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Emerging Approaches in Vascular Surgery - A Review

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Abstract
In the vast advancement of medical sciences, innovation and new technologies in combating different vascular diseases, vascular surgery acts like a beacon. This paper will give the readers a clear picture on the current innovative approaches such as Artificial Inteligence(AI)/ Machine Learning(ML), Robotic-Assisted vascular surgeries, Drug eluting stents, Bioengineered Vascular Grafts, Endovascular Ablation Therapies and Thoracoabdomimal Aortic Aneurysm Endovascular Repair (TAAER). Artificial Inteligence(AI)/ Machine Learning(ML) in vascular surgeries, which provides better disease prognosis and management, Robotic-Assisted vascular surgeries, which provides 3D visualization, better agility, emotional shock prof though it is costly and safety and efficacy evidences still need to be established, Drug eluting stents along with 3 months antiplatelet therapy is very effective in Percutaneous coronary intervention (PCI), Bioengineered Vascular Grafts, which shows promising results in connections with total cavopulmonary with nonhypertrophied right atrium case and also diminishes the risk of arrhythmia in early or later stages and lastly the Endovascular Ablation Therapies like Radiofrequency ablation (RFA) shows better results than endovenous laser ablation (EVLA) in interventions of lower extremities venous insufficiency.
Keywords: *Artificial Inteligence(AI)/ Machine Learning(ML), Robotic-assisted vascular surgeries , Drug eluting stents, Bioengineered vascular grafts, Endovascular ablation therapies.*

Introduction

Vascular surgeries in current scenario are the one of the most innovative interventions in treatment of arterial and venous diseases, aneurysms and traumatic injuries.[1] Endovascular techniques are developed to minimize the number and proportion of lesions. The progress in medicine and technology, such as heparin, similar vaccines, vein grafts, digital imaging, and catheter technology have provided in further vascular advances [2]. The Peripheral arterial disease (PAD) and some related pathological conditions like carotid and aortic diseases are arising globally day by day and its progress is dangerously high in low and middle income countries than in high income countries[3,4]. And in order to accomplish complete universal health coverage along with sustainable development goals, the basic requirements are safe, cost effective surgical as well as anaesthetic care, which is noted by The Lancet Commission on Global Surgery.[5] To manage or diagnose the stages of peripheral arterial disease(PAD), institutions like The society for Vascular Surgery (SVS) Lower Extremity Guidelines Committee are responsible, which aims to assess and manage the asymptomatic disease and intermittent claudication(IC).[6] The issue of high prevalence of PAD can be better managed by figuring out the epidemiology which includes ageing population and alteration of prevalence of risk factors of the diseases. Though the jumping numbers of the prevalence of hypertension, dyslipidaemia, diabetes, obesity and overweight throughout the world has a huge impact on the vascular diseases. And due to shortage of expert vascular surgeon, a large number of PAD patients survives with last stage vascular diseases which is again a serious concern.[7,8,9]Another important approach in vascular surgery is shared decision-making which could minimize the misunderstandings in informed consent. The patient sometimes feels some barriers such as time, continuity of care, patient charecteristics, clinician traits and assumption about knowledge. Apart from this age of the patient, ethnicity as well as education of the patient also influence participation.[10] Apart from this the technological advancements such as artificial intelligence (AI) or machine learning (ML) has begin a new age in clinical studies as well as in healthcare to give a different perceptions in disease diagnosis, prognosis and management.[11,12] Another technology of drug-elutent stent exhibits a upper hand in high bleeding risk patients, when combined with three months dual anti-platelet therapy after percutaneous coronary intervention(PCI)[13]

Contribution of Artificial Inteligence (AI)/ Machine Learning (Ml) in Vascular Surgeries

The emergence of AI has transformed the health care sector by providing better human visualization and its implications in surgical sector is very extensive.[14,15] And Machine in AI, learning is a subset, which tracks patterns from a data by the use of algorithms such as classifiers.[16]

So, the application of AI/ML is very well suited with Vascular surgery for several reasons such as:-

a. Evaluation of Image and Detection of Diseases:- The implementation of endovascular transplantation has potentiated the utility of powerful image analysis software based on machine learning, hence, making vascular surgery a technology and medical imaging-focused field.

b. Forecasting of Disease and Projection:- Most vascular diseases have an objective clinical definition (e.g. abdominal aortic aneurysm [AAA] is defined as 3 cm in size, peripheral artery disease [PAD] is defined as ankle-brachial index <0.9). Machine learning algorithms have shown promising results in predicting abdominal aortic aneurysm growth and identifying patients at high risk of complications after endovascular repair. This allows machine learning algorithms to correct the diagnosis with little or no instructions. Natural language processing is helping to identify patients with peripheral arterial disease from electronic medical records.

c. Mining of Big Data and its evaluation:-In the healthcare sector, big data emergence plays a major part. And from this data efficient and appropriate models can be build by its analysis with ML. Though devloping a platform which collects, evaluates as well as circulates data across different institutes is still needs to be done.

d. Educate about vascular pathophysiology[11,14,17,18,19,20]

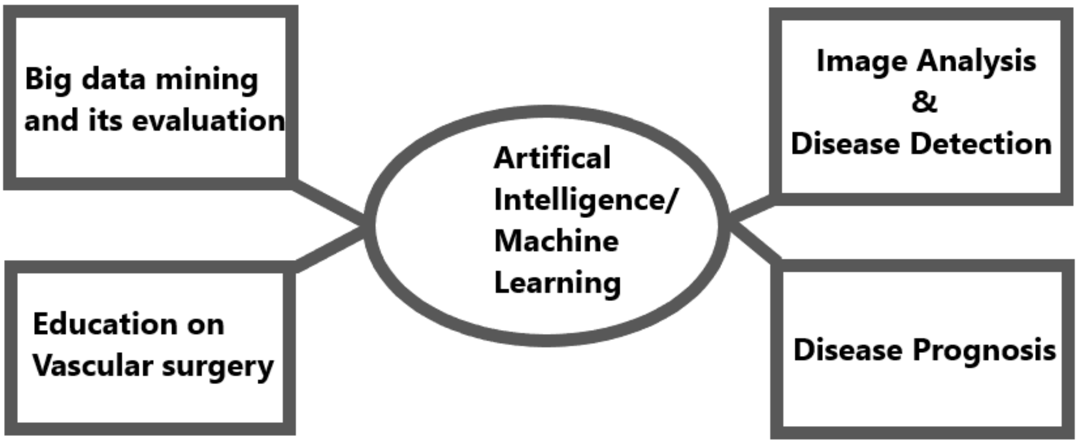

Fig 1:- Application of Artificial Intelligence/ Machine learning

This features of ML provides an upper hand in developing risk prediction model in case of atherosclerotic cardiovascular disease (ASCVD) over conventional pooled cohort equations (PCE).[21] And the electronic reports are now easily accessible but the development of the AI algorithms for compiling these data is still a challenge which get more complicated due to varied coding systems globally.[22] Manisha Bahl and colleagues, observed in their studies that, in identifying high risk patients to surgeons and radiologists support of AI is crucial, and this helped in case of benign lesions which shows 30% decrease in the rates of lumpectomy.[23] Patient-specific risk assessment and planning of operation can be magnified by automated analysis of preoperative data. Any adverse events can be anticipated and prevented by analyzing real time intraoperative monitoring by combing with other data sources. And for betterment of the patient's post-discharge, the combined data of pre-intra- and post operative data should be analyzed.[24] As in case of abdominal aortic aneurysms (AAA), blood flow effects the wall shear stress (WSS), which may cause for rupture of the blood vessel. This rupture can be predicted by determing WSS, by combined analysis of fluid dynamics along with data mining. This WSS distribution throughout the cardiac cycle can be calculated by Machine Learning (ML).[25]

The National Cancer Established (NCI) is leveraging manufactured insights (Al) to move forward early cancer location. Current strategies regularly miss or misdiagnose early-stage cancers, especially pancreatic cancer. The NCI's Early Location Investigate Organize (EDRN) is planning inquire about utilizing expansive datasets (counting manufactured information) to prepare Al models to classify cancers, stratify high-risk people, and progress picture investigation. A collaborative "center and talked" show and challenge competitions advance the improvement and approval of these Al models, pointing to decipher inquire about into moved forward clinical hone for prior and more exact cancer discovery. [26]

And implementation of AI has a promising future because, when comparison between a radiologist and an AI system named MammoScreen was implemented to analyze the 378 mammograms of Saudi Arabian women for the detection of breast cancer. The AI significantly outperformed the radiologist and showed better diagnostic tools as far as sensitivity (92.8% vs 100%), specificity (91.9% vs 67.7%), positive predictive value (91.3% vs 73.8%), negative predictive value(93.3% vs 100%), overall accuracy (92.3% vs 83.1%) and false positive rate (8.7% vs 26.2%) are concerned. [27]

Irbaz Bin Riaz and collegues observed that in the case of localized cancers, unnecessary biopsies could be eliminated with the help of deep learning models, which are very capable not only in detecting but also in grading the cancer by the analysis of images of MRI and pathological data. In biochemically recurrent disease, Al can help with risk stratification and treatment decisions. In advanced prostate cancer, Al is improving outcomes and aiding clinical decision-making by identifying metastatic disease and detecting castration resistance. Large Language Models (LLMs) will transform information stored in electronic medicaI records. [28]

Although Al has great potential to improve patient care, challenges remain, such as the need for diagnosis, transparency and reliability of algorithms (in terms of bias and "black box" issues), integration of Al into healthcare, and ethical issues. Issues related to data privacy and algorithmic bias The extreme objective is to progress the exactness, proficiency, and security of vascular care, driving to superior quiet results. [29,30]

Robotic-Assisted Vascular Surgeries

Robotic technology is already started to transformed both open vascular well as endovascular interventions as it has several advantages such as 3D visualization, capable in graded movement, lack of emotional shocks, improved agility, can be used in telesurgery and many more. Though the high startup cost, lack of touch sensations, unproven benefits and high operational cost are the limitations which needs to be checked. The scientific field uses three main types of robotic systems: semi-active, active, and masters and slaves. Active systems, like PROBOT and ROBODOC, perform pre-programmed activities independently. Semi-active systems can be combined with surface-driven elements. Formal master-slave systems rely on surgeon actions.[25,26] In the last decades the robotic surgery in limited to bariatric and prostatectomy but now with continuous research and development interventions like single port technique with minimized trauma, oral and maxillofacial as well as pediatric surgery are also performed.[27] The study of Lior Gonen and colleagues, in cranial microsurgery, which is a new optical microscope named as Robot-Operated Video Optical Telescope Microscope (ROVOT-m) has more feasibility and safety. As per the reports of the author, a graded increment is observed in case complexities over time; which shows gradual increment in experience with this technique. New users should expect a learning curve during installation and implementation.[28] Another study of William J. Kane reported that, the comparative study of laparoscopic and robotic cholecystectomy procedures, finding robotic surgery longer and more expensive, but with lower readmission rates and hospital stay.[29] This observation is supported by the study of Maria S. Altieri and collegue, where between 2008 and 2012, 166,790 patients underwent laparoscopic surgery and 1458 robotic-assisted surgery, including 186 cholecystectomy cases, 307 RYGB cases, 118 SG cases, 288 EF cases, and 559 colectomy cases. The univariate analysis showed a higher risk of overall complications and HLOS in the laparoscopic group compared to the robotic assisted group (19.28 vs 16.32%, p value = 0.0041 and 5.18 vs 3.92 days, p value<0.0001).[30] And this results shows Robotic technology in operating rooms strengthens future system foundations, with projections showing surgical robots could generate $20 billion annually by 2021.[31]

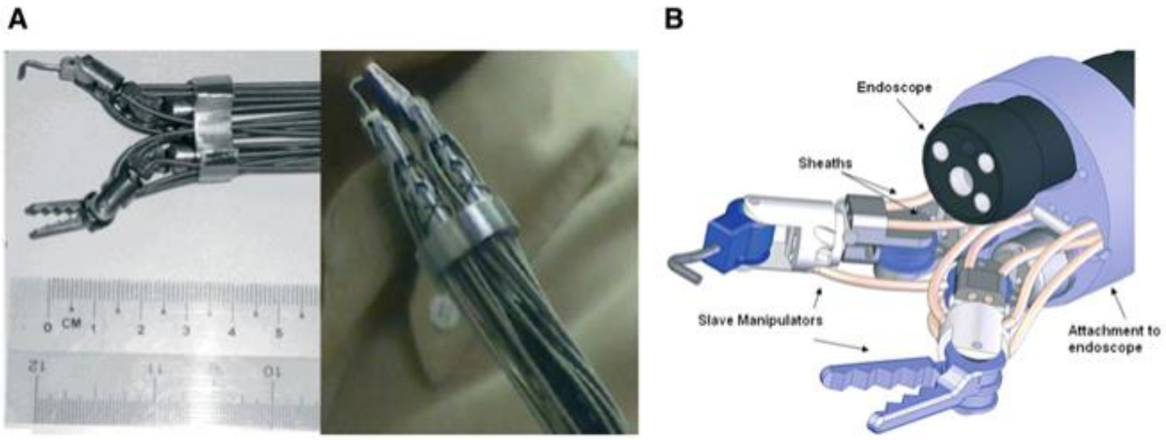

Fig. 2: MASTER; Nanyang Technological University. A The MASTER system has two cable-actuated robotic arms with fixed end effectors. B The system is shown attached to a conventional endoscope[32]

Drug eluting stents

Currently, the standard treatment for symptomatic coronary artery diseased patients, is Percutaneous coronary intervention (PCI) with drug eluting stents (DES) followed by dual antiplatelet therapy (DAPT). The primary aim of DAPT after DES implantation is to eliminate the chance of stent thrombosis(ST) and formation of plaque in other parts of coronary artery.[33] But still the bare-metal stent (BMS) is used in several coronary vessel interventions.

Compared with BMS, the first two generations of DES have better safety in respect of low and global thrombosis and myocardial infraction. However, the use of durable polymer (DP) and metal stents always carries the risk in terms of metal toxicity and long-term polymer retention. Third generation DES with BP and fourth-generation DES with bioresorbable polymer scaffolds have been developed to reduce these risks such as in-stent restenosis, thrombosis rates and target wound failure. Nanoscale engineering, including nanoparticulate, nanotextured, nanofibrous, and nanohin coatings, could enhance PCI effectiveness and safety, though clinical studies are limited. Though the issues regarding low mechanical strength and drug release profiles of these stents is concerning. Hence, the issues of previous generations DES is eliminated by the next generation DES and this process it give rise to new problems resulting a scope for further research in the field.[34,35,36] A study conducted by Pawel Gasior, compares the acute thrombogenicity and overexpansion capacities of bifurcation-specific DES and standard DES at the side branch ostia. Results show less thrombus formation, reduced shear rate areas, and lower drug coating damage in over-expanded stents.[37] Tomonori Itoh and collegues also observed in his study that, bioresorbable polymer sirolimus-eluting stents significantly reduce exposed struts in patients with stable coronary artery disease and ST-elevation myocardial infarction (STEMI), resulting in improved strut-coverage and healing processes, particularly in STEMI patients.[38] This is supported by the study of Yoshihiro Morino, where, a prospective trial using frequency domain-optical coherence tomography (FD-OCT) examined early vascular responses in STEMI patients immediately following CoCr-EES implantation and during a 2-week follow-up. The study found that early vascular responses led to lumen expansion, early strut coverage advancement, improvements in strut apposition and dissection, and a significant reduction in thrombus. The safety of CoCr-EES during the first two weeks may be due to the combination of these characteristics, indicating that early vascular responses to CoCr-EES can improve the safety of STEMI treatment.[39] Now in another study of Masaru Ishida and collegue where they showed safety and feasibility of one-month DAPT followed by P2Y12 inhibitor monotherapy post implantation of biodegradable polymer drug eluting stent (BP-DES), which is similar to the clinical study of REIWA registry.[40]

Bioengineered Vascular Grafts

Tissue engineering offers promising ways to create vascular grafts that mirror the properties of normal human blood vessels. Using tissue engineering techniques, the patient's ownbrain is implanted into a biodegradable scaffold that begins to provide support and cellular connections. As the stent gradually breaks down, new tissue in the blood vessel forms and creates a biocompatible channel. This new approach was first shown by Marc R. de Leval and collegue where, nonhypertrophied right atrium patient was interviened with total cavopulmonary connections which shows promising results. These technique has some advantages such as a) Simple and reproducible in any atrioventricular arrangements; b) minimize the risk of early or late arrhythmias due to low right arterial pressure; c)minimize the risk of arterial thrombosis; and d) throughout the connections the gradient is minimal with favourable flow patterns.[41,42]Currently, Polyethylene terephthalate (PET) and expanded polytetrafluoroethylene (ePTFE) are most widely used grafts, due to its durability and biocompatibility. Studies shows, the cases with PET grafts experienced calcification which is similar to atherosclerotic arteries calcification and hence graft failure, but this is not the case of ePTFE graft calcification. Both of these grafts also inducesimmune responses. Another study of Mackenzie E. Turner and collegue, also demonstrated that, TEVGs shows resistant formation of dystrophic calcification over many years while PTFE grafts are uniformly susceptible to severe dystrophic calcification when used as extracardiac fontan conducts even at durations <1year. But the latest modified PET and ePTFE shows better biocompatibility by eliminating maximum immune response except fibroblastic response.[43]The technique involves using a scaffold that dissolves within 3 to 5 years after a total cavopulmonary connection (TCPC) operation, eliminating the need for permanent foreign materials. This scaffold has growth potential, decreased thrombogenicity, minimal calcification, and infection resistance. It aligns with somatic growth and eliminates pre-operation hospital stays.[44] Again in another clinical trial, approval of tissue-engineered vascular graft for pediatric use to address single-ventricle cardiac abnormalities. The graft initially caused constriction, but angioplasties resolved it. The study suggests avoiding angioplasty in symptomatic early stenosis.[45]

Endovascular Ablation Therapies

Endovascular thermal methods such as radiofrequency ablation (RFA), involves heat applied via catheter in varicose vein surgery,has currently emerged which are better options in terms of safety and effectiveness when compared with surgical methods.[46]Hung-Bun Lam along with Li-Fen Chao has demonstrated in their study that, minimized postoperative pain with better recovery so as to indulge in normal activities, in interventions of endovascular ablations. Among Radiofrequency ablation (RFA) and endovenous laser ablation (EVLA), RFA shows superior pain management. But in case of nerve injury both the procedures exhibits nearly similar results, though, complicated incidences are comparatively higher in case of EVLA.[47] In another study of Wenhong Jiang and collegues, where the insufficiency of treatment for lower extremity varicose veins primarily by radiofrequency ablation (RFA) and laser ablation(LA) were discussed. The study showed that, RFA has more effective results in recent years than LA,in terms of better occlution rates of treated great saphenous veins(GSV) and minimized post-operative complications. The complications are burns, ecchymosis, postoperative pain,paresthesia and recurrence of varicose vein(VV). If this trend continues, then RAF will rise as a superior choice of treatment over LA for treatment of lower extremity venous insufficiency.[48] A study of Scarlett Hao demonstrates the effectiveness of double prepuncture in successful endovenous ablations, particularly in multiple or tortuous GSVs. This innovative technique eliminates chronic venous insufficiency in a single operative session, enhancing patient safety and outcomes in complex venous insufficiency cases, thereby enhancing the efficiency of multi-vein treatments.[49]

Conclusion

Over the past ten years, the evaluation and treatment of venous illness have changed dramatically due to advancements in endovascular technology. In this article we have tried to review all the all the options along with scientific evidence with a physician's clinical experience and the patient's preference to determine the best treatment options for each patient. Surgeons are uniquely positioned to contribute to AI development, enhancing real-time, evidence-based clinical decision support systems to enhance surgeon productivity and patient care.

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