Abstract
Introduction
Robotic colorectal surgery has grown in popularity since the introduction of the da Vinci Surgical System in 2000. Safe use of the robotic platform has been successfully demonstrated in all types of colorectal procedures; however, outcomes remain controversial. The majority of studies are retrospective, and suggest outcomes that are similar to standard laparoscopic surgery. The aim of this critical review was to discuss the robotic colorectal surgeon.

Conclusion
Robotic surgical procedures appear to be associated with increased operative time and cost, but these procedures are also associated with improved surgeon ergonomics, and have great future potential for further advances.

Introduction
Robots have always captivated the human imagination. From early mentions in Homer’s Iliad to blockbuster movies like Terminator, robots invoke images of both wonder and terror. It is with little surprise that Intuitive’s da Vinci surgical robot grew from a novelty on US Food and Drug Administration (FDA) approval in 2000 to a clinical force with over 2,000 active units and 200,000 surgical procedures performed in 2012. While initial use of the robotic system was directed at prostatectomies and hysterectomies, colorectal surgeons have begun to use the system to facilitate minimally invasive surgeries of the hindgut. Robot enthusiasts note ‘beyond human’ surgical accuracy and improved outcomes; detractors emphasise cost and lack of proven benefit. This critical review seeks to evaluate the current status of robotic surgery in the colorectal field, and summarise current controversies.

Discussion
Ergonomics
If there is one purported benefit of the da Vinci Surgical System, which is unassailable, it is that of improved surgeon ergonomics. While this has been an area not often discussed, surgical ergonomics are coming under increased scrutiny. Traditional open surgical procedures, where the surgeon is standing and working through an incision, have been associated with substantial stress to the musculoskeletal system, secondary to prolonged static neck and back bends. The advent of minimally invasive laparoscopic surgery has only introduced new challenges, with digital nerve injuries and neck strain from awkward viewing of the telemonitor being reported. During robotic surgery, the surgeon is seated at a console, using minimal force controllers while viewing the procedure through an ideally positioned three-dimensional (3D) imaging system. While no direct comparisons for surgeon strain exist between robotics and either laparoscopic or open surgery, few experts would argue that the robotic system is more physically taxing (Figure 1). In this way, robotics may allow surgeons to have longer, more productive and injury-free careers. A theoretic concern remains that a successful robotic surgeon may lack the physical fitness to rescue a case in the event of emergency requiring conversion to an open procedure; robotic surgeons should remain well versed in open surgery.

Outcomes
Clinical outcomes following robotic surgery remain controversial. Many series have been published looking at the short-term outcomes following various types of colon operations, but no well-designed prospective study has been conducted.
randomised studies exist. Overall, outcomes are likely to be similar to laparoscopic surgery, but robotic advocates claim advantages over laparoscopy in pelvic operations. Robotic detractors claim that robotic surgery can be associated with an elevated rate of complications, and point to a lack of appropriate training and credentialing standards contributing to this outcome.

Overall, when compared to laparoscopic surgery, robotic surgery involves more trocar sites, many of which are larger than trocars used in laparoscopic surgery. The da Vinci Surgical System uses three robotic arms for instruments, one arm for a camera; and most cases require an additional assistant port for devices not available on all da Vinci robots, including Staplers, energy devices, to insert mesh and remove specimens. This makes for a total of five ports, the smallest of which are the 8 mm robotic instrument arms. This is compared to laparoscopic colon surgery, which can usually be accomplished with a three-port technique, often only one of which needs to be of a size greater than 5 mm. Although the 8 mm robotic trocars do not require closure, there has been one case report of small bowel herniation through a left lower quadrant robotic trocar, which required re-operation and bowel resection on post-operative day 4, following a hysterectomy.

