HHS Public Access
Author manuscript
Semin Vasc Surg. Author manuscript; available in PMC 2023 January 28.

Published in final edited form as:
Semin Vasc Surg. 2021 December ; 34(4): 268–271. doi:10.1053/j.semvascsurg.2021.10.008.

Current Applications of Artificial Intelligence in Vascular Surgery

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Abstract

Basic foundations of artificial intelligence (AI) include analyzing large amounts of data, recognizing patterns, and predicting outcomes. At the core of AI are well defined areas such as machine learning, natural language processing, artificial neural networks, and computer vision. While research and development of AI in healthcare is being conducted in many medical subspecialties, only few applications have been implemented in clinical practice. This is true in Vascular Surgery where applications are mostly in the translational research stage. These AI applications are being evaluated in the realms of vascular diagnostics, perioperative medicine, risk stratification, and outcome prediction, among others. Apart from the technical challenges of AI and research outcomes on safe and beneficial use in patient care, ethical issues and policy surrounding AI will present future challenges for its successful implementation. This review will give a brief overview and a basic understanding of AI and summarize the currently available and used clinical AI applications in Vascular Surgery.

Introduction

Technical advances in medicine have continuously evolved, mostly in an exponential rather than a linear fashion. However, we rarely have experienced such a rapid technical advance in medicine as that of artificial intelligence (AI) technologies and machine learning applications. Although the AI field is diverse, the basic foundations of AI include: 1) analyzing large amounts of data, 2) recognizing patterns, 3) predicting outcomes, and thus 4) aiding in drawing conclusions to improve workflows. Goal of every new technology should be to assist, improve and facilitate human life. Hence, AI applications in medicine and vascular surgery should be designed and implemented with the aim to assist, but not replace the healthcare provider. The goal is to efficiently utilize information beyond the

Declaration of Competing Interest
Uwe Fischer – No financial disclosures
Paula Shireman – No financial disclosures
Judith Lin – No financial disclosures

processing capabilities of humans, thereby decreasing clinician cognitive load, expanding patient-centered treatment options, and improving patient outcomes.

AI combines several methods analyzing large amounts of data, detecting patterns, and making predictions by using ever more sophisticated algorithms. AI is loosely defined as the study of algorithms providing machines the ability to reason and perform cognitive functions such as problem solving, object and word recognition and decision-making.[1] AI in healthcare ranges from analyzing databases for improving clinical and hospital workflow to intraoperative applications such as video analysis. AI offers ever expanding technical opportunities to vascular surgeons, especially in imaging analysis and perioperative risk evaluation. AI is predominately focused on four core subfields: 1) machine learning (ML), 2) natural language processing (NLP), and 3) artificial neural networks and 4) computer vision.[1]

Artificial Intelligence Subfields

Machine Learning—Machine learning (ML) enables machines to learn and make predictions by recognizing patterns. While supervised learning allows the computer to utilize partial labelling of the data, unsupervised learning entails identification of the structure in the data itself. Partial labelling of data is necessary while training an algorithm to identify the aorta or a pathology therefore requiring a radiologist or technician to provide the appropriate annotation of the imaging. The results of both approaches provide predictions about the data without explicit programming. Supervised learning is useful for training a ML algorithm to predict a known result or outcome while unsupervised learning is useful in searching for patterns within data.[2] ML is particularly useful for identifying subtle patterns in large datasets – patterns that may be imperceptible to humans performing manual analyses.[3]

Natural Language Processing—Natural language processing (NLP) emphasizes building a computer’s ability to understand human language and is crucial for large scale analyses of content such as electronic medical record (EMR) data, especially physicians’ narrative documentation. Successful NLP systems must expand beyond simple word recognition to incorporate semantics and syntax into analyses to achieve human level understanding of language.[4]

Artificial Neural Networks—Artificial neural networks are inspired by biological nervous systems and have become of paramount importance in many AI applications[2]. Deep learning networks are neural networks comprised of many layers and can learn more complex and subtle patterns than simple one or two-layer neural networks.[5]

Computer Vision—Computer vision describes machine analyses of images and videos. Significant advances have resulted in machines achieving human-level capabilities in areas such as object and scene recognition. Important healthcare-related work in computer vision includes image acquisition and interpretation in axial imaging with applications including computer-aided diagnosis, image-guided surgery, and virtual colonoscopy.[6] Current work in computer vision uses ML approaches to focus on higher level concepts such as image-based analysis of patient cohorts, longitudinal studies, and inference of more subtle conditions such as decision-making in surgery.

