Use of Surgical Robots on Cardiology Surgery: Advantages and Barriers for its Implementation

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ABSTRACT

Surgical robots are computer-assisted electromechanical devices that aid surgeons and are designed to replicate human movements into more steady precise motions, giving more accurate and delicate operations. The purpose of this research was to study the evolution of technical features of surgical robots on cardiology to determine technical advantages and barriers of these technologies. In one study out of all 50 patients that had endoscopic atraumatic coronary artery bypass robotic surgery, 49 reported they would recommend the surgery to another. Features make instrument manipulation more intuitive by eliminating the fulcrum effect, which removes the surgeon from twisting and turning in awkward positions. In another research, operative times were longer with robot-assisted surgery with an average of 97.1 minutes compared to traditional laparoscopy with an average of 82.1 minute. Additionally, scars are eliminated with robot-assisted surgeries, which decrease blood loss, length of stay, postoperative pain, and narcotic use. The results of this study suggest that the benefits of advancement in technical features of robotic cardiac surgery outweigh the barriers.

INTRODUCTION

Robots are machines that perform complex actions controlled by a computer to replace human effort (Merriam-Webster, 2013). Surgical robots are computer-assisted electromechanical devices that aid surgeons (Herron, Marohn, & The SAGES-MIRA Robotic Surgery Consensus Group, 2008). Theatre operating robots have been designed to replicate human movements into more steady precise motions, giving more accurate and delicate operations (Lobontiu & Loisance, 2007). Surgical robots have the ability to enhance aspects of surgery that could not be accomplished by humans. Over the past four years, the use of robotic technology has implemented rapidly and the number of robot surgery has tripled since 2007(Barbash & Glied, 2010). Robotic surgery had made possible to perform tasks that are difficult and unable to do for surgeons. Robots have an increased degree of freedom, which greatly enhances surgeons' capability to manipulate. Surgical robots also have the ability to scale larger movements into micro motions inside the patient (Barbash & Glied, 2010).

The use of robotic surgery is not to replace surgeons but to assist. Surgical robots are not autonomous and to lessen the work of surgeons (Lobontiu & Loisance, 2007). These new innovative machines have been used to increase patient care by making more precise and more minimal invasive incisions. Smaller incisions give faster recovery leaving smaller scars and decrease the use of pain medication (Stoyanov, Darzi, & Yang, 2005).

The cost of robotic surgery for cardiology has not been significantly higher than the cost of the conventional surgery, but improvement in post-operation for quality of life makes robotic approaches more cost-efficient (Bell, Torgerson, Seshadri-Kreaden, Suttle, & Hunt, 2008). The benefits of cardiac robotic surgery justify investment in this technology. Cardiac robotic surgery decreases hospital stay; therefore, making more spots available for patients giving potential for additional revenue. The concept of new innovative robotic surgery has stimulates the public interest and impelled more patients for referral (Bell, et al., 2008). For mitral valve surgery, using robotics has become the preferred method as a replacement for specialized centers worldwide because of outstanding results (Rodriguez & Chitwood, 2009).

There are three types of surgical robots: one is invoked on command which is preprogrammed offline, the second type is an assistant device, and the third type is a remote manipulator (Baltayian, 2008). There are many kinds of robotic surgery for cardiology. These robotic heart surgeries include: mitral valve repair and replacement, tricuspid valve repair and replacement, coronary artery bypass, ablation of atrial fibrillation, atrial septal defect repair, patent foramen ovale repair, removal of cardiac tumors, and lead placement (Cleveland Clinic, 2013).

A coronary artery bypass is a cardiac surgery used to relieve angina and reduce the risk of coronary artery disease (Serruys, et al., 2009). In coronary artery bypass graft surgery, an artery is harvested from another area of the body, such as an arm or leg. That artery is then used to "bypass" the occluded artery within the heart to reestablish blood flow. The viewer shows images on two monitors with resolution of 2.0 mrad/line pair for the scope.

There are many different types of robots in the market such as Cody Evander, Probot, Robodoc, Puma, Neuromate, PathFinder, CyberKnife, Aesop, Zeus, and da Vinci. The most common use for robotic assisted heart surgery is the da Vinci System (Baltayian, 2008). In May 1998, the first robotic assisted heart bypass surgery was perform using the da Vinci Surgical System (Bodner, Wykypiel, & Schmid, 2004).

The da Vinci Surgical System has three dimensional stereoscope viewers, which are designed to mimic human hand, wrist and finger movement, allowing a wider range of precision and motion (Cleveland Clinic, 2013). The surgeons sit at the control console and view the images and control the arms of the instrument. This has allowed the surgeons to perform more precise surgeries than those performed in traditional surgery (McLeod & Medler, 2005).

