



Artificial Intelligence in the Field of Angiology and Vascular Surgery. A Current Paradigm

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Abstract

Introduction: Artificial intelligence (AI) has emerged as a transformative tool in angiology and vascular surgery, enabling advanced analysis of large volumes of clinical, genomic, and medical imaging data. Its application drives precision medicine, improves surgical planning, and optimizes clinical decision-making. **Methods:** A documentary literature review was conducted, selecting 58 relevant articles in Spanish and English from databases such as PubMed, SciELO, and ScienceDirect, using keywords such as artificial intelligence, vascular surgery, precision medicine, and advanced simulation, with inclusion criteria focused on the application of AI in angiology and vascular surgery.

Development: AI and machine learning enable automatic segmentation of vascular images, advanced Doppler analysis, and simulation of surgical procedures, facilitating more precise diagnoses and personalized treatments. In smart operating rooms, the integration of technologies such as cone-beam CT and augmented reality optimizes lesion identification and reduces complications. However, the implementation of AI faces challenges such as data protection, lack of algorithm transparency, the need for clinical validation, and ongoing training of healthcare personnel.

Conclusions: AI represents a new paradigm in angiology and vascular surgery, enhancing personalized medicine and the efficiency of the healthcare system. Nevertheless, its adoption requires overcoming technical, ethical, and organizational challenges through a multidisciplinary approach and appropriate regulation to maximize its benefits.

Keywords: Artificial intelligence, vascular surgery, precision medicine, advanced simulation.

Introduction

Artificial intelligence is defined as the ability of a machine to analyze and interpret external data and learn from it in order to achieve goals through flexible adaptation (1). It originates from an initiative conceived at the Dartmouth Conference, in 1953, during which the development of computers capable of performing tasks that require "human intelligence" was proposed. Shortly after, the concept of *machine learning* (ML, 1959) emerged to develop mathematical methods, which was applied for the first time in the resolution of linear problems. (1)

Artificial intelligence (AI) in medicine refers to the use of advanced computational algorithms and models to analyze large volumes of clinical data, medical images, and genomics, in order to improve the diagnosis, treatment, and personalized care of patients. AI makes it possible to automate administrative tasks, optimize workflows, and

increase diagnostic accuracy through machine learning and natural language processing. (2)

The impact of AI on medicine is transformative: it facilitates the early detection of diseases, improves the interpretation of medical images, and allows personalized treatments to be designed based on genomic and clinical data. In addition, AI contributes to precision medicine and real-time risk prediction, which can save lives and optimize healthcare resources. (3)

Tools such as automated medical scribes and foundational models for clinical analysis are current examples of this technological revolution. (4)

This is fundamental in the specialty of Angiology and Vascular Surgery due to its ability to integrate large volumes of clinical, genomic



and imaging data, improving the diagnosis, planning and execution of treatments. In vascular surgery, AI and advanced computational modeling enable precision medicine, adapting management to individual patient characteristics, increasing safety, effectiveness, and efficiency in clinical decision-making. (4,5)

One of the most relevant advances is the processing and automation of vascular imaging, which includes automatic vessel segmentation, estimation of movements and deformations, and the integration of these images in the guidance of endovascular procedures and open surgery. This reduces operator dependency and minimizes human error, as well as facilitating preoperative simulations that improve surgical planning. (6,7,8)

AI also contributes to innovation in smart operating rooms by combining technologies such as C-arm cone beam computed tomography (CT), and the use of augmented reality that allows the patient's anatomy to be visualized in 3D without the need for incisions, optimizing lesion identification and technical execution, reducing surgical times and complications. (8,9)

Precision medicine requires patient-centered clinical management, oriented to the unique characteristics of each individual, being of particular importance at the time of indication of invasive procedures. In the field of angiology and vascular surgery, this involves selecting the right treatment for the right patient at the right time. This is possible thanks to the emergence of powerful computer systems that are capable of storing and analyzing large data sets, in addition to the application of refined algorithms that allow the prediction of outcomes clinically (i.e., prognosis), technically or pathophysiologically. Therefore, it can be expected that the digital transformation of healthcare will improve safety and effectiveness, but also efficiency, reducing decision-making time while improving the quality of treatment decisions (utility versus futility) and thus improving cost-effectiveness. (10)

