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Robotic surgery: the coming of a new era in surgical innovation

'Robotic surgery is here to stay. With continued innovation and technological improvement, the robot will continue to redefine how surgery is performed.'

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There are few surgical fields where open procedures are not performed in a minimally invasive fashion, using keyhole-sized openings to access the target organ. Whether simple or complex, the majority of surgical procedures have been successfully performed or attempted laparoscopically. In a number of fields, open surgery has been completely replaced by laparoscopy, such as cholecystectomy [1]. Similarly, in urology, open nephrectomies are being replaced by the laparoscopic approach [2]. Currently, there is a laparoscopic charge underway for several common procedures including prostatectomy, cystectomy, cardiac valve surgery and revascularization surgeries [2–4].

The success of laparoscopy has been due to its overall appeal to both patients and surgeons. The keyhole-sized openings resulted in shorter convalescence due to the overall reduction of trauma to the body. We have already advanced from using 10-mm holes to access the target organ, to 5 mm, and to instruments as small as 2 mm (needlescopic), thereby limiting the collateral trauma associated with surgical intervention [5,6]. Procedures that normally require a postoperative stay are now performed on an out-patient basis, with improved cosmesis [7]. Patients require less postoperative care and recover faster, consequently returning to their normal routine more rapidly.

Traditional keyhole surgery offers a number of advantages over the open approach; however, several drawbacks limit its widespread adoption. When these procedures are performed laparoscopically they are easier on the patient but provide significant challenges to the surgeon. Conventional laparoscopic instrumentation offers poor ergonomics, limits a surgeon's range of motion, eliminates tactile feedback and loses 3D visualization.

As technology has improved, these limitations are being addressed, improving the surgeon's ability to perform complex procedures. The development of robots to assist in surgery has allowed the surgeon to regain range of motion, with increased precision and dexterity through tremor filtration and motion scaling. In addition, recent optical developments have allowed a 3D visualization that was lost with conventional laparoscopy [8]. With robotic assistance, surgeons perform procedures in a minimally invasive fashion, with equivalent or even higher standards, compared with traditional open surgery.

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Robots in surgery are not new. For the last 20 years or so, robots of different forms, performing a variety of functions have been used in the operating theatre [9]. However, with the arrival of the daVinci™ robot over the last 5 years, robot-assisted surgery has been increasingly performed, leading many to question the future of open surgery in a number of surgical disciplines. In urology, for example, the robot is transforming prostatectomy, which has been known as a highly complex procedure in the open setting, and even more so with the laparoscopic approach. Similarly, the precise suturing required for cardiac valve surgeries is being transformed by the robot as these procedures become more technically feasible.

Despite the steady improvements made in the use of robots in surgery, many continue to perceive the robot as a temporary phenomenon in the operating room. Robotic surgery, however, is here to stay. With continued innovation and technological improvement, the robot will continue to redefine how surgery is performed. It is rather a disruptive technology, which is steadily improving and increasingly meeting the needs of users. Robots have gone from a camera-holding role, to one where they work as an extension of a surgeon's fingers. The technology is being shunned by most sophisticated laparoscopists who continue to develop their skills, which the robot may soon render obsolete. Emerging robotic technology is poised to cause disruption to both laparoscopists and open surgeons who will resist its adoption. It will be a challenge to let go of what has been successful for decades, to put aside what has been perceived as the gold standard of surgery.

The tepid reaction to the robot has been due to a number of factors. The daVinci™ robot, for example, has an initial cost of more than a million dollars, and maintenance costs approaching a quarter of a million dollars, which prohibit its adoption at most medical centers around the world. It provides superb ergonomics, allowing the surgeon to perform complex procedures with ease. As it stands, however, it is cumbersome, occupying a large space over the patient, making it difficult for the bedside assistant.

