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MINIREVIEWS

Robotics and surgery: A sustainable relationship?

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Abstract

Robotic surgery is increasingly being employed to overcome the disadvantages associated with use of conventional techniques such as laparoscopy. However, despite significant promise, there are some clear disadvantages and robust evidence base supporting the use of robotic assistance remains lacking. In this paper, the advantages and drivers for robotics will be discussed, its drawbacks and its future role in surgery.

Key words: Robotics; Surgery; Simulation; Patient safety

Core tip: Robotic technology is increasingly being employed in surgery to overcome the disadvantages associated with use of conventional techniques such as laparoscopy. However, despite significant promise, robust evidence base supporting the use of robotic assistance remains lacking. Prospective, multicentre randomised controlled trials to evaluate efficacy, long-term outcomes, safety and cost are the next steps before widespread uptake of this technology to treat patients. Moreover, with the unprecedented need for patient safety, it is imperative that adequate training and assessment strategies are in place to bridge the gap between conventional techniques and robotic surgery without harm to patients.

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INTRODUCTION

Robotic surgery is increasingly being implemented to overcome drawbacks associated with the use of conventional techniques such as laparoscopy, especially in complex procedures. However, despite holding significant promise, robotic surgery is associated with some clear disadvantages and robust evidence base supporting robotic assistance remains lacking[1].

The introduction of minimally invasive techniques to general surgery has been described as "the most dramatic change in surgery since the introduction of anaesthesia"[2]. This has led to many procedures being performed exclusively *via* the laparoscopic approach, such as a cholecystectomy. Reasons include reduced blood loss and post-operative pain, reduced risk of infection, reduced length of hospital stay and faster return to daily activities[3]. However, these superior results are only when the initial learning curve has been taken into account.

Laparoscopic surgery is associated with several challenges. Disadvantages and complications have been well documented[4]. Long, rigid instruments amplify tremor, reduce range of motion and degrees of freedom. This is exacerbated by the fulcrum effect whereby instrument tips move in a direction opposite to those of surgeon's hands[5]. Loss of 3-dimentional (3D) vision and having to view a 2-dimentional image, not directly under the control of surgeon, enhances these difficulties by leading to loss of traditional eye-hand target axis[6]. The laparoscopic technique is associated with poor ergonomics and health problems in surgeons such as nerve injuries[7]. Robotic systems, such as the da Vinci, have thus emerged to overcome few of these limitations.

The 3D, high-definition imaging of robotic technology facilitates stereotactic vision of the operation field and makes depth perception possible[8]. The camera is surgeon-controlled and the area of interest can be magnified up to 10 times. The surgeon's hand movements can be scaled (5:1, 3:1, or 1:1) so that large hand movements are translated into smaller movements inside the patient[9]. Combined with tremor abolition, this facilitates precise surgical manoeuvres. Endowrist instrumentation provides 7 degrees of freedom and improves range of motion, enhancing dexterity, comparable to that attained in open procedures[10]. The surgeon's comfort is increased by the ergonomic sitting position, reducing fatigue (both physical and cognitive) due to exhausting positions or movements often observed in conventional laparoscopy[11]. The intuitive movements in robotic surgery can potentially shorten the learning curve compared to conventional laparoscopy[12]. Thus, less experienced laparoscopic surgeons may acquire skills to conduct robotic surgeries in a relatively shorter time period compared to attaining corresponding proficiency in conventional laparoscopy. Significant progress in robotic applications has been in procedures that cannot be performed by a laparoscopic approach, *i.e.,* cardiac and endovascular surgery.

CARDIAC SURGERY

A Total Endoscopic Coronary Artery Bypass (TECAB) can now be performed using the robotic slave system, da Vinci, from the Left Internal Mammary Artery to the Left Anterior Descending artery without the need for a strenotomy[13]. Successful results have been reported by several groups as a result of reduced post-operative pain, better cosmesis and faster healing due to lack of a strenotomy incision[14]. Procedures requiring extreme precision or fine visualisation, such as coronary anastomosis are facilitated by the high magnification and tremor-free, precise microinstrumentation[15]. Greater patient satisfaction is also reported[16]. Off-pump procedures (*i.e.,* on a beating heart) avoid complications of cardiopulmonary bypass and are associated with a lower incidence of atrial fibrillation, stroke and death in the elderly[17]. Robotic surgery is also useful for mitral valve reconstruction. 3D visualisation allows good view of the ventricle needed for suturing in chordal reconstruction[18]. Greater range of motion facilitates the complex cutting and needle loading angles in the confined space of the left atrium[18].