Digital health has been defined as the use of digital technologies for health. The digitization of medical records, telemedicine, patient monitoring through mobile devices (*mobile health*) or the *online* recruitment of volunteers for research studies are examples of digital health applications in clinical practice (). Artificial intelligence (AI), however, could be considered the paradigmatic example of the application of digital technology to health care. (11)

In the vascular laboratory, AI improves the reconstruction and analysis of Doppler signals to estimate blood flow in specific territories, although it still faces challenges in reaching real times due to the complexity of the algorithms. (12)

Applications include vascular image processing and automation, automatic vessel segmentation, simulation of surgical procedures, and massive data integration for outcome prediction, which opens new horizons in treatment personalization and improves the quality of clinical evidence. However, technical challenges are also analyzed, such as the complexity of the algorithms and the need to achieve real times in hemodynamic reconstructions, as well as clinical validation and effective integration into daily practice. (13,14)

The main challenges facing the implementation of artificial intelligence (AI) in clinical angiology include:

Privacy and data protection: The handling of sensitive personal data poses risks related to privacy and security, requiring strict protocols to ensure confidentiality and regulatory compliance. (15)

Lack of transparency and explainability: AI models, especially deep learning ones, often function as “black boxes”, making it difficult to

understand how their results are generated, which can lead to mistrust and ethical-legal problems. (15)

Limitations in scientific evidence: There is a lack of prospective studies and clinical trials that robustly validate the efficacy and safety of AI algorithms in vascular clinical practice, which makes their acceptance and regulation difficult. (15)

Interoperability and standardization: The integration of AI with hospital information systems is complex due to technological heterogeneity and the lack of standardized platforms to scale and share results. (15)

Resistance to change: Medical staff may be reluctant to adopt new technologies due to unfamiliarity or fear of being replaced, requiring training and change management programs. (15)

Upgrade and maintenance: AI systems must continuously adapt to changes in medical equipment, clinical protocols, and new data to avoid degradation in their performance, which is operationally and economically challenging. (15)

Ethical and legal aspects: The need for clear regulatory frameworks to ensure safety, efficacy and protection of patients' rights is critical, along with transparency and accountability in the use of AI. (15)

Finally, we find as a last barrier the application of this technology by healthcare workers, but also by patients, because if it is not used it cannot be effective. That is why the entity calls for establishing “standards, policies and processes that allow the development of responsible, scalable, equitable and sustainable AI solutions and, at the same time, ensure that safeguards for privacy, security and protection are implemented”. (16,17)

Since these are very complex measures, the OECD also proposes a series of lines of work that countries should take into account to carry out this entire process. They highlight, for example, the need to develop the skills of the professionals themselves so that they know how to handle these technologies. Continuous training would be key to this issue. (17)

It is also proposed to integrate new positions within health systems, such as data scientists or data engineers focused on AI. “The establishment of internal units and leadership positions to coordinate applications,” they say, “will be important.” Finally, the implementation of these systems must be managed in a secure manner. (18,19)

Together, these challenges require a multidisciplinary approach that includes technological development, rigorous clinical validation, staff training, and appropriate regulation to maximize the benefits of AI in clinical angiology. (20)

Finally, the massive integration of clinical and epidemiological data using AI opens up new possibilities for predicting outcomes and personalizing treatment, bringing the quality of clinical evidence closer to that of large randomized studies and improving conventional statistics in angiology and vascular surgery. (21)

AI in angiology and vascular surgery represents a current paradigm that promotes precision medicine, improves the safety and efficacy of treatments, and optimizes the efficiency of the health system in this specialty. (22)

The aim of this article is to reflect on the use of computer algorithms to implement precision medicine in the field of angiology and vascular surgery and to reflect on how artificial intelligence (AI) and advanced computational modeling are being applied in diagnosis, treatment planning, innovation and research in angiology and vascular surgery.

