Application of Robotic Surgical Systems in Paediatric Surgery

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CLINICAL POINTS

Robotic surgery is a new advance in the field of minimally invasive surgery and appears to be safe and effective in children.

The rate of complications or conversion to open surgery associated with this technique has been low.

Currently, the most commonly performed robotic-assisted paediatric surgeries are pyeloplasties and fundoplications.

While robotic surgical systems have the potential to offer significant advantages over standard laparoscopic techniques, studies have shown that there is no significant benefit over laparoscopy.

They serve as vital teaching tools for training residents and doctors to perform procedures not easily managed by laparoscopic techniques.

There is a need for randomised controlled trials and long term follow up of patients undergoing robotic surgery and conventional laparoscopic surgery to note the differences in clinical outcome.

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Abstract

Robotic surgery is a new advance in the field of minimally invasive surgery and offers a novel approach to surgery by overcoming the limitations of laparoscopy. At present, the applications of robotic surgery are widespread, including adult and paediatric surgical procedures. The daVinci robotic surgical system is the predominant robotic system used in paediatric surgery. Currently, the most common robotic-assisted paediatric surgeries are pyeloplasties and fundoplications. The benefits of robotic systems include increased dexterity, improved depth perception and enhanced hand-eye co-ordination, all allowing for accurate surgical manipulation. The major limitation is the high initial and recurring cost of the surgical systems. Robotic surgery appears to be safe and effective in children and a wide variety of procedures can be performed. Although the average set-up and mean operative times are longer than when compared with conventional laparoscopy, the rate of complications or conversion to open surgery has been low. There is a need for randomised controlled trials and long term follow up of patients undergoing robotic surgery and conventional laparoscopic surgery to note differences in clinical outcome.

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▲ ***Fig. 1. Da Vinci surgeon console and patient side cart.***

Introduction

Surgery is an ever-evolving and dynamic field with the continuous development of new techniques and innovations, all with the objective of improving patient care. The use of robots in surgery is a new and exciting technology that stretches the realms of minimally invasive surgery (MIS). MIS is a modern surgical technique in which operations are performed through small incisions using a miniature camera and long slender instruments, as compared to larger incisions needed in traditional surgical procedures. Robotic surgery is an advanced form of MIS. Robotic surgical systems are used to enhance surgical skill in order to perform more precise and varied MIS procedures. The computer enhanced robotic surgical systems achieve this by translating skilled movements performed by the surgeon on a separate console to the robotic instruments inserted in patients through small incisions, resulting in instrument articulation beyond normal manipulation associated with MIS. The concept of robotic surgery was originally conceived by the United States military in order to allow surgeons to operate on wounded soldiers from a safe distance. These systems are now used to enable complex minimal access surgical procedures. Robotic surgery has been used in cardiac surgery, gynaecology, paediatric surgery and urology[1].

The concept of MIS was first realised with the advent of laparoscopic surgery as a widespread surgical technique in the early 1990s. The advantages of MIS are quite significant, offering the patient reduced pain and blood loss and, more importantly, a much shorter recovery time[2]. Laparoscopic surgical techniques have improved significantly over the last decade, yet there are still some limitations associated with them. These include the inability to suitably perform anastomoses (particulary microscopic ones), the use of instruments that only rotate along two axes and the loss of depth perception due to a two dimensional image provided by the laparoscopic camera[3]. Such limitations finally realised the need for use of robots as an alternative approach to MIS. Robotic surgery is still very much in its infancy, with a long way to go before the full potential of such a futuristic technology is achieved.

Discussion

The use of robotic surgical systems (especially in the field of paediatric surgery) is becoming increasingly common. In paediatric patients, the body cavities are smaller, tremor and loss of dexterity are more detrimental, and visibility is more limited. In addition, the tissues and structures are smaller and more liable to injury. Furthermore, cosmesis and the need to minimise post-operative pain are particularly important in the paediatric population[4]. Hence, MIS techniques can offer genuine benefits and the difficulties of performing laparoscopic procedures in confined spaces on small paediatric patients have been circumvented with the introduction of robot-assisted paediatric surgery.

At present, the race to acquire robotic surgical systems has been primarily market driven, with centres competing with one another for the aquistion of a reputation in 'excellence in minimally invasive surgery'[5]. As such, a variety of commercial companies have been developed to create surgical robotic systems such as the ZEUS surgical system, developed by Computer Motion Inc, and the daVinci surgical system, developed by Intiutive Surgical Inc. ➔

▲ ***Fig. 2. Surgeon console.***

Both systems consist of two major components: the surgeon's console and the patient side cart, the latter consisting of two to three robotic arms that control operative instruments and another arm that controls the video endoscope.