However, there are disadvantages. Robot-assisted TECAB is a technically demanding and time-consuming procedure. It is associated with a significant learning curve[19]. Nevertheless, it represents a feasible alternative to conventional coronary artery bypass[20].

ENDOVASCULAR SURGERY

Another emerging domain of robotic surgery is that of endovascular robotics. The conventional endovascular catheters present several limitations within the vascular tree. These include their small range of shapes and sizes, difficulty in maneuvering the tip with the lack of stability[21]. Hence, interventionalists have to frequently change catheters and this presents a major risk of vessel trauma or distal embolization as a result of alteration of guidewire position[21]. This is especially critical in the aortic arch, where stroke, as a result of cerebral embolisation, may occur[21].

Riga *et al*[22] demonstrated that Endovascular Aneurysm Repair using a robotically steerable catheter system is feasible and may improve catheter maneuverability, stability and precision. Pre-shaped conventional catheters can rotate around one axis only, presenting a major drawback when fine and controlled movements are required in multiple planes[22]. Conversely, a steerable multidirectional catheter may overcome this hurdle and may be especially useful with regards to anatomically difficult cannulation in fenestrated stent-grafting[23]. This system also minimises operator radiation exposure, as the workstation is located outside the endovascular suite and away from the radiation source. Robotic endovascular catheters may lead to improved accuracy, reduce time and minimise radiation exposure in complex vascular procedures in particular[23]. Moreover, robotic endovascular catheters have been demonstrated to lead to a statistically significant faster skill acquisition in novice surgeons[24]. Hence, there is a potential to shorten the learning curve so that trainees can attempt more complex endovascular procedures earlier and with a greater degree of safety[24]. Yet, transferability of these findings to the operating room (OR) is debatable.

DRAWBACKS AND THE FUTURE

Despite the numerous advantages, robotics in surgery has drawbacks that hinder the widespread

Table 1 Drawbacks associated with robotic surgery

Drawback	Discussion
Cost	The da Vinci system costs approximately $1.5 million with maintenance fees of about $150000 per year[43,44]. Likewise, robotic endovascular catheter systems are expensive, have high maintenance costs, with the additional cost of disposable catheters. However, there is no conclusive data regarding the cost-effectiveness of these robotic systems. Moreover, an economic model, with quality of life adjustment, has not been performed for any of the robotic systems[44]
Evidence	Currently, the evidence for robotic surgery's efficacy and safety is largely from retrospective studies often with small sample sizes or from an institution's initial cases/experiences, where the surgeon may be at the start of his/her learning curve[44]. Hence, conclusions about safety and efficacy must be interpreted with caution
Preparation, floor space and emergencies	The Theatre team must also be trained with the device set-up including troubleshooting problems that may arise during operations. Hence, the robotic surgery venture is likely a time, cost and resource-intensive process[45]. Moreover, considerable floor space is needed, with bulky instruments; this may be problematic and considerable cost may be incurred for renovations before robotic surgery can be employed. Furthermore, in an emergency, there may be a delay in converting to an open procedure since the bulky instruments cannot be as easily removed as in conventional laparoscopy[44]
Unproven efficacy	Current evidence base for efficacy of robotic surgery is mainly from small, retrospective studies. Prospective, multicentre randomized clinical trials to evaluate safety, efficacy, long term outcomes and cost analysis are required to prove that robotic assistance is indeed superior to conventional techniques before its widespread use

Table 2 Definitions of validity and reliability

Type	Definition
Face Validity	Extent to which the simulator resembles real life scenarios
Content Validity	Extent to which the domain that is being measured is being measured by the simulator/assessment tool
Construct Validity	Extent to which a simulator measures the trait it purports to measure
Concurrent Validity	Extent to which the results of the assessment tool correlate with the gold standard for that domain
Predictive Validity	Ability of the simulator to predict future performance
Test-Retest Reliability	Measure of a test to generate similar results when applied at two different points
Inter-Rater Reliability	Measure of agreement between two or more observers when rating an individual's performance

implementation of its usage (Table 1). In particular, the evidence base supporting robotic assistance remains lacking[1]. This extends beyond the examples provided above. A robotic prostatectomy is now the standard of care in many centres; despite only one RCT and substantial publication and selection bias, the results have showed no significant improvement in patient morbidity compared with conventional laparoscopy[25]. Likewise, a Cochrane review showed no differences in safety and efficacy for benign gynaecological robotic surgery compared to conventional laparoscopy[26].