Artificial Intelligence Applications in Vascular Surgery

All four subfields of AI have been applied in healthcare and to surgery. Vascular surgery especially depends substantially on diagnostic imaging and large amounts of patient data. The ability of AI to analyze those data, detect patterns and draw conclusions surpasses human capacities and has already proven beneficial to patient treatment and outcomes. This review focuses on four key areas of AI application in vascular surgery: vascular diagnostics, perioperative medicine, risk stratification, and outcome prediction.

AI in Vascular Diagnostics

The prime application of AI in general and especially in vascular surgery is the ability to analyze large amounts of data. AI can accurately predict which patients are at risk and need of intervention using imaging platforms. Even before the need for an intervention, AI offers methods of diagnosing the severity of vascular pathology such as peripheral artery disease (PAD) based on analysis of noninvasive diagnostics.

A study using deep learning analysis of arterial pulse waveforms was used to test proof-ofconcept and potential challenges for this method. A deep convolutional neural network capable of detecting and assessing the severity of PAD based on analysis of brachial and ankle arterial pulse waveforms was constructed, evaluated for efficacy, and compared with the state-of-the art ankle-brachial index (ABI) using many virtual patients that were created to investigate the potential and challenges in DL-based pulse wave analysis for PAD diagnosis. This study demonstrated robust PAD detection performance superior to the ABI technique against a wide range of PAD severity threshold levels for labeling of healthy subjects and PAD patients.[7] This study showed that AI, in a theoretical setting with virtual patients, can diagnose patients earlier compared to traditional methods with higher sensitivity, specificity, and accuracy.[7] Consequently, with early PAD diagnosis treatment can be initiated even before symptoms appear both with medical treatment and lifestyle modifications.

AI also is a useful tool in the interpretation and analysis of abdominal aortic aneurysm (AAA) imaging. A comprehensive review of articles using AI in the diagnosis and treatment of patients with AAA showed that AI could be used to help surgeons in preoperative planning. [8] In addition, the potential of AI-driven data management was predicted to be crucial in the development of AAA evolution and risk of rupture evaluation as well as postoperative outcomes. AI can also aid in decision making on types of surgical treatment. Especially, AI would allow investigators to detect the aneurysm more easily; to characterize its anatomic characteristics (including the presence of calcifications and intraluminal thrombus); and to automatically calculate the diameters, lengths, distances, and volumes of the aneurysm and vessels. This automated AAA assessment would be helpful in perioperative planning such as sizing of the endograft. The authors also concluded that data derived from automatic analysis of AAA images could be combined with clinical and biologic characteristics of patients to develop multiplevariable scores, allowing identification of predictive patterns and better assessment of the prognosis of patients.[8] Thus, *AI could aid in creation of an individualized surveillance program.* Lareyre *et al*. developed an automated software system to enable a fast and robust detection of the vascular system and detect AAA in computer tomography angiographies. The software automatically detects the aortic lumen and AAA characteristics including the presence of thrombus and calcifications.[9] These data can be used to improved surgical intervention planning including types of interventions. Recommendations for the best instrumentation and graft type are on the horizon.

Flores *et al*. reviewed the status of ML and AI on PAD detection, treatment, and outcomes. The combination of ML, NLP, computer vision and artificial neural networks were shown to have the potential of harnessing all available information in modern EMR to retrieve the diagnosis of PAD and describe severity of the disease. Especially, disease detection using complementary clinical and genetic data was described as future application for PAD diagnosis. [10]

Perioperative Medicine, Risk Stratification, and Outcome Prediction

Although clinical applications are in their infancy the ability to analyze large amounts of patient data in an unbiased fashion enables AI to determine patient risk for the perioperative period providing tools to individualize and thus optimize patient care. Perioperative intelligence uses technologies such as ML,[11] AI,[12] and big data[13] to provide appropriate and safe perioperative care.[14] Maheshwari *et al.* point out the need for high quality continuous data from multiple domains to make better predictions.[14] Hence, data acquisition and management are crucial for successfully applying the available AI tools which in turn can deliver vital information to assess patient disease and outcome risk.