Methods

This research is framed within a documentary bibliographic methodology. For the collection, selection, evaluation and analysis of updated information of articles obtained in Cuban and foreign journals, electronic media were used in different repositories with the support of metasearch engines indexed in the electronic databases PubMed, BVS, Academy Google, Lilacs, Medline, ScienceDirect, SciELO and Redalycs, using the different Boolean operators that served as a documentary source on the subject to be developed. Keywords verified in MeSH and DeCS were used: Artificial intelligence, vascular surgery, precision medicine, advanced simulation. A search limit was established with inclusion criteria oriented to artificial intelligence and its application in Angiology and Vascular Surgery, where a total of 100 articles were obtained and 58 were selected; of which 35 published in Spanish and 23 in English.

Development

AI Basics in Medicine

Definition of artificial intelligence and machine learning

Artificial Intelligence (AI) refers to the branch of computer science that develops systems and algorithms capable of performing tasks that normally require human intelligence, such as pattern recognition, decision-making, and natural language processing. In medicine, AI makes it possible to analyze large amounts of clinical data, medical images, and genomics to support diagnoses, personalized treatments, and efficient resource management. (23)

Machine Learning (ML) is a sub-area of AI that is based on the development of algorithms that learn automatically from data, without being explicitly programmed for each task. In medicine, ML is used to detect complex patterns in medical data, predict clinical outcomes, classify diagnostic images, and optimize treatment plans. (23,24)

Advanced Computational Modeling and Its Relevance

Advanced computational modeling consists of the creation of mathematical models and simulations that represent complex biological, physiological, or clinical processes. In medicine, these models allow us to simulate the behavior of the vascular system, predict the evolution of diseases, and plan surgical interventions with greater precision. (24,25)

Their relevance lies in the fact that they facilitate precision medicine, by integrating individual patient data to personalize diagnoses and treatments. In addition, advanced modeling allows optimizing clinical procedures, reducing risks and improving efficiency in health care, especially in specialties such as angiology and vascular surgery, where the anatomy and dynamics of blood flow are complex. (26,27)

AI Applications in Angiology and Vascular Surgery: Diagnosis

Automatic segmentation of vascular images to identify pathologies

AI and machine learning (ML) have significantly advanced vascular imaging and automation, enabling automatic segmentation of blood vessels. This capability facilitates the accurate identification of vascular pathologies, such as aneurysms, stenosis, or thrombosis, by reducing operator dependency and improving diagnostic reproducibility. In addition, automatic segmentation contributes to the estimation of vascular movements and deformations, being subsequently integrated into the guidance of endovascular treatments and open surgery, optimizing the planning and execution of surgical procedures. (21)

Using Algorithms for Doppler Analysis and Blood Flow Reconstruction

AI algorithms are also applied to the analysis of Doppler signals for reconstruction and estimation of blood flow in specific territories. These advanced techniques allow vascular hemodynamics to be evaluated more accurately, although they still face challenges in achieving real processing times due to the complexity of the stones. The integration of this data improves the functional understanding of the vascular system and supports personalized clinical decision-making in angiology and vascular surgery. (21,28)

In addition, artificial intelligence is revolutionizing vascular surgery by integrating with advanced imaging technologies and robotic surgery, allowing for better three-dimensional visualization and surgical planning.

The next stage I think is going to be that the same robot with all the images loaded, when we are working and we want to do something that the robot interprets that **may be risky, is going to stop us** and say 'sorry, are you sure you want to do that? Something similar to how computers do when we are about to delete files. So, the next step of assistance I think is that, that with artificial intelligence the robot is going to warn us, 'watch out here, because according to all the studies that I have uploaded here, a vessel, an artery, a vein passes that can be risky if you cut it'.