Results from high quality, prospective, multi-centre randomized clinical trials (RCTs) are urgently required to evaluate the true efficacy of robotic surgery. Enhanced patient care may justify any higher costs. For surgeons uncomfortable with advanced conventional techniques, robotic surgery may reduce the time for them to reach procedure proficiency. For experienced surgeons, robotic surgery may enhance precision and decrease physical and mental workload.

With an unprecedented need for patient safety[27], it is imperative that adequate training and assessment strategies are in place to bridge the gap between conventional techniques and robotic surgery without harm to patients. This is especially important now with reduced working hours and training opportunities following calmanisation and introduction of the European Working Time Directive[28]. Possible avenues include: (1) Virtual Reality (VR) simulation; (2) Use of dual consoles; and (3) Training courses.

VR SIMULATION

VR simulation has been well established for conventional laparoscopy and has shown to improve skill transfer to the operating room[29,30]. However, its effectiveness in robotic surgery is less clear[31]. Before a simulator is used, it must fulfil a criterion with regards to validity and reliability (Table 2)[31]. Indeed, a study by Hung *et al*[32,33] showed that the da Vinci Skills Simulator demonstrated content, face and construct validity. The performance of the expert group was superior to intermediate/novice group when evaluating parameters such as overall score, motion economy and time to completion[32]. Specific proficiency-based curricula need to be developed in order to provide structured training with in built measures of assessment. However, while VR simulation for Robotic Surgical Training is a promising tool, data on skills transfer to the operating room is still lacking and further work is required before we can draw any firm conclusions about its efficacy in training. Another promising strategy is use of a dual console.

DUAL CONSOLE

The dual console allows collaboration between the trainee and an experienced mentor[31]. There are two collaborative modes: (1) "Swap mode" enables the experienced surgeon and the trainee to operate in parallel and switch control of the robotic arms; this facilitates parts of the operation requiring multiple hands, for example vessel isolation[31,33]; and (2) "Nudge mode" enables trainee and mentor to share the two robotic arms which is useful during key parts of the operation whereby the mentor can guide the hands of the trainee[31,33,34]. Marengo *et al*[35] suggested that use of dual consoles might shorten the learning curve and increase trainees' confidence in performing procedures. However, the data for the efficacy of dual consoles is scarce and prospective, RCTs are required to evaluate their true efficacy in surgical training[31].

TRAINING COURSES

Training courses, using animal, inanimate or cadaveric models have shown promise[31]. Assessment parameters include time to setup and operate, complications, errors and quality as determined by the Objective Structured Assessment of Technical Skills score[34,36]. Dulan *et al*[37] have developed a proficiency-based robotic training program that demonstrates construct and content validity as well as feasibility. Further validation of such curricula should be encouraged since we know that for conventional laparoscopy, achieving proficiency ascertains whether a surgeon has the aptitude to perform a procedure; this is not related to the length of training[38]. Aggarwal *et al*[39] demonstrated that a proficiency-based curriculum for laparoscopic cholecystectomy could shorten the learning curve resulting in faster skill acquisition. Moreover, such curricula for robotic surgery may provide the opportunity to exercise deliberate practice that has been regarded as a key practice to enhance and acquire "expert performance"[40,41]. And crucially, proficiency-based curricula may allow standardisation in training and assessment[39].

Finally, future development and innovation in more advanced technology for procedures that are challenging to perform with conventional as well as current robotic technology is warranted with the ultimate aim of improving patient outcome. The new imaging-sensing-navigated, kinematically enhanced robot, a flexible-access robot with integrated multimodal and multi-scale sensing, can enable the surgeon to guide tools into regions of the body that are difficult to access with the current technology[42]. It has already shown promising results *in vivo*, with clinical translation planned in the next couple of years[42].

CONCLUSION

Like when laparoscopic surgery was introduced, establishing the role of robotic surgery will take time and to ascertain which patients are most likely to benefit from it. Prospective, multicentre randomised controlled trials to evaluate efficacy, long-term outcomes, safety and cost are the next steps before widespread uptake of this technology to treat patients.

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