Focusing on PAD risk stratification, AI can be used to efficiently and accurately mine data from electronic health records (EHRs) to create clinical databases from which models can be developed to predict PAD risk and the associated mortality risk. In this study, diverse clinical, demographic, imaging and genomic information of patients undergoing coronary angiography were utilized. The applied ML models outperformed the standard logistic regression models for the identification of patients with PAD and predicting future mortality.[15] Specifically, for limb-related outcomes Davis at al examined the ability of their model of algorithms to predict surgical site infections after lower extremity revascularization. Their model predicted with an AUC of 0.66 post-bypass surgical site infections and could identify several patient and procedure risk factors.[16]

Challenges and Policy

AI and ML are increasingly applied to health care with great potential and peril.[17] Great potential exists in the ability to develop low-cost, superior predictive models. Great perils include ML bias[18–21] especially in minority populations and explainability of the algorithms.[17] A recent National Institutes of Health workshop concluded that data quality was a significant concern for the trustworthiness of machine intelligence in healthcare. [22]

Multiple challenges are present to implement AI algorithms into clinical settings. First, algorithms require clinical validation to assess performance in multiple real-world settings.[23] Second, providers and patients must trust the output of AI algorithms.[24] Third, AI output must be user-friendly, interpretable, and most importantly, actionable.[25] Finally, algorithms must be seamlessly integrated into clinical workflows.[24] Most algorithms have been developed for image analysis given the large amounts of annotated data available on pathology and radiology imaging studies. A list of FDA-cleared imaging algorithms is available at https://models.acrdsi.org/“ https://models.acrdsi.org/.

Ethical issues include protecting patient privacy of data used for algorithm development.[24] Algorithms developed with minimal patients from under-represented and minority populations can lead to biased algorithms, further propagating health care disparities.[26] US Food & Drug Administration (FDA) approval of AI technologies is challenging due to the opacity of black-box algorithms that lack explanations for their predictions or recommendations and permit continued learning of algorithms adapting to new data.[27, 28]

Conclusions

AI and associated technologies have started their journey into daily diagnostics, treatment, and patient outcome strategies. Vascular medicine has enormous potential for using these technologies. It is possible to retrieve and assemble a disease picture that was previously incomplete and partially hidden in a large amount of patient data dispersed over different electronic systems. This data mining process will enable improved diagnostics enabling a tailored, personalized treatment algorithm that can predict and more importantly improve disease outcomes faster and more accurately. Despite the exponential increase in studies, publications and even review articles on the subject, the utilization of AI in healthcare has just begun. Keeping the focus on vascular medicine, vascular specialists are using the potential of AI less than neurologists, oncologists, and cardiologists. While a critical approach is certainly warranted, applications of AI in vascular surgery should be developed and implemented in patient care if rigorous testing in real-world settings proves to be beneficial.

Properly tested and carefully implemented AI has the potential to facilitate vascular medicine and add exponential value to our diagnostic and treatment arsenal. In addition, with the ability of effective data mining, imaging analysis across medical fields, and development of intelligent predictive models, AI can aid in improving team-based care with an improve patient-centered focus. Embracing this potential will be the first step in developing a leadership role in AI implementation and using this technology in our daily routine and quest to improve patient care.

Advancing AI in clinical Vascular Surgery practice will be an essential task in establishing leadership in Vascular Medicine. This will also include addressing criticism, caution, hesitancy and even bias openly. Limitations of AI in vascular medicine must be clearly recognized and the highest standard in patient safety must be met. Adhering to these principles will help establishing a leading role in healthcare AI.

Funding/Support:

This research was supported by grant U01TR002393 (Shireman), from the National Center for Advancing Translational Sciences and the Office of the Director, NIH.

Role of the Funder/Sponsor:

The funding sources had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication. The opinions expressed here are those of the authors and do not necessarily reflect the position of the Department of Veterans Affairs or the United States government.

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