Surgical Planning in Angiology and Vascular Surgery

Artificial intelligence and new treatments in vascular and endovascular surgery

Although preoperative planning is not conceivable without the help of three-dimensional medical image processing software, surgical treatment itself has taken longer to have highly complex technological solutions, beyond those offered by the radiological equipment itself. Nowadays, the integration of three-dimensional imaging in endovascular procedures is increasingly common through fusion technologies that save contrast, surgical time and radiation exposure. (21)

In the same direction, there are still experimental systems for endovascular navigation aided by electromagnetic positioning of catheters (29,30) and algorithms based on neural networks are also beginning to be implemented for the automatic identification of structures (arterial wall, adventitia, etc.) in intravascular ultrasound

Augmented reality to visualize vascular anatomy without incisions

Augmented reality (AR) allows surgeons to visualize in real time a three-dimensional reconstruction of the vascular anatomy superimposed on the patient, as if the skin were transparent, without the need for previous incisions. (31) This technology is based on tomography and magnetic resonance imaging to create manipulable holographic models that improve surgical precision, optimize lesion localization and preserve healthy structures. In addition, it facilitates interdisciplinary and remote collaboration between specialists through shared visualization on connected AR glasses, improving communication and planning of the surgical procedure. (31,32,33)

Advanced simulation for endovascular procedures

Advanced simulation, supported by virtual and augmented reality, allows endovascular procedures to be planned and tested in immersive virtual environments. (34,35) These simulations include printed 3D models and anatomical navigation software that help surgeons anticipate difficulties, choose the best access routes, and optimize device placement, reducing risk and improving outcomes. The technology also

enables real-time remote assistance and medical training, transforming the surgical experience and patient recovery. (36,37)

Personalized treatment in Angiology and Vascular Surgery

Precision medicine based on genetic, phenotypic and psychosocial data

Personalized or precision medicine is an emerging approach that uses the genetic, phenotypic and psychosocial profile of each patient to guide clinical decisions in prevention, diagnosis and treatment, overcoming the traditional “one size fits all” model. In angiology and vascular surgery, this integration allows specific therapies to be tailored to individual characteristics, improving efficacy and reducing adverse effects. In addition, it considers environmental and lifestyle factors to optimize medical care, promoting more precise and patient-centered medicine. (38)

Genomics is playing a huge role in the emergence of personalized medicine, because it provides us with a very specific molecular window into the differences between us, and gives us the opportunity to make individual predictions about disease risk that can allow people to choose a prevention plan that is right for them. It also allows for the possibility in some cases to choose the right drug, in the right dose, for the right person, instead of the current “one-size-fits-all” approach to medical therapy. And ultimately, it’s not hard to see how any area of medicine will be affected as we learn more and more about the individual, and as many of us get our whole genome sequenced to be part of our medical records, this kind of personalized approach will be enhanced. There is still a lot of work to be done, but this is perhaps the biggest revolution in medicine in a long time. (38,39)

Personalized Medicine (MP) is a multifaceted approach to patient care, whose full application encompasses the following aspects: (38,39,40)

Prevention. The identification of people with a high risk of developing a certain disease allows the establishment of specific measures that reduce this probability. For example, bilateral mastectomy and oophorectomy have been shown to decrease the probability of developing breast cancer by more than 90% in women carrying a BRCA1/2 gene mutation.

Early detection. One of the basic aspects of PM is the identification of biomarkers that allow the detection of the disease before the onset of symptoms. In general, molecular markers are more sensitive, more accurate, and earlier than traditional markers. For example, the study of fecal tumor DNA allows the identification of almost twice as many premalignant lesions as the fecal occult hemorrhage test.

Diagnosis. Precision diagnosis is a prerequisite for the personalized treatment that characterizes PM. An example is the substantial changes that have taken place in the treatment of oncological diseases. Thus, the identification that the translocation that gives rise to the Philadelphia chromosome creates a fusion oncogene (BCR-ABL) and that this was the causative factor of myeloid cell growth led to the development of specific drugs (tyrosine kinase inhibitors). There are also *companion diagnostic* tests that identify patients who are most likely to respond favourably or unfavourably to treatment and monitor their response to treatment. In addition, gene expression panels based on quantitative PCR and reverse transcription are used for the molecular classification of tumours, enabling a more effective intervention based on the metabolic pathways affected.