Undoubtedly, robot manufacturers will eventually improve in this regard. Improved functionality will accompany increased miniaturization, by using technology that is already available. Next-generation robots will need to augment the reality of, and not reduce, a surgeon's sense. Sensory, haptic feedback is necessary for the robotic arms to be a true extension of a surgeon's fingertips. Similar to the improved 3D visualization, improved high-fidelity sensors will allow sensation beyond what is normally perceived with the human touch. Next-generation surgical systems will allow the integration of all available data and imaging studies to be used seamlessly, and to allow the surgeon to work, making microsurgical manipulation, while providing the utmost precision. The combination of live laparoscopic images with virtual 3D images, reconstructed from 2-mm sliced-enhanced spiral computer tomography scanning, have been used to augment reality in laparoscopic surgery. Marescaux reported the first use of this technology in humans, performing a laparoscopic adrenalectomy. The augmented images helped identify, and avoid injury to, the adrenal vein. This technique allowed increased delineation of dissection planes and helped avoid injury to structures not directly in view of the laparoscope [10]. In addition to reality augmentation, future robots will be equipped with sensors capable of detecting changes taking place as a result of tissue manipulation, or due to the stress associated with surgery. Advances in microelectrical mechanical systems (MEMS) will allow these to be a reality very soon.

It has taken a long time to go from large cumbersome surgical instruments to the current delicate ones that allow previously unknown surgical intervention. With the fast pace of present-day technologic improvements, microrobots are just around the corner. Keyhole surgery is making large incisions a thing of the past. Will keyhole surgery itself be relegated to history in the near future, as part of what one could describe as natural surgical evolution? Abdominal exploration preceded the use of peritoneal lavage in the management of selected cases of blunt abdominal trauma. Laparoscopy, using trocars as small as 2 mm, are used at some centers to evaluate patients in this setting. One can predict that soon the emergency room staff or the ambulance personnel in the field will be able to place a microrobot in the form of a capsule inside a patient via a nasogastric tube, which will survey the bowel and other viscera to assess for possible injuries requiring surgical intervention. It may render diagnostic laparoscopy unnecessary, while it avoids the unfortunate delays which lead to the significantly high mortality seen in the early moments following an accident. Virtual capsule colonoscopy is a practical application of this concept currently in use [11,12]. Will such a capsule be able to intervene and have the processing capability (using artificial intelligence applications) to restore the integrity of affected or diseased structures?

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A number of inventors have reported on the use of microrobots capable of intervening at the cellular level [12]. Dr E Jager of Sweden's Linkoping University recently reported experiments where robots (measuring 670 μm tall and 170–240 μm wide) were used to move tiny glass beads invisible to the naked eye [13]. These robots can be made mobile, with arms, wrists and fingers capable of carrying out defined tasks. They are capable of working when submerged in liquids, such as urine or blood, bypassing the limitations of artificially flying insects and silicon microrobots, which could not operate under water. These microrobots can serve to both diagnose and deliver necessary treatment at the cellular level, extending our capabilities to unimaginable levels. They will certainly redefine our notion of minimally invasive intervention. Will they have a preventative role, capable of correcting cellular damage before the rest of the tissue or organ is affected and well before an abnormality becomes clinically significant? However we choose to use these microrobots they will generate debates of similar magnitude to those currently generated by stem cell research applications.

In the current era, whether a robot is used to augment the reality of the surgical field or standard laparoscopic equipment are used, we are in awe when we compare keyhole surgery with interventions where large incisions are made. Just as keyhole surgery is steadily replacing open surgery, emerging technologies will also lead to the disruption of keyhole surgery, as more functional and reliable microrobots are developed. The immersive surgical experience provided by the available robots can be augmented further when all of a surgeon's senses are used. One must be ready to assess available technologies in order to select those that promise the greatest good to the patients we serve. Keyhole surgery, which is still in its infancy, is filled with promises and surprises as unexpected utilization or abandonment are recognized. Proper collaboration is necessary among surgeons, biomedical engineers, equipment manufacturers, healthcare administrators and ethicists to speed the course of surgical evolution, thereby improving outcome while we hold our promise to do no harm. Only with such approach will we limit the ethical concerns raised by Asimov as we actively gather more autonomous and intelligent tools in our armamentarium [14].

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