Many patients use the internet to find information about the different possible treatment for conditions (Hartzband & Groopman, 2010). Robotic surgery can be marketed as new innovated technology as an advantage over alternative healthcare organizations.

The purpose of this research was to study the evolution of technical features of surgical robots on cardiology to determine technical advantages and barriers of these technologies.

METHODOLOGY

The methodology of this study was a literature review. PubMed, Science Direct, Google Scholar and EbscoHost databases were reviewed for articles. Key terms used in the search included ‘cardiac’, AND ‘robotic’, AND ‘surgery’, OR ‘heart’. The search was limited to articles published 2003 through 2013 so that only current articles would be represented in the search results. Articles were limited to the English language and those attainable in full text. Primary and secondary data were included from original articles, research studies and reviews. Articles were chosen after review of abstracts was performed. References cited by published sources were also reviewed for relevant articles. Thirty-one articles were chosen for this research. This search was completed by HA, CP, and AH and validated by AC. Academic articles and sources were reviewed so that relevant categories were structured. The findings are presented in subsequent sections using categories of technical features of cardiac surgery robots under the headings: Surgical Cardiac Robots in Hospitals, Technical Features of Surgical Cardiac Robots, Benefits of Robotic Surgery, and Barriers of Robotic Surgery.

The conceptual framework was customized from Yao (2010) conceptual framework. This framework presents the need for robotic surgery that stem from inaccurate problems in surgery. The adoption of robotic surgery has benefits and barriers that may impede the adoption (Figure 1).

Insert Figure 1

RESULTS

Surgical Cardiac Robots in Hospitals

There are many different technical features for surgical cardiac robots. All of these technical features have benefits and barriers. A systematic analysis found that of 400 randomly selected hospitals, only 37% provided robotic surgery information on their website homepage (Jin, et al., 2011). Out of all 50 patients that had endoscopic atraumatic coronary artery bypass robotic surgery, 49 said they would recommend the surgery to another. In addition of 44 patients, 40 thought that surgeons should add heart robotic surgery to their website (Jin, et al., 2011).

Surgeons from the University of Chicago Medicine were pioneers in robotic cardiac surgery and regularly use robots for various procedures. The University of Chicago Medicine is one of very few hospitals that offer a wide range of robotic cardiac approaches for cardiac conditions (University of Chicago Medicine, 2013). The Mayo Clinic uses the da Vinci Surgical System to treat many complex conditions. The Mayo Clinic uses robots for several heart conditions such as mitral valve disease, heart disease, coronary artery disease, and atrial septal defect (Mayo Clinic, 2013).

Technical Features of Surgical Cardiac Robots

The most common surgical robot used for cardiac is the da Vinci System, but there are also other robots that are used such as the AESOP 3000 (Bolotin, et al., 2004). There are a variety of techniques to perform each different heart surgery. One heart surgery is the mitral valve repair, which is a treatment for severe mitral regurgitation, hypertension, and congestive heart failure. The arm of the robot converges at obtuse angles to produce lateral atrial wall stress (Nifong, et al., 2005). This tears the atriotomy leading to less mitral valve exposure. The 3-D high-resolution endoscope was put through the mini-thorcotomy. Needles were taken using long magnetic device and the suture remnants were removed from the area (Nifong, et al., 2005).

Benefits of Robotic Surgery

Technical features of cardiac surgical robots can attribute to many advantages. Surgeons have the ability to manipulate instruments and tissues easier with increased degrees of freedom, which greatly enhances dexterity. These features also make instrument manipulation more intuitive by eliminating the fulcrum effect, which removes the surgeon from twisting and turning in awkward positions (Lanfranco, Castellanos, Desai, & Meyers, 2004). The fulcrum effect creates many obstacles, which include inversion, scaling of movements, and altered sensation of forces (Nisky, et al., 2012).

Robotic instruments also move the same way surgeon's hands would move, which also eliminates the fulcrum effect. The combination of the wristed robotic instruments and articulation of the robotic arms allow the surgeon seven degrees of freedom (Leddy, Lendvay, & Satava, 2010). A great improvement from the conventional laparoscopic camera views is the 3-D view with depth perception greatly enhances vision. Overall these features can increase dexterity, hand eye coordination, restore ergonomic position and improve visualization. The surgeon is also able to directly control a stable visual field with increased maneuverability and magnification (Lanfranco, et al., 2004).

Robot assisted surgery also benefits the patients as well as the surgeon. The use of large morbid unsightly scars is eliminated with robot-assisted surgeries. This often decreases blood loss, length of stay, postoperative pain, and narcotic use in surgical fields where robot-assisted surgery is being utilized (Leddy, et al., 2010).