**Right colectomy**

Many reports include documenting of the safety of robotic right hemicolectomy. All the reports observed similar complication rates, nodal harvest and length of stay when compared to similar laparoscopic series. Notably, operative times are significantly longer than standard laparoscopic surgery. In 2006, Rawlings and colleagues observed operative times of 219 minutes for robotic surgery versus 169 minutes for laparoscopic right colectomies. Later, in 2010 series, shorter operative were demonstrated, but they remained longer for robotic surgery, i.e., 159 minutes versus 118 minutes for laparoscopic right colectomy observed in a 2010 series. deSouza and colleagues also argued that right colectomy makes an ideal training operation, early in a surgeon’s robotic career. It is difficult to know if this justifies the additional operation room (OR) time and cost associated with a robotic technique for an operation, where no additional benefits are realised. It can easily be argued that these skills can be learned in a training laboratory environment. Robotics does add the possibility of performing an intracorporeal ileocolic anastomosis with the endorrost suturing capabilities, which allows the colonic extraction site to be moved away from the umbilicus. This may have benefits in reducing incisional hernias and wound infections; however, this technique can also be accomplished laparoscopically, with a mean operative time of 120 minutes. There are no data comparing the outcomes between these two advanced procedures. Advances in robotics have also led to some initial reports of single incision robotic right colectomy, but again, this has been accomplished with standard laparoscopic equipment in a more expedient fashion.

**Sigmoid resection**

Again, many reports of sigmoid colectomy using the da Vinci Surgical System exist. Many similar conclusions were made with regards to right colectomy can also be made for sigmoid colectomy. Overall, complications and outcomes are comparable to laparoscopic surgery, and operative times appear to be longer; however, fewer direct comparisons exist for sigmoid colectomy compared to right colectomy. The additional suturing capabilities of the robot may allow for advanced procedures on the left side of the colon, such as natural orifice specimens extraction through the rectum. Again, these techniques have been better demonstrated with standard laparoscopic equipment to date. It should be observed that even fewer reports of total or subtotal colectomies employing the robotic technique exist, likely secondary to the limited operative field of the robotic system, which would require repositioning several times during such an operation.

**Rectal resection and total mesorectal excision**

The majority of discussion about robotics in colorectal surgery has centred around rectal cancer. Propo-ponents suggest the 3D visualisation and the increased mobility of the robotic instruments that enables them to perform a more complete total mesorectal excision (TME) compared to standard laparoscopic techniques, while sparing the pelvic nerves and reducing complications. Available data suggest similar outcomes for laparoscopy. Baek and colleagues reported a series of 64-stage I–III cancer patients, who underwent robotic TME, where there were no positive circumferential margins; however, adequacy of the TME specimen was not reported. Several series of robotic TME suggest adequate short-term outcomes, with operative times in the neighbourhood of 300 minutes, low or zero positive margin rates and acceptable rates of anastomotic leak of 7%–10%. A comparative study for TME found no difference in short-term outcomes or oncologic adequacy of the resected specimen compared to laparoscopic TME. Again, a meta-analysis of the subject identified 16 studies comparing laparoscopic and robotic TMEs; this found longer operative time and cost for robotic procedures; however, they were observed to have lower blood loss. No differences in adequacy of resected specimen or complications were observed. Kim and colleagues observed an earlier return in bladder function in robotic versus laparo-scopic patients, but no overall differences were seen in bladder or sexual function at six months. Further study is needed to determine if this is a significant difference that will be realised by all surgeons.

Licensee OA Publishing London 2013. Creative Commons Attribution Licence (CC-BY)

Rectopexy

The enhanced suturing capabilities of the da Vinci have naturally made it a system used in rectopexy, where the rectum is suspended to the sacrum via either suture or mesh. A study of 77 patients, who underwent robotic rectopexy revealed acceptable operative times, with an average of 223 minutes, with low morbidity (10%) and recurrence at 13%24. This series observed resolution of the learning curve for 18 patients, which is shorter than what is reported for prostatectomy. This operative time remains longer than laparoscopic rectopexy, in which similar series reported an average OR time of 98 minutes25. With the increasing popularity of anterior rectopexy with mesh26, the robotic system may pose additional advantages as more suturing is required over traditional suture-rectopexy.

Learning curve

The length of time it takes a surgeon to become proficient at robotic surgery is a matter of considerable debate. There is increasing evidence that for traditional robotic surgeries, especially prostatectomy, this may be longer than initially realised. A recent review found the learning curve to be close to 1,600 cases for three urologic surgeons at a single institution27. Certainly, this has great implications for which surgeons should be credentialed to perform these techniques, especially in the field of colorectal surgery, where significant evidence of improved outcomes is lacking. Fortunately, the reported learning curve for colorectal cases appears to be markedly shorter than that of prostate surgery. Akmal et al. reported no difference in outcomes for the first 40 robotic TME cases compared to the second 40 robotic TME cases, in an 80 case series28. This could argue that the robotic technique is acquired easily by experienced laparoscopic surgeons; alternatively, it could also argue that the learning curve has not yet been achieved. Their overall data argue for the former, as their outcomes were comparable to laparoscopic series. A separate study of the learning curve in 50 robotic rectal surgeries identified a learning phase of 15–25 cases29, reinforcing that the learning curve in colorectal surgery may be more manageable than that observed for prostatectomy.