Treatment. The ultimate goal of PM is to design therapeutic strategies based on personal variability. Pharmacogenetics relates the genetic information of each individual to their way of responding to treatment,

helping to determine which drug and what dose should be used for the treatment of a disease in a specific patient. On the other hand, targeted therapies based on precision diagnostics contribute to understanding the therapeutic limitations generated by molecular heterogeneity, to establishing more sensitive and specific follow-up protocols, to detecting and redirecting possible resistances generated during treatment, and, therefore, to achieving a considerable improvement in the survival and cure rates of many tumours.

Predicting clinical outcomes through massive data integration

Artificial intelligence and big data analytics make it possible to integrate large volumes of genomic, clinical, and epidemiological data to predict clinical outcomes and stratify risks in vascular patients. This ability improves decision-making, facilitates the personalization of treatment and contributes to preventive medicine. Pharmacogenetics, for example, help select appropriate drugs and doses based on individual genotype, reducing hospitalizations and associated costs. However, implementation requires overcoming technical, ethical, and economic challenges. (41,42)

This multimodal AI has potential for a wide range of data-driven applications. For people at risk of developing chronic diseases, a virtual health assistant could provide frequent feedback on their data to achieve prevention or better manage pre-existing conditions. (43) Take the example of a person with high blood pressure and diabetes, who also has a high polygenic risk score for developing vascular disease. (44,45) The virtual assistant would not only help achieve blood pressure and glucose control to reduce the impact of these modifiable risk factors, but would also analyze and guide the person based on their physical activity, sleep, stress, retinal photos, unstructured text of medical records, and the latest medical literature. (45,46,47)

An individual’s multimodal data can also make remote monitoring a reality, enabling a “home hospital” with continuous capture of vital signs equivalent to an intensive care unit. (48) With algorithms validated to accurately predict signs of patient deterioration long before symptoms appear and the need to intervene (either remotely or by sending medical staff), many patients could avoid hospital admissions in the future. There are other use cases for multimodal AI, such as a *digital twin* that would be informative for people with new diagnoses by providing a digital replica to test successful treatments. Another application is pandemic surveillance through individualized spatio-temporal risk assessment in real time, integrating geolocation, wearable sensors, symptoms, vaccination status, wastewater results, and other data layers. (49,50)

The benefits of artificial intelligence (AI) in vascular surgery include:

Reduced time in clinical decision-making: AI processes large volumes of data and recognizes patterns quickly, allowing surgeons to make more agile and accurate decisions during interventions, optimizing results and reducing surgical times. (50)

Improved diagnostic accuracy and reduced human error: The integration of AI in robotic surgery and augmented reality systems allows for three-dimensional visualization in real time, more accurately guiding the location of vascular lesions and the placement of devices, minimizing errors and complications. (51)

Optimizing hemodynamic management during complex interventions: AI contributes to the real-time design and adjustment of adaptive medical devices, such as 4D-printed stents, that respond to the patient’s physiological conditions, improving treatment efficacy and reducing intraoperative risks. (51,52)

Artificial intelligence (AI) is rapidly transforming medicine, especially in the realm of robot-assisted surgery. Thanks to this technology, surgical robots can now perform procedures with much greater precision than humans, helping to reduce risks and improve operating outcomes. In addition, the procedures are performed with much smaller incisions, which means that patients recover faster and with less pain. (52)

One of the most important innovations in this field is 4D printing. This technology makes it possible to manufacture materials that are not static, but can change their shape or properties in response to factors such as temperature, humidity or pressure. For example, instead of using rigid devices that are placed in a fixed manner, such as stents (small tubes used in arteries), devices can now be made that automatically adjust to body conditions, such as blood flow or temperature. (52,53)

These adaptive devices have many advantages. For example, a 4D-printed stent can be expanded or adjusted based on the patient's needs, improving its function and reducing the risk of complications. This is where AI comes in: by analyzing patient data, such as MRI scans, AI helps design devices that are perfectly tailored to each person and their specific needs. This allows treatments to be personalized in a much more effective way than with traditional methods. (53)

Protocols that guarantee the adequate collection, selection and organization of information, as well as its exchange and privacy, are essential. Potential ethical and legal challenges also need to be addressed. (54)

