular surgeons. Phlebology is not recognized as a separate specialty in Colombia and is considered one of the principal areas of vascular surgery. Trauma ranks third among the leading causes of mortality in the country, and trauma patients, including those with vascular injuries, are treated by general surgeons [10].

In Russia, high-technology cardiovascular care is concentrated in Federal Centers of Cardiovascular Surgery, where both elective and emergency procedures are performed. A steady increase is observed in the number of cardiovascular interventions, including heart valve reconstruction, myocardial revascularization, implantation of artificial pacemakers, and complex congenital heart defect repairs in children, among others [11].

In the review by Yu.L. Shevchenko, the main directions for the development of modern surgery are outlined. These include expansion of surgical capabilities (intraoperative diagnostics, 3D visualization, precise positioning, robot-assisted surgery, alternative methods of intervention and cardiac function replacement), minimization of tissue trauma (endovascular and other minimally invasive techniques), interdisciplinary collaboration through telecommunication and telemedicine, and optimization of patient rehabilitation [12].

Vascular Interventions

Endovascular procedures once revolutionized the field of vascular surgery, establishing themselves as a minimally invasive alternative to open vascular operations. The shift toward percutaneous access, shorter hospital stays, and reduced perioperative complications led to a gradual replacement of traditional open vascular surgery [13]. For example, in the treatment of aortic aneurysms, laparotomy–thoracotomy or an abdominal incision was poorly tolerated by most patients and was associated with a higher rate of perioperative complications. Although endovascular aortic repair demonstrated lower mortality risks than open repair within the first six months, the long-term eight-year outlook showed a substantial increase in risks associated with the endovascular approach [14]. Expectations for improving these outcomes are increasingly linked to the growing adoption of robotic surgery.

Angioplasty (with or without stenting) is a procedure aimed at enlarging the lumen of coronary arteries obstructed or narrowed due to atherosclerotic processes. The procedure involves inserting a catheter with an inflatable balloon through the skin of the extremities into the vascular system (via transradial or transfemoral access) and advancing it to the site of occlusion. The balloon is then inflated, expanding the stenotic segment, compressing the atherosclerotic plaque against the arterial wall, and restoring the vessel lumen. Percutaneous coronary intervention (PCI) with stent implantation is performed in severe forms of coronary artery disease. A stent is a hollow cylindrical structure with a mesh-like metallic wall. Bare-metal stents caused endothelial injury, followed by inflammation, neointimal hyperplasia (intimal thickening), and restenosis. As a result, stents coated with antiproliferative drugs (such as everolimus) were developed. Later, bioresorbable stents emerged; they gradually degrade and disappear over time [15, 16].

The scope of stenting is extensive, and it is used in vasorenal hypertension (stenting of stenotic renal arteries), postoperative thrombosis (portal vein stenting and thrombectomy), and other conditions. In addition, in several diseases (tumors, hemorrhage, etc.), various forms of vascular embolization are employed to eliminate local blood flow [17, 18]. Stenting of the carotid arteries is associated with a higher rate of stroke within the 30-day postoperative period compared with traditional carotid endarterectomy (9.2% vs. 3.1–6.2%). This led to the development of dual-layer stents (nitinol stents with mesh coverings) capable of capturing and removing thrombotic and plaque debris from the bloodstream [19]. Avoiding internal carotid artery stenting in patients after mechanical thrombectomy resulted in an increased incidence of ineffective intracranial reperfusion [20].

Endovascular surgery also includes procedures such as inferior vena cava filter placement (for thrombus filtration), TIPS (transjugular intrahepatic portosystemic shunting), regional chemotherapy (delivery of therapeutic agents into the target organ through the vascular system), and thrombolysis (catheter-directed dissolution of a thrombus) [21].

In patients with intermittent claudication who do not respond to prior conservative therapy, lower-limb revascularization may be performed, particularly in cases of chronic limb-threatening ischemia. Both endovascular and open surgical interventions may be used. The advantages of endovascular surgery include minimal invasiveness, the possibility of using local anesthesia, reduced perioperative risks, and shorter recovery time [22]. The benefits of endovascular interventions over open surgery are still being debated. In a study by A. Farber et al., in patients with limb-threatening ischemia, the primary outcome (amputation or major reintervention) occurred in 42.7% of patients in the surgical group (revascularization using the great saphenous vein) and in 57.4% in the endovascular group. The authors concluded that open surgical treatment demonstrated greater durability [23]. Opposite findings were reported in a phase 3 randomized clinical trial (United Kingdom, Sweden, Denmark; n = 345), where outcomes of venous bypass surgery and endovascular intervention (balloon angioplasty + drug-eluting stents) were compared in patients with severe lower-limb ischemia. Major amputation or death occurred in 63% of patients in the bypass group and in 53% in the endovascular group ($p = 0.037$). Thus, endovascular treatment was associated with higher amputation-free survival and fewer deaths [24]. Additional clinical trials are needed to establish clear indications that would allow optimal use of the advantages of endovascular surgery.