Appropriate training and practice on robotic systems may help to shorten the learning curve as well. A well-designed robotic skills course demonstrated good skill acquisition and retention in surgeons of various levels of training30. Training software has also been developed by the da Vinci’s parent company, and can be helpful in gaining familiarity with the skills required for successful robotic surgery. As with anything, the surgeon must remain dedicated to the practice of robotic surgery; use of daily goal setting can be helpful30.

Cost

The cost to the healthcare system of robotics is something of enormous debate. Little medical literature exists directly addressing the costs of laparoscopic versus robotic colorectal surgery; a single analysis from Korea documents a difference in cost of $15,000 for robotic surgery versus $10,000 for laparoscopic surgery for total hospital charges in US dollars31. A review of the nationwide inpatient sample from 2008 to 2009 found that for colorectal surgery in the United States, use of a robotic surgical system increased costs from $15,800 to $19,231 compared to laparoscopic surgery32. The same review reported no difference in overall complication rates and length of stay. Certainly, robotics is more expensive; however, how much so is unclear; especially given the differences between different countries in how health care charges are derived and handled. One number that is known is that Intuitive Surgical Inc. had revenues of 2.2 billion dollars in 2012. This increase in spending can be justified if there are improvements in outcomes or length of stay; however, such downstream savings have not yet been proven to date. Further advances in robotic technology and competition in the marketplace may help to reduce the cost of surgical robotics in the coming years.

Complications

There has been a recent interest in poor robotic surgical outcomes, leading trial lawyers to solicit cases and even consider class-action lawsuits33. Any injury during surgery is unfortunate, and bad outcomes are not limited to robotic surgery. The FDA MAUDE database, designed to keep track of adverse outcomes related to medical devices lists 4,600 events relating to the da Vinci Surgical System34. Available data from case series, however, does not support the observation that robotic surgery is associated with a higher rate of adverse outcomes compared to laparoscopic or even open surgery. Certainly, investigators reporting series are likely going to have good outcomes, and there exists a publication bias. This does however; demonstrate that robotic surgery appears to be safe in the right hands. Larger population based studies also support the observation that robotic and laparoscopic approaches have similar complication rates; in a review of the 2008–2009 inpatient sample, robotic surgery was observed to have a 3.0% intra-operative complication rate compared to 3.3% for laparoscopy35. Post-operative complication rates were observed to be 21.7% and 21.6% for robotic and laparoscopic surgeries, respectively.

These issues highlight the requirement for appropriate training of robotic surgeons, as well as credentialing standards. Equally important is appropriate disclosure to the patient of the surgery being proposed, as well as the risks and benefits. For innovative robotic procedures, this should include a discussion of unknown risks as well as a disclosure of how many similar procedures the physician has performed36. Such discussions will protect both patients and physicians in a medical field.
where technology advances often supersede the rate at which reliable data from well-designed studies can be generated.

**Conclusion**

Robotics in colorectal surgery has advanced, and will likely be a long-term part of the colorectal field. All colorectal operations have been performed safely in a robotic fashion; however, outcomes appear to be similar to standard laparoscopic surgery. There has been a suggestion of benefit in improved pelvic autonomic nerve preservation, with use of the robotic surgical system, but this has been observed in only one retrospective study, and should be interpreted with caution. The increased cost and operative time involved with robotic surgery may limit its application in colorectal surgery. Hopefully, future advances in the technology will help to reduce or eliminate these two barriers to use. Future advances may also facilitate procedures considered experimental now; or even procedures, which have not yet been performed, such as single-site colectomy with intracorporeal anastomosis and natural orifice specimen extraction. Robotic surgeons should be well-trained, and hospitals should maintain strict credentialing standards, especially in light of evidence that the learning curve for these techniques may be significant. Robotic surgeons should also disclose to patients pre-operatively, the risks and benefits of the technique and the possible limitations of their personal experience.

**Abbreviations list**

3D, three-dimensional; FDA, US Food and Drug Administration; OR, operation room; TME, total mesorectal excision.

**References**

Critical review


34. Medical devices [FDA U.S. Food and Drug Administration]. Silver Spring, MD: U.S. Food and Drug Administration; 2013 [updated 19 Jul 2013]