Vascular Surgery and Robotics

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Abstract

The application of robotics to Vascular surgery has not progressed as rapidly as of endovascular technology, but this is changing with the amalgamation of these two fields. The advent of Endovascular robotics is an exciting field which overcomes many of the limitations of endovascular therapy like vessel tortuosity and operator fatigue. This has much clinical appeal for the surgeon and hold significant promise of better patient outcomes. As with most newer technological advances, it is still limited by cost and availability. However, this field has seen some rapid progress in the last decade with the technology moving into the clinical realm. This review details the development of robotics, applications, outcomes, advantages, disadvantages and current advances focussing on Vascular and Endovascular robotics.

Key Words: Endovascular, robotics, vascular

History - Origin of Robots

Machines capable of carrying out complex actions have been in existence since ancient times. The origin of the word “robot” is attributed to the brothers Capek in 1923, the Czech-Russian root words robotnik or robota (forced labor, compulsory service, drudgery, to work) used in the play R.U.R.: Rossumovi Univerzální Roboti (Rossum’s Universal Robots) later translated to the English “robot”. The word robotics finds its roots in the works of Isaac Asimov’s fictional works on humanoid machines - this was in the 1940’s. The Oxford dictionary defines a robot as “a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.” The first patent for such an industrial robot (the Unimate) went to George C. Devol for “Programmed Article Transfer” on June 13, 1961. With improvements in other fields of science, the robotics has also had rapid technological advances. Robots now have far reaching real world applications in education, entertainment, industry, and research apart from being popular content in fiction or literature.

Robotics - Early Development

Medical robotics has also seen significant developments. Robots were developed for the care of disabled, pharmacies, prosthetics, and simulation. Some of these were true robots whereas others were controlled by human operators. The first surgical robots (Arthrobot, PUMA 560) were developed in the 1980’s. Minimally invasive surgery began in 1987 with the first laparoscopic cholecystectomy. Research from NASA and Stanford on telepresence surgery was promoted with the aim of developing an operative interface that could reduce wartime mortality and be used for surgery in space stations. The motivation for robotic surgery thus stemmed from the need to overcome limitations of laparoscopic techniques, expand the benefits of minimally invasive surgery, and the theoretical appeal of remote and unmanned surgery. This eventually led to the development of the Stanford Research Institute Green Telepresence Surgery system, the Automated Endoscopic System for Optimal Positioning, and the ZEUS robotic surgical systems. The SRI system was eventually developed into the Da Vinci Surgery System. This robotic system from Intuitive Surgical was the first robot granted by the Food and Drug Administration (FDA) approval for general laparoscopic surgery in 2000. Its use has grown with applications in cardiac, gynecologic, thoracic, and urologic Surgery. It is used for over 2 million procedures a year in over 300 centers worldwide.

Robotics rapidly established its applications in nice areas in the above fields. The minimally invasive nature of operations, reduced bleeding, pain, scar size, complications, hospital stay, and faster healing had particular application in cardiothoracic surgery. At about the same time, cardiology (electrophysiology) started utilizing remotely operated steerable sheath for catheter guidance to treat...
atrial fibrillation and arrhythmias. The Hansen Medical Sensei robotic catheter system and the Stereotaxis Magnetic Navigation System were the two main robots in this field. The Hansen Medical in partnership with Philips developed the Magellan™ Robotic System, an endovascular robotic catheter system designed to enable remote manipulation of robotically steerable catheters and standard guidewires using advanced controls and visualization. This was the first purely vascular robot and received FDA approval in 2012.

**Development of Robotics in Vascular Surgery**

Early attempts at creating a minimally invasive surgical option for aortic pathology led to the development of laparoscopic aortic surgery. The techniques developed were totally laparoscopic (dissection/anastomosis laparoscopic) and lap-assisted techniques (hand-assisted or laparoscopic dissection with minilaparotomy/conventional anastomosis). However, lap aortic surgery proved to have a steeper learning curve, require additional equipment, and hence did not gain widespread popularity.\(^\text{[4-7]}\)

In parallel, the development of endovascular therapeutics made percutaneous treatment a less invasive treatment option with fewer complications. Scientific and industrial focus drove developments in this at a much faster rate, and as of now, a majority of vascular procedures performed in the West are endovascular. The “less invasive” nature of this treatment has driven patients and physicians to utilize an endovascular first approach for many pathologies.

Robotics were applied to vascular problems essentially an extension of minimally invasive surgery. There are two broad areas of application: Robotic-assisted laparoscopic surgery and the more recent, endovascular robotics. The former uses the Da Vinci system and the latter uses Hansen/Magellan system.