Vascular procedures can be accompanied by complications, especially in extensive interventions. One of the most common intraoperative complications is vascular hypotension, with a reported incidence ranging from 8% to 88% (a decrease in systolic blood pressure below 30 mm Hg), which leads to prolonged hospitalization [25]. Patients who undergo vascular surgery for abdominal aortic aneurysm frequently develop cardiac, respiratory, renal, gastrointestinal, and hematologic complications. Neurological complications are more commonly observed after endarterectomy performed for carotid artery stenosis. Following aorto-femoral bypass grafting, diabetes decompensation is reported more often than after other vascular procedures [26].

Human factors may hinder optimal outcomes in vascular surgery. Adverse postoperative events occur in approximately 14% of surgical patients, with up to 10% classified as severe and 3.6% resulting in mortality. Along with medication-related errors, operating room errors constitute one of the leading causes of death in healthcare. The most frequent contributing factor is lack of communication. Team-based simulation in the training of future vascular surgeons is endorsed by the European Society for Vascular Surgery (ESVS). In addition, vascular interventions negatively affect the physical ergonomics of vascular surgeons. Increased load is placed on the neck and torso, and these procedures are associated with elevated psychological and cognitive demands [27].

Robotic surgery

Robotic surgery represents the equivalent of open surgery performed in a minimally invasive manner, using dynamic “wristed” instruments that replicate the surgeon’s hand movements inside the body. The first surgical robots (Robodoc) were developed as early as the 1980s and were initially used in urology and orthopedics. Further developments in this field were supported by the U.S. Department of Defense, with the aim of creating a fully autonomous electromechanical surgeon capable of providing assistance to wounded personnel on the battlefield. The foundation for modern robotic platforms was laid by the Green Telepresence System, which included a working surgical console and a remote operative unit. This system, originally designed for open surgery, was quickly adapted for laparoscopic procedures. Early trials of surgical robotic systems were performed in vascular interventions. For many years, two leading companies in the field, Computer Motion (the Zeus robot) and Intuitive Surgical (the da Vinci robot), competed in surgical robotics. In 2003 the companies merged, and the unified enterprise continued producing the da Vinci line, which became the standard of modern robotic surgery. Today the da Vinci robotic platform is used for vascular procedures, including repair of infrarenal aortic aneurysm, thoracofemoral bypass, treatment of type II endoleak after aortic endoprosthesis placement, repair of splenic artery aneurysm, median arcuate ligament release, left renal artery transposition, and thrombectomy of the inferior vena cava [13].

The da Vinci surgical system consists of three components: the surgeon's console, the patient-side cart, and the vision cart. The surgeon sits in an ergonomic position at the console, viewing the operative field through a stereoscopic viewer that provides a three-dimensional image. Hand and foot controls convert the surgeon's own movements into micromotions at the tips of the instruments. The patient-side cart typically includes four robotic arms that hold the instruments and/or endoscopic equipment. The vision cart contains the optical and processing units that provide visualization of the surgical field, including fluorescent imaging with the Firefly dye.

A total of five generations of the da Vinci robotic system have been developed. The first robot was released in 1999, followed by successive modifications leading to the da Vinci S (2006), da Vinci Si (2009), da Vinci Xi (2014), da Vinci SP (2018), and da Vinci 5 (2024). The system provides high-quality three-dimensional magnification, and its wristed instruments (EndoWrist technology) replicate the full range of human hand motion with seven degrees of freedom. Motion scaling allows the operating surgeon to precisely adjust the ratio between hand movement and instrument motion. A 5 mm movement of the hand can be translated into a 1 mm movement of the instrument tip, increasing precision during all manipulations. In vascular surgery this facilitates arteriotomy and anastomosis creation and reduces the number of inadvertent injuries.

The system is also capable of filtering out the surgeon's physiological tremor, further decreasing tissue trauma and bleeding. The newest da Vinci model incorporates haptic feedback. Near-infrared fluorescence imaging enables real-time assessment of perfusion after intravenous administration of indocyanine green [28].

In a 2025 review by Y. Alsabbagh et al., publications describing more than 1,500 patients who underwent robot-assisted vascular procedures were analyzed, including aortic, venous, visceral, and decompression surgeries. The authors note that endovascular robotics enhances catheter navigation accuracy and reduces radiation exposure to the surgeon. However, the widespread adoption of this promising technology is limited by its high cost and the requirement for extensive training [29].

Artificial Intelligence in Vascular Surgery

Recent decades have been marked by rapid advances in technologies related to artificial intelligence (AI), and medicine has not remained unaffected by this trend. Artificial intelligence is defined as the use of computer algorithms to automate specific tasks with the goal of replicating human cognitive and learning processes. For example, Apple's Siri operates on AI algorithms that enable it to perceive, recognize, and respond to human speech in a manner similar to that of a person. As digital assistants continuously learn, they become increasingly accurate in their responses and interactions [30].