Barriers of Robotic Surgery

The robotic surgery systems are not without its flaws and still have many imperfections. The da Vinci mimics human like movement, but lacks autonomy and does not give tactile feedback. The uses of these tools are complex and are difficult to learn. The robotic systems also take a longer amount of time to change instruments, which lengthen operating time (Berlinger, 2006). Longer operating room time has been documented for robotic cases, which required three to four endoscopic instruments. Each instrument costs $2,000 and was used a total of ten times per instrument factoring in costs of $800 per case and $200 per instrument (Morgan, et al., 2004). When mini coronary artery bypass graft was compared to Off-Pump Coronary Artery Bypass (OPCAB), miniCABG sustained much longer operating room times 3161+/- 606 minutes to OPCAB 1765 +/- 499 minutes respectively (Poston, et al., 2008). Conventional mitral valve repair and robotic mitral valve repair were compared over a period of time from June 2005 to June 2008. Operating times were documented as 18% longer when surgeons utilized robotic mitral valve repair compared to conventional repair 239 minutes vs. 209 minutes (Kam, Cooray, Kam, Smith, & Almeida, 2010). Evidence has indicated that operative times were significantly longer with robot-assisted surgery with an average of 97.1 minutes ranging from 77-126 minutes compared to traditional laparoscopy with an average of 82.1 minutes ranging 55-120 minutes (Beninca, Garrone, Rebecchi, Glaccone, & Morino, 2003). Some other barriers of the system have been that the robots themselves do not come equipped with many tools so these systems are also extremely large and bulky machines, which hamper the surgeon when making certain maneuvers during surgery (Giulianotti, et al., 2003). There has been evidence shown that given the current level of technology, robotic surgeries do not provide a much different outcome compared to the traditional laparoscopic techniques (Beninca, et al., 2003). One of the most difficult barriers to overcome has been the education of the hospital staff, particularly in the operating room, and teaching these individuals the differences between robotic surgery and the traditional laparoscopic surgery (Amodeo, Linares, Joseph, Belgrano, & Patel, 2009).

The problem of inaccuracy in surgery is a need for robotic surgery. Applications and adoptions of robotic heart surgery can produce benefits and barriers. Benefits can promote adoption whereas; barriers can impede adoption as show in the conceptual framework for robotic cardiac surgery technical features in Figure 1. These barriers include: is very expensive, high startup cost, absence touch of human sensation, and training staff robots. Results showed that benefits include: 3-D visualization, improved dexterity, seven degrees of freedom, and ergonomic positions as shown in Table 1.

Insert Table

DISCUSSION

The results of this study suggest that benefits of advancement in technical features of robotic cardiac surgery outweigh the barriers. Cardiac surgery robots bring many positive facts into the health care industry. These facts are not only beneficial to physicians but as well as the patients. Patients have experienced greater post-operative outcomes such as decreased pain and scaring. The National Aeronautics and Space Administration (NASA) are implementing the use of robotic surgery for emergency on astronauts through simulated condition in submarines. The Pentagon is investing on a project to create surgical robots to perform operation on wounded soldiers that are overseas (Morris, 2005).

Cardiac surgery robots have had a positive influence on how well physicians perform their job. With the help of these robots physicians have greater degrees of freedom, and enhanced vision from the 3-D camera views. These robots also can make the physician's jobs are easier and produce better patient outcomes such as the elimination of unsightly scars in turn decrease blood loss. Other outcomes included are the decrease of postoperative pain, narcotic use and postoperative length of stay. With the current technology in place it can be built upon even more to make the robots perform better as technology advances.

The principle barriers to the implementation of cardiac robot optic surgery are costs, time, and perceived lack of improved clinical outcomes. One problem with the current Da Vinci system that it is expensive and drive up intraoperative costs due to increasing operating room time. Although evidence has been shown that robotic surgeries can decrease recovery time and improve morbidity rates, there is still concern with high start-up costs associated with robotic systems. When amortized over a system's lifetime, capital and maintenance costs can add significantly to the cost of each procedure (Poston, et al., 2008). Maintenance costs in order to operate these systems have been estimated at over $138,000 annually; not including the original cost of the system itself $1,200,000 that can cause concern for cost containment issues (Amodeo, et al., 2009). Some barriers can be considered as a function of both time and cost. Whenever an innovative system has been implemented into daily operations, at first there has been an imminent learning curve associated with surgeons in order to become well versed in the product being used. The increased time in the operating room is also a function of costs as fewer surgeries per day can be performed. Ultimately all healthcare decisions must consider clinical outcomes. While cost and operating room time add to the hospital budget, hospital length of stay and pain medications consumed are reduced. Some barriers have been reduced with time and experience. Competition may reduce the purchase price of robotic technology, much like computers. Education on robotic surgery could be included as part of surgery residency which would ultimately reduce operating times.

A limitation that specifically relates to the use of cardiac robotic surgery is incomplete and delayed motion tracking. These systems not only add a second information processing system but also can cause inertia by additional electronic and mechanical parts, which could affect dexterity (Modi, Rodriguez, & Chitwood Jr., 2009). The learning curve to learning the system also places a limitation to the use of robotic cardiac surgery. It is a complex system to learn and requires complex training programs (Modi, et al., 2009).