**Laparoscopic-assisted Robotic Surgery**

The Da Vinci robot has four main components: The surgeon console, patient-side cart, EndoWrist Instruments, and Insite Vision System. The equipment position may differ according to the individual case. The surgeon sits at a console where a three-dimensional (3D) image of the field is displayed. The hand control uses the same movements as in open surgery which is replicated exactly by the endowrist in the operative field [Figure 1].\(^\text{[8]}\)

From 2003 to 2009, four major series reported results of laparoscopic-assisted robotic surgery. One hundred forty-seven patients using the Da Vinci system and 15 patients using the Zeus system (not in production after acquisition by intuitive surgical) have been published by four authors.

The pathologies treated were abdominal aortic aneurysms in 21 patients, common iliac aneurysm in 2, and aortoiliac occlusive disease in 137.\(^\text{[4-11]}\) Technical problems such as bleeding or system malfunction required conversion in 3–20%. Morbidity was similar to open surgery (3–20%), mortality was 0.6%. Robot-assisted aortic surgery was reported to have a shorter anastomosis time than laparoscopic surgery. Other than the above pathologies, reports of treatment of renal artery aneurysm, visceral artery pathology, inferior vena cava tumors, and occlusions are also published but the overall numbers are very small.

Robotics had the potential to overcome the disadvantages of a laparoscopic system. The loss of 3D visualization, compromised dexterity, amplification of hand tremors, limited degrees of motion, loss of tactile sensation, and the fulcrum effect could be eliminated. In addition, robotics could scale movements, enable microanastomosis, and telesurgery. It did not need the surgeon to use heavy lead shields and was overall more ergonomic for the operator.

In spite of its advantages, the problems of cost, equipment size, mechanical problems, unproven benefit, acquisition of a new skill, increased operative time, and a steep learning curve prevented wider use.\(^\text{[7-10]}\)

**Endovascular Robotics**

With the rapid development in endovascular therapy, robotics was also applied to overcome challenges posed by failure of endovascular treatment. Conventional guidewires, catheters, and sheaths were limited by shape, size, maneuverability/control of the distal tip, and friction
embolization from the vessel wall necessitating high levels of operator skill, technical performance, and long learning curves. Extreme vessel tortuosity, excessive calcification, thrombus, difficult lesion morphology and location, increased radiation exposure, nephrotoxicity, and operator fatigue were the other challenges at which robotic solutions were directed.

Remotely controlled steerable catheter navigation for endovascular procedures were an off-shoot of technology developed for robotic cardiac ablation and mapping for the treatment of arrhythmias. Two main types exist: Magnetically steerable (Niobe system) and electromechanically steerable (The Hansen Sensei robotic catheter system). The latter and its second generation Magellan system is the system currently applied to peripheral endovascular interventions.\[3, 12-14\]

The Magellan system consists of three components: A bedside workstation and a robotic arm is controlled from the remote workstation by the surgeon and the hardware is the third component. The early hardware utilized was a 9 Fr/6 Fr telescoping guide - leader catheter platform which was unsuitable for use in smaller vessels. Newer 6 Fr single catheter and 10 Fr/7 Fr systems have also been developed. Conventional 014 or 035 guidewires can be used [Figure 2]. The operator has independent control of both outer and inner catheter. These have 180° bending and 360° rotational capacity- they can thus form any catheter shape. The catheter can also be stiffened or relaxed providing differing stability or flexibility without catheter exchange/movement. Other different sizes of catheters are also under development.\[14-23\]

Following preclinical and in vitro studies, this system has been used in human series with encouraging results. A wide spectrum of pathologies can be managed with this system and its use in carotid, aortic, renal, visceral splanchnic, hepatic, iliac, and extremity vascular beds has been successful. In these stenting (including TEVAR, fenestrated EVAR, and EVAR), angioplasty, embolization, and crossing of femoral/popliteal CTO’s have been performed. It has also been used in endovenous procedures.

Compared to conventional methods, the advantages of robotic endovascular surgery are shorter procedure time and fluoroscopic exposure time, better stability and positional control of the catheter tip with decreased catheter changes/movements, and improved performance in tackling tortuous and angulated blood vessels. It has a shorter learning curve and maintains increased operator comfort. The cost of the system and disposable catheters, longer set-up time, technical support, and lack of tactile feedback are the main current disadvantages.\[15-18\]

The Robotic Vascular and Endovascular Registry has been set up to collect retrospective/prospective multidisciplinary data about use and early follow-up data from multiple centers. It has enrolled almost 1000 cases from 17 centers worldwide; initial results are awaited.\[23\]

**Future Directions**

The clinical feasibility of robotics is only limited by our imagination. Technological flux is constant; further technical advancements in haptics, speed of information transfer, hardware development, integration with other specialties such as nanomedicine, computational fluid mechanics, artificial intelligence, and bionics will possibly bring in novel solutions to vascular surgery in the near future.

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**Conflicts of interest**

There are no conflicts of interest.

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