Deep learning, a subset of AI, ultimately manifests as an exceptional ability to recognize, classify, and detect patterns in large datasets, which makes AI attractive to virtually all medical specialties. Today AI is utilized in the management of vascular diseases, including aortic aneurysms, peripheral vascular disorders, carotid artery stenosis, and venous diseases of the lower extremities [31].

The four main areas of AI—natural language processing, artificial neural networks (ANNs), computer vision, and machine learning—are utilized for screening and diagnosing vascular diseases, as well as for developing predictive models that assess the risks of various clinical scenarios. Machine learning methods have been applied for diagnosis, prognosis, and image segmentation in cases of carotid artery stenosis, aortic aneurysm or dissection, peripheral arterial and venous disease, and renal artery stenosis. AI-related computer vision is aimed at creating systems for automatic detection and characterization of arterial lesions based on Doppler ultrasound or CT angiography data [32, 33].

The use of CT (ultrasound, MRI) image segmentation with convolutional neural networks has enabled objective assessment of the abdominal aorta (and carotid arteries), evaluation of wall calcification, and calculation of cardiovascular risk [34]. AI in vascular disease is relevant not only at the diagnostic stage but also throughout the perioperative period, assisting in vascular assessment, risk stratification, and prediction of postoperative outcomes [35].

In a study by B. Li et al., the concept of virtual assistants was presented, and their potential benefits for vascular surgery for both clinicians and patients were described [36]. With advancements in AI and machine learning, virtual assistants are becoming increasingly sophisticated and demonstrate significant potential for improving healthcare delivery in areas such as diagnosis, treatment, and education. In hospitals in Toronto, an early warning system monitors patients for increased risk of mortality or ICU admission. It is estimated that virtual assistants could automate 15–35% of all healthcare working hours [37]. A recently developed AI-based virtual assistant allows intraoperative identification of suboptimal stent placement during endovascular repair of abdominal aortic aneurysms with high precision [38].

Telemedicine in Vascular Surgery

Telemedicine in vascular surgery has a wide range of applications, from patient monitoring to remote aneurysm repair [39, 40]. In a review by M.I. Herrera et al., which included 29 publications, it was shown that only 65.5% of articles on telemedicine in vascular surgery reported its use for teleconsultations and postoperative follow-up. Another 20.6% of articles focused on the establishment of virtual clinics specializing in vascular surgery, including postoperative care and consultations. Only 17.2% of articles addressed the role of telemedicine in direct patient treatment.

The review highlighted the most relevant examples of telemedicine applications in vascular surgery:

- Remotely controlled robots for endovascular aneurysm repair;
- Remote neuromonitoring of spinal cord function during open repair of descending thoracic and thoracoabdominal aortic aneurysms;
- Mobile applications (e.g., Walk Mate) for patient tracking and voice-based exercise guidance, where GPS-based devices calculate speed and distance covered;
- Use of digital biomarkers for patient classification to distinguish between those requiring standard care and those needing complex care or vascular surgery;
- Telemedicine systems for postoperative care, including wound monitoring and home-based consultations after vascular interventions [41].

The most likely future of telemedicine in vascular surgery appears to be operative telepresence for patients with vascular pathology. Telemedicine-assisted interventions allow procedures to be performed remotely, which can be especially relevant for patients in remote areas or for those unable to travel to the surgical center.

Training of Vascular Surgery Specialists

In the 1970s and 1980s, issues related to education, certification, and specialization in vascular surgery came to the forefront. Specialized certification in general vascular surgery became an important step in establishing it as a distinct field. At the same time, the endovascular revolution was emerging. Interventional radiologists, due to their access to imaging tools, considered percutaneous interventions to be within their domain and did not support the training of other physicians. In 1989, a group of doctors in Springfield (USA) organized specialized training in a well-equipped angiography suite, and the training outcomes were excellent. Vascular surgeons expanded the possibilities of endovascular aortic therapy, and some successfully attempted to integrate endovascular units into the operating room. By 2009, more than 80% of fellowship positions in endovascular surgery were occupied by vascular surgeons. Nevertheless, challenges and conflicts arose due to competition from surgeons in related specialties [42].

The sustained growth in demand for vascular surgery highlights the importance of improving the quality of vascular surgeon training. Adequate specialist preparation requires access to optimal educational resources and sufficient training duration. Despite the significance of vascular surgery education, relatively few publications on this topic have been released, and more than 60% of them focus on the use of training simulators [43].

Cadaveric training is considered the gold standard for simulation-based education. However, its application is limited due to the scarce availability of cadavers, lack of "training" pathology, high costs, and ethical considerations. As a more cost-effective alternative, artificial bench simulators and box trainers have been developed to practice procedural skills outside the operating room. In the late 1990s, virtual reality (VR) simulators adapted to trainee needs were introduced. Immersive VR, using a head-mounted display, combines elements of both virtual and real-world training. The adoption of virtual technologies was further accelerated by the COVID-19 pandemic, during which forced lockdowns gradually changed the paradigm of surgical education. The ultimate goals of such training are competence and the development of expert skills [44].