This study was limited by researcher bias as search terms were limited to gathering the most relevant articles. Publication bias may also be present; some of the studies found were from providers using this technology as opposed to independent research studies. Large amount of the information obtained for this research study supported the use of cardiac surgical robots.

Practical Implications

Surgical robots have the potential to provide surgical care in underserved areas; however, the cost is too expensive for areas where it is needed most. Robotic surgery can provide surgical care to patients that do not have direct access to a surgeon. Patients and healthcare professionals can gain useful knowledge on the benefits and barriers of robotic heart surgery for educational purposes. As technology advances, there will be more demand for robotic heart surgery in the future. Further research and clinical trials in this topic should be performed to provide new data and expand existing knowledge.

CONCLUSION

The finding of this study suggest that the cost barrier is the main factor impeding the adoption of cardiac surgery robots as the benefits still outweigh the barriers. The implementation of cardiac surgery robots would likely benefit patients, physicians, and hospitals and could be the new standard of practice in most hospitals.

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Table 1: Benefits and Barriers of Cardiac Robotic Surgery

	Benefits	Barriers	Cost/Time
Robotic Cardiac Surgery	3-DVisualization (Lanfranco, et al., 2004) Improved Dexterity (Lanfranco, et al., 2004) Seven Degree of Freedom (Leddy, et al., 2010) Elimination of Fulcrum Effect (Nisky, et al., 2012) Ergonomic Position (Lanfranco, et al., 2004)	Very Expensive (Morgan, et al., 2004) High Start Up Cost (Amodeo, et al., 2009) Absence of Touch Sensation (Berlinger, 2006) Longer operative Times (Beninca, et al., 2003) Training Staff on Robots (Amodeo, et al., 2009)	$2,000 per Instrument (Morgan, et al., 2004) $1,200,000 to purchase (Amodeo, et al., 2009) 97.1 vs. 82.1minutes (Beninca, et al., 2003)

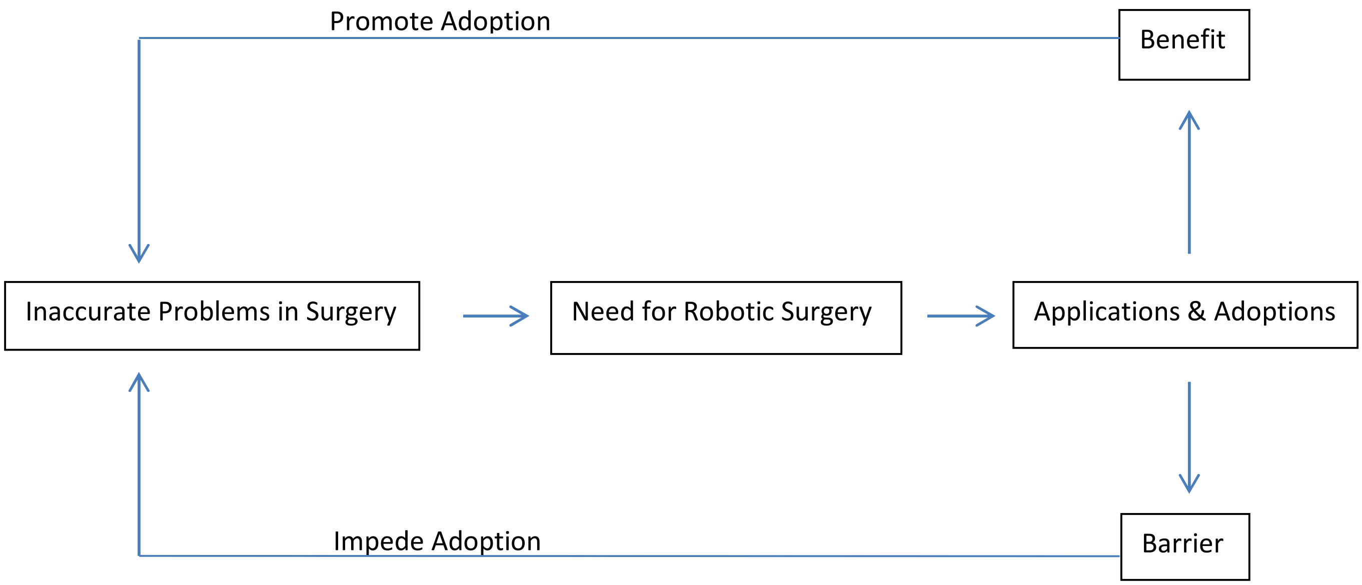

Figure 1: Conceptual Framework: Robotic Cardiac Surgery Technical Features
Source: Yao (2010)