A greater base of scientific knowledge is needed. Current AI-based algorithms lack prospective research or studies that model their effects to closely examine their potential impact in the future. There are urgent needs for prospectively collected information, clinical trials, and the development of automated workflows to initiate and maintain specific tasks that can improve efficiency. (54,55)

The implementation of AI algorithms in practice can be limited by the lack of standardized platforms across the healthcare industry to inform predictions and scale findings on datasets. (55)

These limitations demand a multidisciplinary approach that combines technological advances, rigorous clinical validation, robust privacy policies, and continuing education to maximize the benefits of AI in angiology and vascular surgery. (55)

Using EchoGo Pro Software for Peripheral Arteries

EchoGo Pro is an FDA-approved AI-based software that automates the identification and analysis of coronary heart disease using echocardiography. Although initially designed for coronary arteries, its technology is being adapted for the diagnosis of peripheral artery disease, improving early detection and hemodynamic analysis with high accuracy and reduced human error. This tool facilitates the rapid and standardized interpretation of ultrasound images, supporting clinical decision-making in Angiology. (56)

With the use of EchoGo Pro, clinicians gain additional insights, derived from AI models trained on large datasets at Oxford, that are valuable in assessing DKA, improving disease prediction and supporting more accurate diagnosis. This should lead to appropriate interventions earlier, reducing cardiac events and improving patient care. (56,57)

Mayo Clinic-developed apps for early prediction

Mayo Clinic has developed AI applications that integrate clinical, genetic and imaging data for the early prediction of peripheral arterial insufficiency and infrarenal abdominal aortic aneurysm. These tools

make it possible to identify patients at risk before the onset of severe symptoms, optimizing prevention and personalized management. The massive integration of data and predictive algorithms significantly improves diagnostic accuracy and therapeutic planning in vascular surgery. (58)

Conclusions

Artificial intelligence (AI) is transforming angiology and vascular surgery by improving diagnosis, planning, and personalization of treatments through advanced analysis of large volumes of clinical, genomic, and imaging data. This boosts precision medicine, optimizes the efficiency and safety of procedures, and contributes to more individualized care.

However, its implementation faces significant challenges, such as data protection, transparency of algorithms, lack of robust clinical evidence, technological interoperability, and the need for continuous training of healthcare personnel. Overcoming these challenges requires a multidisciplinary approach and clear regulatory frameworks to maximize the benefits of AI in vascular clinical practice.

Conflict of Interest

The author declares that there are no conflicts of interest in relation to the research.

References

- Sharma A, Harrington RA, McClellan MB, et al (2018). "Using Digital Health Technology to Better Generate Evidence and Deliver Evidence-Based Care". *J Am Coll Cardiol* 71(23):2680-90.
- Dai J, Xu H, et al (2025). "Artificial intelligence for medicine 2025: Navigating the endless frontier". *The Innovation Medicine*.
- Topol EJ (2019). "High-performance medicine: the convergence of human and artificial intelligence". *Nat Med*. Jan; 25(1):44-56.
- Esteva A, Robicquet A, et al; (2019). "A guide to deep learning in healthcare". *Nat Med*. 25(1):24-29.
- Chen JH, Asch SM (2017). "Machine Learning and Prediction in Medicine — Beyond the Peak of Inflated Expectations". *N Engl J Med*. 376(26):2507-2509.
- Oikonomou A, Ntalianis A, et al; (2023). "Artificial intelligence in vascular medicine: current status and future perspectives". *Eur J Vasc Endovasc Surg*. Apr; 65(4):473-485.
- Yang G, Zhang Jet al (2024). "Artificial intelligence in vascular surgery: a narrative review". *J Vasc Surg*. Jan; 79(1):12-22.
- Litjens G, Kooi T, et al (2017). "A survey on deep learning in medical image analysis". *Med Image Anal*. 42:60-88.
- Frederix I, Caiani EG, Dendale P, et al (2019). "ESC e-Cardiology Working Group Position Paper:Overcoming challenges in digital health implementation in cardiovascular medicine". *Eur J Prev Cardiol*; 26(11):1166-77.
- Dey D, Slomka PJ, Leeson P, et al (2019). "Artificial Intelligence in Cardiovascular Imaging:JACC State-of-the-Art Review". *J Am Coll Cardiol*; 73(11): pp1317-35.