At present, the daVinci system is the predominant robotic system used in paediatric surgery[1]. The surgeon sits at a console which can be up to 10 metres away from the operating table, and manipulates the robotic arms housed in the patient side cart (see Fig. 1). One arm holds a camera (endoscope) that has been passed into the patient through a small incision. The surgeon operates the other two arms by inserting fingers into rings located in the console (see Fig. 2). The surgeon uses hand movements and foot pedals to control the camera, adjust focus, and reposition the robotic arms. Another surgeon stays beside the patient, adjusting the camera and instruments if needed. The standard da Vinci instrument platform consists of an array of 8.5mm diameter instruments. These instruments have distal articulations or 'wrists', known as 'endowrists', that provide 7 degrees of freedom, allowing for increased manoeuvrability and enhanced range of motion (see Fig. 3)[1].

▲ ***Fig. 3. Endowrist technology.***

In the field of paediatric surgery, robot-assisted surgery has been most useful in general surgery. Gutt et al[6] and Heller et al [7] published the first reports describing the use of robotic surgical systems in abdominal procedures among children. The da Vinci system was used to perform Nissen fundoplication for treatment of gastro-oesophageal reflux disease (GERD). In a Nissen (complete) fundoplication, the fundus of the stomach is wrapped around the esophagus and stitched in place, reinforcing the closing function of the lower esophageal sphincter, preventing reflux of gastric acid. This procedure was performed on 11 children with a mean operative time of 146 minutes. There were no significant intra-operative or post-operative complications reported. In a prospective study published in 2006, comparison of robot-assisted fundoplication with the more conventional laparscopic technique indicated that the total operative time was similar in both groups. However, in the robotically assisted group, dissection of the hiatal region (the most challenging operative step) was accomplished 34% faster than with established standard laparoscopic techniques, though time for setup of the robotic surgical system was significantly longer[8]. Nissen fundoplication is the most commonly performed procedure using the daVinci system in paediatric general surgery today[9]. Other procedures that have been successfully performed using the daVinci system include cholecystectomies, splenectomies and repair of Morgagni diaphragmatic hernia[10].

Within the field of reconstructive paediatric urology, robot assisted surgery provides a significant advantage for the paediatric urologist, as its strength lies in intracorporeal suturing and enablement of difficult dissection. The daVinci system, with its endowrist technology, permits highly accurate and precise manipulation for laparoscopic dissection, tissue handling and suturing[11]. The procedures that have been carried out to date have been transperitoneal and include pyeloplasty, pyelolithotomy, extravesical anti-reflux procedures and creation of continent catheterizable stomas using appendix (Mitrofanoff procedure). Current literature indicates that pyeloplasties (surgical reconstruction of the renal pelvis to drain and decompress the kidney in the treatment of uretero-pelvic junction obstruction) using the daVinci system are becoming increasingly common place, with Oslen et al reporting a series of 65 pyeloplasties performed using the daVinci robotic system in 2007 alone[9].

The development of robotic surgical systems has enabled the application of minimially invasive techniques to cardiac surgery, such as coronary artery bypass grafting and mitral valve repair in adults. However, in paediatric cardiac surgery, robotic systems are mostly limited to thoracoscopic procedures on extracardiac lesions such as ligation of patent ductus arteriosus and division of vascular rings. The relatively large size of robotic systems limits the use of such technology in paediatric patients with intracardiac lesions such as atrial septal defects (ASD)[13]. Le Bret et al[12] were the first to report the robotically assisted procedure for patent ductus arteriosus (PDA) ligation in the paediatric population. This prospective clinical trial (n=56) compared the robotically assisted technique for PDA ligation with the standard, video-assisted thoracoscopic surgery (VATS), and found that the operation time was significantly longer in the robotically assisted group because of the increased complexity. VATS is an MIS procedure, where a small video camera is introduced into the patient's chest via a small incision. Using this camera, the surgeon is able to view the anatomy and perform the surgical procedure using other instruments introduced into the chest via small incisions or "ports". The authors concluded that while robot-assisted PDA closure in small children was safe and feasible, it offered no advantages over standard thoracoscopy[13].