The shortage of vascular surgeons necessitates additional recruitment of young specialists and appropriate training [4]. In a study by L.B. Davidovic et al., the authors emphasized the need for dedicated fellowships in aortic surgery or complex aortic procedures, as the rise of endovascular techniques reduces trainees' exposure to open aortic surgery. At the same time, conversion to open surgery after a failed endovascular procedure can be highly challenging. Training of new fellows employs both simulators (which are costly) and virtual reality programs (an effective and inexpensive alternative) [45].

An effective educational curriculum with maximal cost-effectiveness is highly important for healthcare and vascular surgery in particular. Involving high-level vascular surgeons in training is economically demanding. In the PROSPECT study (Proficiency-Based Stepwise Endovascular Curricular Training), trainee surgeons learned and practiced basic endovascular maneuvers for atherosclerotic disease without direct instructor guidance. The program combined manual skills training on simulators with e-learning. This form of knowledge acquisition outperformed traditional instruction. Nevertheless, students learned through two approaches, and the type of training sessions did not affect overall learning outcomes [46].

In the United States, vascular surgery trainees take an annual in-training examination (VSITE), the results of which correlate with successful completion of the written Vascular Qualifying Exam (VQE) and the oral Vascular Certifying Exam (VCE) [47].

In Russia, postgraduate training in cardiovascular surgery is conducted exclusively for graduates of medical faculties, based on the Order of the Ministry of Education and Science of the Russian Federation dated August 25, 2014, No. 1106 "On Approval of the Federal State Educational Standard for Higher Education in the Specialty 31.08.63 'Cardiovascular Surgery' (Level of Training for Highly Qualified Personnel)" [48]. Thus, there is currently no unified, internationally approved training and certification system in vascular surgery, and multiple international discussions (conferences, meetings) will likely be required to standardize education and skills in vascular surgery, particularly in light of the increasing technological complexity in this field of medicine.

DISCUSSION

The reviewed publications on the current state of vascular surgery demonstrate the absence of a stable set of knowledge and skills sufficient for a new specialist to fully master in this field. This is due to the rapid increase in the number of techniques, approaches, and technologies, as well as changes in the technological work environment, observed over the past decades and continuing in real time. In addition to the scientific and technical acceleration of previous centuries, associated with the general accumulation of knowledge and the development of new operative protocols, a number of inventions have also provided impetus for further research in vascular surgery. Key milestones include the introduction of laparoscopy (endoscopy), stenting, the invention of cardiopulmonary bypass devices, pharmaceutical advances (anticoagulants, anesthesia, etc.), the emergence of robotic systems, 3D visualization, artificial intelligence, and telemedicine.

Healthcare systems in various countries, particularly those with limited resources, often lack sufficient means to implement these latest developments and provide adequate training for both practicing and new specialists. Furthermore, the concentration of inventions and manufacturing (and patent systems) in certain countries makes the dissemination of technologies themselves (rather than final products) to other regions of the world challenging. Consequently, there are certain limitations in diversity on the market: for example, the leading robotic platform for surgical interventions remains the da Vinci system, for which no equivalent competitive systems exist. Nevertheless, it should be noted that this system, in addition to suppressing tremor, reduces surgeon motor errors, decreasing trauma and unplanned bleeding. Of course, there is a risk of gradual loss of tactile skills, but the latest da Vinci model includes a haptic feedback device that partially addresses this issue.

Taking all of this into account, analyzing general trends, it can be hypothesized that the ultimate goal of many developments may be the creation of a fully autonomous robotic system, integrated with artificial intelligence and telemedicine, capable of providing assistance without human involvement. Of course, such a prospect still seems infinitely distant; however, given the increasing complexity of vascular procedures, the "branching" of vascular specializations, and the shortage of specialists, it can be assumed that some corporations are already working in this direction. Moreover, it can be speculatively suggested that future directions in vascular surgery may focus on addressing issues of small-caliber vessels, which, when affected in multiple locations, can significantly impair local hemodynamics.

CONCLUSION

The most relevant aspects of modern vascular and endovascular surgery include the emergence and implementation of robotic platform technologies, artificial intelligence with telemedicine, and high-quality 3D visualization. These developments effectively distance the vascular surgeon from the operative field and, consequently, from the patient. Further advancements will likely lead to even greater autonomy of the technical aspects of vascular surgery from the operating surgeon, whose role may ultimately (in the future) be reduced to supervising the functioning of the "robot-AI tandem."

REFERENCES

1. Aday A.W., Matsushita K. Epidemiology of Peripheral Artery Disease and Polyvascular Disease. / A.W. Aday, K. Matsushita // Circ Res. – 2021. – Vol. 128(12). – Pp. 1818-1832. doi: 10.1161/CIRCRESAHA.121.318535.
2. Joynt Maddox K.E., Elkind M.S.V., Aparicio H.J., Commodore-Mensah Y., de Ferranti S.D., Dowd W.N., Hernandez A.F., Khavjou O., Michos E.D., Palaniappan L., Penko J., Poudel R., Roger V.L., Kazi D.S. Forecasting the Burden of Cardiovascular Disease and Stroke in the United States Through 2050—Prevalence of Risk Factors and Disease: A Presidential Advisory From the American Heart Association. / K.E. Joynt Maddox, M.S.V. Elkind, H.J. Aparicio, et al. // Circulation. – 2024. – Vol. 150(4). – Pp. e65-e88. doi: 10.1161/CIR.0000000000001256.
3. Barshes N.R., Minc S.D. Healthcare disparities in vascular surgery: A critical review. / N.R. Barshes, S.D. Minc // J Vasc Surg. – 2021. – Vol. 74(2S). – Pp. 6S-14S.e1. doi: 10.1016/j.jvs.2021.03.055.
4. Barth U., Meyer F., Halloul Z. Lack of experienced surgeons in vascular surgery—A joint task. / U. Barth, F. Meyer, Z. Halloul // Chirurgie (Heidelb). – 2023. – Vol. 94(9). – Pp. 780-788. doi: 10.1007/s00104-023-01900-2.
5. Glyantsev S.P., Shchelkunov N.B., Gekova T.Yu. Evolution of Innovations in Vascular Surgery. / S.P. Glyantsev, N.B. Shchelkunov, T.Yu. Gekova // Verkhnevolzhsky Medical Journal. – 2016. – Vol. 11. – Iss. 3. – Pp. 4-10.
6. Goldstone J. Pioneers in Vascular Surgery: F. William Blaisdell. / J. Goldstone // J Vasc Surg. – 2021. – Vol. 74(5). – Pp. 1763-1764. doi: 10.1016/j.jvs.2021.03.026.
7. Nio D., Diks J., Bemelman W.A., Wisselink W., Legemate D.A. Laparoscopic vascular surgery: a systematic review. / D. Nio, J. Diks, W.A. Bemelman, W. Wisselink, D.A. Legemate // Eur J Vasc Endovasc Surg. – 2007. – Vol. 33(3). – Pp. 263-271. doi: 10.1016/j.ejvs.2006.10.004.
8. Dotter C.T., Judkins M.P. Transluminal Treatment of Arteriosclerotic Obstruction: Description of a New Technic and a Preliminary Report of Its Application. / C.T. Dotter, M.P. Judkins // Circulation. – 1964. – Vol. 20(5). – Pp. 654-670. https://doi.org/10.1161/01.CIR.30.5.654.
9. Boyd A.J. Vascular Surgery in Canada: Challenges in the Great White North. / A.J. Boyd // Eur J Vasc Endovasc Surg. – 2021. – Vol. 62(6). – Pp. 842-844. doi: 10.1016/j.ejvs.2021.08.025.
10. Muñoz A. Vascular Surgery in Colombia: Art and Science in Evolution. / A. Muñoz // Eur J Vasc Endovasc Surg. – 2021. – Vol. 62(2). – Pp. 155-157. doi: 10.1016/j.ejvs.2021.06.005.
11. Bogachevskaya S.A., Bogachevskiy A.N., Bondar V.Yu. Three-Year Contribution of Federal Centers for Cardiovascular Surgery to the Development of High-Tech Medical Care for Patients with Cardiovascular Diseases in Russia. / S.A. Bogachevskaya, A.N. Bogachevskiy, V.Yu. Bondar // Electronic Scientific Jou: 10.21045/2071-5021-2016-47-1-2. URL: https://cyberleninka.ru/article/n/trehletniy-vklad-funktsionirovaniya-federalnyh-tsentrov-serdechno-sosudistoy-hirurgii-v-razvitie-vysokotehnologichnoy-meditsinskoy (accessed: 29.11.2025).
12. Shevchenko Y.L. Cardiovascular Surgery as an Indicator of the Development of Medical Science and Healthcare in a Country: Main Trends. / Y.L. rnal. Social Aspects of Population Health. – 2016. – No. 47. – Pp. 1-19. doiShevchenko // Corporate Health and Industrial Medicine. – 2024. – Vol. 1. – No. 1. – Pp. 8-19.
13. Lengyel B.C., Chinnadurai P., Corr S.J., Lumsden A.B., Bavare C.S. Robot-assisted vascular surgery: literature review, clinical applications, and future perspectives. / B.C. Lengyel, P. Chinnadurai, S.J. Corr, A.B. Lumsden, C.S. Bavare // J Robot Surg. – 2024. – Vol. 18(1). – Pp. 3-28. doi: 10.1007/s11701-024-02087-2.
14. Antoniou G.A., Antoniou S.A., Torella F. Editor's choice—endovascular vs. open repair for abdominal aortic aneurysm: systematic review and meta-analysis of updated peri-operative and long-term data of randomized controlled trials. / G.A. Antoniou, S.A. Antoniou, F. Torella // Eur J Vasc Endovasc Surg. – 2020. – Vol. 59(3). – Pp. 385–397. doi: 10.1016/j.ejvs.2019.11.030.
15. Chhabra L., Siddiqui W.J. Angioplasty. / L. Chhabra, W.J. Siddiqui // In: StatPearls [Internet]. 2023 Aug 7. Treasure Island (FL): StatPearls Publishing; 2025. PMID: 29763069. URL: https://www.ncbi.nlm.nih.gov/books/NBK499894/(accessed: 29.11.2025).
16. Jimenez-Quevedo P., Bernardo E., Del Trigo M., Otsuki S., Nombela-Franco L., Brugaletta S., et al. Vascular injury after stenting—insights of systemic mechanisms of vascular repair. / P. Jimenez-Quevedo, E. Bernardo, M. Del Trigo, S. Otsuki, L.

Nombela-Franco, S. Brugaletta, et al. // Circ J. – 2022. – Vol. 86(6). – Pp. 966-974. doi: 10.1253/circj.CJ-21-0649.
17. Volkov S.V., Bagin S.A., Udovichenko A.E., Korobkov A.O., Mostovoy I.V. Stenting and embolization of visceral arteries in elective and emergency surgery: experience of a multidisciplinary hospital. / S.V. Volkov, S.A. Bagin, A.E. Udovichenko, A.O. Korobkov, I.V. Mostovoy // International Journal of Interventional Cardioangiology. – 2013. – No. 35. – Pp. 32.
18. Arab S.F., Alhumaid A.A., Abu Alnasr M.T., Altuwaijri T.A., Al-Ghofili H., Al-Salman M.M., et al. Review of renal artery stenosis and hypertension: diagnosis, management, and recent randomized controlled trials. / S.F. Arab, A.A. Alhumaid, M.T. Abu Alnasr, T.A. Altuwaijri, H. Al-Ghofili, M.M. Al-Salman, et al. // J Kidney Dis Transpl. – 2022. – Vol. 33(1). – Pp. 147-159. doi: 10.4103/1319-2442.367807.
19. Stabile E., Gerardi D. Carotid artery stenting with dual-layer stent: expanding evidence with a randomized trial. / E. Stabile, D. Gerardi // JACC Cardiovasc Interv. – 2021. – Vol. 14(21). – Pp. 2388-2390. doi: 10.1016/j.jcin.2021.08.051.
20. Veunac L., Saliou G., Knebel J.F., Bartolini B., Puccinelli F., Michel P., Hajdu S.D. Revascularization of carotid artery occlusion using stenting versus non-stenting in endovascular management of tandem occlusion stroke. / L. Veunac, G. Saliou, J.F. Knebel, B. Bartolini, F. Puccinelli, P. Michel, S.D. Hajdu // J Clin Neurosci. – 2022. – Vol. 98. – Pp. 15-20. doi: 10.1016/j.jocn.2022.01.036.
21. Avduyevsky V.D., Kolbenev E.I. Endovascular surgery—a new section of radiology. / V.D. Avduyevsky, E.I. Kolbenev // Bulletin of Medical Internet Conferences. – 2013. – Vol. 3. – Iss. 11. – Pp. 13-18.
22. Houghton J.S.M., Saratzis A.N., Sayers R.D., Haunton V.J. New Horizons in Peripheral Artery Disease. / Houghton J.S.M., Saratzis A.N., Sayers R.D., Haunton V.J. // Age Ageing. – 2024. – Vol. 53(6). – pp. afae114. doi: 10.1093/ageing/afae114.
23. Farber A., Menard M.T., Conte MS., Kaufman J.A., Powell R.J., Choudhry N.K., et al. Surgery or endovascular therapy for chronic limb-threatening ischemia. / Farber A., Menard M.T., Conte MS., J.A. Kaufman, R.J. Powell, N.K. Choudhry et al. // N Engl J Med. – 2022. – Vol. 387. – 2305–16. doi: 10.1056/NEJMoa2207899.
24. Bradbury A.W., Moakes C.A., Popplewell M., Meecham L., Bate G.R., Kellyet L. al. A vein bypass first versus a best endovascular treatment first revascularisation strategy for patients with chronic limb threatening ischaemia who required an infra-popliteal, with or without an additional more proximal infra-inguinal revascularisation procedure to restore limb perfusion (BASIL-2): an open-label, randomised, multicentre, phase 3 trial. / A.W. Bradbury, C.A. Moakes, M. Popplewell, L. Meecham, G.R. Bate, L. Kellyet al. // Lancet. – 2023. – Vol. 27. – pp. 1798–1809. doi: 10.1016/S0140-6736(23)00462-2.
25. Filiberto A.C., Loftus T.J., Elder C.T., Hensley S., Frantz A., Efron P., Ozrazgat-Baslanti T., Bihorac A., Upchurch G.R.Jr., Cooper M.A. / A.C. Filiberto, T.J. Loftus, C.T. Elder, S. Hensley, A. Frantz, P. Efron, T. Ozrazgat-Baslanti, A. Bihorac, G.R.Jr. Upchurch, M.A. Cooper // Surgery. – 2021. – Vol. 170(1). – pp. 311-317. doi: 10.1016/j.surg.2021.03.054.
26. Bolognesi R., Tsialtas D., Bolognesi M.G., Assimopoulos S., Azzarone M., Volpi R. Perioperative complications following major vascular surgery. Correlations with preoperative clinical, electrocardiographic and echocardiographic features. / R. Bolognesi, D. Tsialtas, M. G. Bolognesi, S. Assimopoulos, M. Azzarone, R. Volpi. // Acta Biomed. – 2022. – Vol. 93(3). – pp. e2022255. doi: 10.23750/abm.v93i3.12961.
27. Norton J., Yule S., Darwood R. Human Factors in Vascular Surgery: A Glimpse into the Future. / J. Norton, S. Yule, R. Darwood // Eur J Vasc Endovasc Surg. – 2024. – Vol. 68(3). – pp. 290-293. doi: 10.1016/j.ejvs.2024.06.042.
28. Watson J., Lumsden A., Bavare C. Robotic-Assisted Vascular Surgery: A Clinical Perspective. // Methodist Debakey Cardiovasc J. – 2025 – Vol. 21(5) – pp. 35-48. doi: 10.14797/mdcvj.1657.
29. Alsabbagh Y., Erben Y., Jlilati A., Sarmiento J., Jacobs C., Elli E.F., Farres H. Robotic-Assisted Vascular Surgery: Current Landscape, Challenges, and Future Directions. / Y. Alsabbagh, Y. Erben, A. Jlilati, J. Sarmiento, C. Jacobs, E.F.Elli, H. Farres // J Clin Med. – 2025. – Vol. 14(20). – pp. 7353. doi: 10.3390/jcm14207353.
30. Flores A.M., Demsas F., Leeper N.J., Ross E.G. Leveraging Machine Learning and Artificial Intelligence to Improve Peripheral Artery Disease Detection, Treatment, and Outcomes. / A.M. Flores, F. Demsas, N.J. Leeper, E.G. Ross // Circ Res. – 2021. – Vol.

128(12). – pp. 1833–50. doi: 10.1161/CIRCRESAHA.121.318224.
31. Thaxton C., Dardik A. Computer Science meets Vascular Surgery: Keeping a pulse on artificial intelligence. / C. Thaxton, A. Dardik // Semin Vasc Surg. – 2023. – Vol. 36(3). – pp. 419-425. doi: 10.1053/j.semvascsurg.2023.05.003.
32. Lareyre F., Behrendt C.A., Chaudhuri A., Lee R., Carrier M., Adam C. et al. Applications of artificial intelligence for patients with peripheral artery disease. / F. Lareyre, C.A. Behrendt, A. Chaudhuri, R. Lee, M. Carrier, C. Adam et al. // J Vasc Surg. – 2023. – Vol. 77(2). – pp. 650–8.e1. doi: 10.1016/j.jvs.2022.07.160.
33. Li B., Feridooni T., Cuen-Ojeda C., Kishibe T., de Mestral C., Mamdani M., et al. Machine learning in vascular surgery: a systematic review and critical appraisal. / B. Li, T. Feridooni, C. Cuen-Ojeda, T. Kishibe, C. de Mestral, M. Mamdani, et al. // NPJ Digit Med. – 2022. – Vol. 5(1). – pp. 7. doi: 10.1038/s41746-021-00552-y.
34. Butova X., Shayakhmetov S., Fedin M., Zolotukhin I., Gianesini S. Artificial Intelligence Evidence-Based Current Status and Potential for Lower Limb Vascular Management. / X. Butova, S. Shayakhmetov, M. Fedin, I. Zolotukhin, S. Gianesini // J Pers Med. – 2021. – Vol. 11(12). – pp. 1280. doi: 10.3390/jpm11121280.
35. Fischer U.M., Shireman P.K., Lin J.C. Current applications of artificial intelligence in vascular surgery./ // Semin Vasc Surg. – 2021. – Vol. 34(4). – pp. 268–71. doi: 10.1053/j.semvascsurg.2021.10.008.
36. Li B., Beaton D., Lee D.S., Aljabri B., Al-Omran L., Wijeysundera D.N., Hussain M.A., Rotstein O.D., de Mestral C., Mamdani M., Al-Omran M. Comprehensive review of virtual assistants in vascular surgery. / B. Li, D. Beaton, D.S. Lee, B. Aljabri, L. Al-Omran, D.N. Wijeysundera, M.A. Hussain, O.D. Rotstein, C. de Mestral, M. Mamdani, M. Al-Omran // Semin Vasc Surg. – 2024. – Vol. 37(3). – pp. 342-349. doi: 10.1053/j.semvascsurg.2024.07.001.
37. How artificial intelligence is helping Toronto hospitals predict patient outcomes and save lives. // Gemini 2022. [Internet]. URL: https://www.geminimedicine.ca/post/how-artificial-intelligence-is-helping-toronto-hospitals-predict-patient-outcomes-and-save-lives (The link is active: 29.11.2025).
38. Li A., Javidan A.P., Namazi B., Madani A., Forbes T.L. Development of an artificial intelligence tool for intraoperative guidance during endovascular abdominal aortic aneurysm repair. / A. Li, A.P. Javidan, B. Namazi, A. Madani, T.L. Forbes // Ann Vasc Surg. – 2023. – Vol. 99. – pp. 96-104. https://doi.org/10.1016/j.avsg.2023.08.027.
39. Peres P., Lupson M., Dawson J. The Benefits of a Centralised Remote Surveillance Programme for Vascular Patients. / P. Peres, M. Lupson, J. Dawson // Journal of Vascular Surgery. – 2023. – Vol. 77(3). – pp. 913-921. doi: 10.1016/j.jvs.2022.10.045.
40. Riga C.V., Bicknell C.D., Rolls A., Cheshire N.J., Hamady M.S. Robot-assisted Fenestrated Endovascular Aneurysm Repair (FEVAR) Using the Magellan System. / C.V. Riga, C.D. Bicknell, A. Rolls, N.J. Cheshire, M.S. Hamady // Journal of Vascular and Interventional Radiology. – 2013. – Vol. 24(2). – pp.191–196. doi: 10.1016/j.jvir.2012.10.006.
41. Herrera M.I., Presencio L.E., Breñosa M.J., Ortega M.A., Torre D.I., Río-Solá ML.D. Systematic Review of Telemedicine and eHealth Systems Applied to Vascular Surgery. / M.I. Herrera, L.E. Presencio, M.J. Breñosa, M.A. Ortega, D.I. Torre, ML.D. Río-Solá // J Med Syst. – 2022. – Vol. 46(12). – pp. 104. doi: 10.1007/s10916-022-01895-z.
42. Dalsing MC. A changing Society for Vascular Surgery reflects the journey of vascular surgery. / M.C. Dalsing // J Vasc Surg. – 2023. – Vol. 78(5). – pp. 1132-1145. doi: 10.1016/j.jvs.2023.06.022.
43. Treffalls R.N., Treffalls J.A., Barsoum N.S., Shrestha N., Yan Q., Davies M.G. An analysis of vascular surgery education publications reveals an educational shortage. / R.N. Treffalls, J.A. Treffalls, N.S. Barsoum, N. Shrestha, Q. Yan, M.G. Davies // J Vasc Surg. – 2023. – Vol. 77(5). – pp. 1522-1530.e6. doi: 10.1016/j.jvs.2022.12.066.
44. Mao R.Q., Lan L., Kay J., Lohre R., Ayeni O.R. , Goel D.P., de SA D. Immersive virtual reality for surgical training: a systematic review. / R.Q. Mao, L. Lan, J. Kay, R. Lohre, O.R. Ayeni, D.P. Goel, D. de SA // J Surg Res. – 2021. – Vol. 268. – pp. 40-58. https://doi.org/10.1016/j.jss.2021.06.045.
45. Davidovic L.B., Milloro R., Koncar I., Zlatanovic P. Open Vascular Surgery Education: Need for the Second Step. / L.B. Davidovic, R. Milloro, I. Koncar, P. Zlatanovic // Eur J Vasc Endovasc Surg. – 2021. – Vol. 61(1). – pp. 155-156. doi: 10.1016/j.ejvs.2020.10.011.