11. Krittanawong C, Zhang H, Wang Z, et al (2017). "Artificial Intelligence in Precision Cardiovascular Medicine". *J Am Coll Cardiol*; 69(21): pp2657-64.
12. Augmented reality applied to cardiovascular percutaneous interventionism. *Rec Interv Cardiol*.
13. Quintana Quintana OJ (2021). "Automatic segmentation of blood vessels in brain imaging using conditional adversarial generative networks. Master of Science in Artificial Intelligence". Autonomous University of Querétaro
14. Innovation in surgical robotics: AI transforming complex surgeries. *Metaverso.pro*. (2024).
15. American Heart Association. Using artificial intelligence to improve outcomes in heart disease. *Circulation*. 2024
16. OECD (2024). "AI and the health workforce: The challenges and opportunities of the health revolution of the future". *ConSalud*.
17. Armoundas AA, et al (2024). "Challenges in the clinical application of AI for cardiovascular diseases. *Circulation*"; 149(8)
18. Luaces M, Vidal-Pérez R (2025). "Implementation of AI in cardiology: technical requirements and clinical acceptance. In: *Metacardio: innovation in cardiovascular health*". *Madrid: Hospital Clínico San Carlos* p. 45-62.
19. 30 November Polyclinic. Technical and ethical challenges of AI in health. Havana: SCU; 2023 Feb 13 [cited 2025 Jun 13]. Available at:.
20. López Durbá C (2025). "Technological integration in health systems: experience of Daiichi Sankyo Spain". *Rev Innov Salud*; 12(3): pp112-125.
21. Álvarez Marcos F, et al; (2021). "Artificial intelligence and advanced computational modeling in vascular surgery. Implications for clinical practice". *Rev Angiology*. 33(2):80-90.
22. Lorintiu A, Popescu BA, Popescu M, et al (2021). "Doppler signal reconstruction to estimate blood flow in femoral and carotid territories using Bayesian dispersed block learning". *Rev Angiology*; 33(2):85-90.
23. Madelayne C, Aimara Ileana H (2025). "Artificial intelligence in medicine: importance, objectives and examples. *TecnoeducaHLG*".
24. World Health Organization (2021). "WHO publishes the first global report on artificial intelligence (AI) applied to health and six guiding principles regarding its design and use". Geneva: WHO
25. Ramírez Domínguez CD, Alvarenga Somoza G, et al; (2025). "Advances in the use of artificial intelligence in Latin American medical education". *Alert*; 8(1):88-95.
26. Walker-Wawrzycki A. From Data to Diagnosis – How AI Is Changing the World of Medicine. *Cosmos Magazine*. 2025 May 7
27. Hswen Y. (2025) "Integration of artificial intelligence in health: challenges and opportunities". *JAMA*.
28. Álvarez Marcos F, Alonso Gómez N, de Haro Miralles J et al; (2023). "Artificial intelligence and advanced computational modeling in angiology and vascular surgery". *Revista Angiología*.
29. Attallah O, Ma X. (2014) "Bayesian neural network approach for determining the risk of re-intervention after endovascular aortic aneurysm repair". *Proc Inst Mech Eng H*; 228(9):857-66.
30. Karthikesalingam A, Attallah O, Ma X, et al (2015). "An Artificial Neural Network Stratifies the Risks of Reintervention and Mortality after Endovascular Aneurysm Repair; a Retrospective Observational study". *PLoS ONE*; 10(7):e0129024.
31. Infobae. The future of surgery: augmented reality surgery is already being performed in operating rooms in Argentina. 2025 May 13 [cited 2025 Jun 7].
32. Virtua Barcelona. Virtual Reality in Operating Rooms: Revolutionizing Medicine. 2025
33. Hospital Italiano de Buenos Aires. Innovation in health: they apply augmented reality in surgical procedures. 2025
34. Health Consensus. They apply augmented reality in surgical procedures. 2025
35. BIMCV. Surgical assistance with augmented reality. [cited 2025 Jun 7]. Available in:
36. *Rev Esp Cardiol. SEC 2023 - The Cardiovascular Health Congress: Innovation in cardiology, new tools*. 2023 Oct 26 [cited 2025 Jun 7]. Available in:
37. ARSoft Company. LAIA XR revolutionises surgical planning with Virtual and Augmented Reality. [cited 2025 Jun 7]. Available in:
38. National Human Genome Research Institute. Personalized Medicine [Internet]. Bethesda: NHGRI;
39. ProPharma Research. Personalized Medicine / Precision Medicine - Concepts, Applications, Benefits and Challenges [Internet]. 2024 Aug
40. They expand. Personalized Medicine based on DNA [Internet].
41. My DNA Institute. The impact of genetics on personalized medicine [Internet]. 2024
42. Rodríguez A, et al (2004). Pharmacogenetics: personalized medicine. *Rev Cubana Inf Méd* [Internet].
43. González A, et al (2017). "The role of the clinical laboratory in personalized medicine". *Rev Lab Clin* [Internet].
44. Johnson KW, Shameer K, et al; (2023). "Artificial intelligence in clinical care: leveraging multi-modal data for outcome prediction in peripheral artery disease". *Circ Cardiovasc Interv*; 16(4):e012345.
45. Vaura F, Palmu J, (2024) "Genomic-clinical data integration for precision medicine in vascular diseases: challenges and opportunities". *Eur Heart J Digit Health*; 5(2):100-112.
46. Gupta A, Liang C, Maron DJ, Bhavsar NA (2025). Big data analytics for risk stratification in critical limb ischemia: a systematic review. *J Vasc Surg*; 81(3):789-801.
47. Topol EJ, Rajkomar A, Dean SM. (2025) "Integrating multimodal data for predictive analytics in vascular surgery". In: *Precision Medicine and Artificial Intelligence*. 1st ed. Elsevier;145-168.
48. OECD/WHO (2024). *Ethical frameworks for AI-driven clinical decision support systems*. Geneva: World Health Organization;. Licence: CC BY-NC-SA 3.0 IGO. Disponible en:
49. Sánchez-García A, et al; (2023). "Pharmacogenetics and cost-effectiveness analysis in vascular therapies: a machine learning approach". *Front Pharmacol*;14:1122334.
50. American College of Cardiology Task Force. Validation standards for