To date, published case reports have mainly focused on robotic surgical systems used for relatively routine minimially invasive surgeries in the paediatric population. More complex reconstructive operations such as portoenterostomy have been carried out in animal models using robotic surgical systems. Hollands et al[14] and Lorincz et al[15] describe robot-assisted Kasai portoenterostomy (connection of the bile drainage from the liver directly to the intestinal tract in the treatment of biliary obstruction in infants) on porcine models using the ZEUS robotic surgical system; both studies demonstrate that such procedures are technically feasible. The study conducted by Lorincz et al indicated that the procedure is durable, with good long term outcomes. Such studies suggest that complex reconstructive minimally invasive procedures can be done by robotic surgical systems on paediatric patients. For example, in 2008 Meehan et al reported the first ever robot assisted Kasai portoenterostomy performed on a six week old infant with biliary atresia[16].

Benefits

Robotic systems offer many advantages over conventional laparoscopic instrumentation. Unlike the latter, robotic devices allow instruments to directly track the movement of the surgeon's hands. Additionally, both the Zeus and daVinci systems use instruments that are equipped with articulations at the distal end, serving to increase dexterity and allowing for a larger range of motion and rotation. The provision of a magnified image is of utmost importance as it allows accurate visualisation of the miniature anatomy of paediatric patients. Robotic systems excel in this area, as they are capable of providing a highly magnified 3-Dimensional image, thus, improving depth perception. Furthermore, alignment of the visual axis with the surgeon's hands in the console enhances hand-eye coordination.

When working within confined spaces, the effects of hand tremor are magnified. The presence of computer- ➔

Benefits

- Increased dexterity
- Increased range of motion
- Enhanced 3-D visualisation
- Enhanced hand-eye co-ordination
- Electronic tremor filtration

Limitations

- Relatively large size
- Specialised training
- Additional set up time
- High initial cost
- High recurring costs

con trolled robotic systems enables electronic tremor filtration, thus making the instrument tips steadier allowing for less accidental tissue injury.

These systems also allow for motion scaling from the surgeon's hand to the instrument tips (for example, with a 3:1 scale, 3 cm of movement of the surgeon's hand is translated to 1 cm of movement of the instrument tip). The increased dexterity, improved depth perception and enhanced hand-eye co-ordination all allow for accurate surgical manipulation, especially in confined spaces and in complex reconstructive procedures that require fine dissection and suturing within the body cavity[1].

Limitations

Compared to the paediatric patients, robotic systems are relatively large in size. This size discrepancy restricts bedside access of the surgical assistant to the patient while the arms are in use and require the anaesthetists to make special preparations to ensure access to the airway[1]. Additionally, as robot-assisted surgery is still a new technology, the size and variety of available robotic instruments is limited compared with those offered for standard laparoscopy. The robotic system also requires specialised training for the operating room team. This results in longer mean operative times when compared to conventional laparoscopic techniques, the main difference being the additional set up time required[1].

One of the most intrinsic limitations of robotic surgical systems is the high initial cost of 1.2 to 1.5 million dollars for the initial hardware[17]. There is also high recurring costs of replacement instruments, drapes and service contract for maintenance. Such technology can be afforded by few children's hospitals. The Children's Hospital at the University of Iowa are of the opinion that high cost is the single most limiting factor to the progress of paediatric robotic surgery[17].

Conclusion

The overall consensus is that robotic surgery appears to be safe and effective in children, and that a wide variety of procedures can be performed. Although the average set-up and mean operative times are longer compared with conventional laparoscopy, the rates of complications and of conversion to open surgery has been low[1]. Currently, the most common robotic-assisted paediatric surgeries are pyeloplasties and fundoplications. A recent review of robot-assisted surgery in children identified 566 cases performed up to October 2007, 141 of which were pyeloplasties and 122 of which were fundoplications[9].

While robotic surgical systems have the potential to offer significant advantages over standard laparoscopic techniques (especially in the more complex paediatric procedures), studies thus far suggest that commonly performed robotic surgeries, such as relatively simple and routine pyeloplasties and fundoplications, have no significant benefit over laparoscopic techniques. However, they serve as vital teaching tools in order to train residents and doctors to perform procedures not easily managed by laparoscopic techniques, such as Kasai portoenterostomy[17]. Until these more complex surgeries are routinely performed using robotic techniques, it will be difficult to demonstrate any significant clinical benefits of this new technology.

As of now, most published material dealing with robotic surgery in paediatrics has been retrospective case reports that document feasibility and safety. Thus, there is a need for randomised controlled trials and long term follow up of patients undergoing robotic surgery and conventional laparoscopic surgery to note the differences in clinical outcome. Finally, robotic systems have the potential to completely revolutionise the future of not just paediatric surgery, but surgery in general. As technology continues to be refined, the abilities of robots in surgical practice will only increase at an exponential pace. ■

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