46. Lawaetz J., Skovbo Kristensen J.S., Nayahangan L.J., Van Herzeele I., Konge L., Eiberg J.P. Simulation Based Training and Assessment in Open Vascular Surgery: A Systematic Review. / J. Lawaetz, J.S. Skovbo Kristensen, L.J. Nayahangan, I. Van Herzeele, L. Konge, J.P. Eiberg // Eur J Vasc Endovasc Surg. – 2021. – Vol. 61(3). – pp. 502-509. doi: 10.1016/j.ejvs.2020.11.003.
47. Rowe V.L., Sheahan M., Jones A.T., Moreno B.I., Perler B.A., Brown K.R., Barry C., Upchurch G.R.Jr., Aulivola B., Huber T.S. The vascular surgery in-training examination predicts performance on qualifying examination. / V.L. Rowe, M. Sheahan, A.T. Jones, B.I. Moreno, B.A. Perler, K.R. Brown, C. Barry, G.R.Jr. Upchurch, B. Aulivola, T.S. Huber // J Vasc Surg. – 2022. – Vol. 76(6). – pp. 1721-1727. doi: 10.1016/j.jvs.2022.07.014.
48. Spasennikov B.A. Professional trajectory of a physician (anesthesiology-resuscitation, surgery, cardiovascular surgery). / B.A. Spasennikov // On the Way to Civil Society. – 2024. – No. 3. [Internet] URL: https://cyberleninka.ru/article/n/professionalnaya-traektoriya-vracha-anesteziologiya-reanimatologiya-hirurgiya-serdechno-sosudistaya-hirurgiya (accessed: 29.11.2025).