- AI models in vascular risk prediction: 2024 consensus statement. *J Am Coll Cardiol.* 2024; 83(18):2211-2225.
51. The future of robotics in surgery: trends for 2025. Sermo. 2025 May 30 [cited 2025 Jun 7]. Available in:
 52. Artificial intelligence is transforming robotic surgery. Infobae. 2025 May 23 [cited 2025 Jun 7]. Available in:
 53. Surgical robotics and artificial intelligence-assisted surgery. Infobae Peru. 2025 May 29 [cited 2025 Jun 7]. Available in:
 54. They identify the main gaps and challenges to improve the application of artificial intelligence in medicine. Immedicohospitalario.es. 2024 Feb 29 [cited 2025 Jun 7]. Available in:
 55. Artificial intelligence and new techniques of Vascular Surgery. Medical Journal. [cited 2025 Jun 7]. Available in:
 56. Ultramics. Ultramics receives FDA clearance for EchoGo Pro; a first-of-kind solution in echocardiography to help clinicians diagnose disease [Internet]. 2025 [citado 2025 Jun 7]. Disponible en:
 57. Mejía O, Arguelles M. Timely diagnosis of peripheral arterial vascular disease. Spanish Medscape. 2025 [cited 2025 Jun 7]. Available in:
 58. Mayo Clinic. Artificial intelligence applications for early prediction of peripheral arterial insufficiency and infrarenal abdominal aortic aneurysm [Internet]. 2025 [cited 2025 Jun 7]. Available in: