Robotic innovations (instruments and new robots)

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Introduction

Robotic surgery is an emerging technique in rapid evolution and diffusion, developed with the aim of making surgery less invasive and more comfortable for both patients and surgeons. In the beginning, several different kinds of robots were developed, but their costs were too high, which in turn amplified difficulties in spreading the technique. In addition, the tendency to choose minimally invasive thoracic surgery relies heavily on the reduction of the number and size of incisions (up to a single-port surgery), and the use of more sophisticated devices, aiming at improving the haptic feedback, which is currently lost in robotic systems. However, during the last two decades, the benefits of robotic surgery have been recognized, spurring competition between various medical companies to reduce costs, resulting in a 'democratization' of robotic surgery.

On one hand, several advantages of the "Robotic Era" exist: high definition and three-dimensional vision, improved ergonomics, the 'EndoWrist' system, the absence of 'fulcrum-effect', motion scaling and tremor-filtering, ambidexterity, intuitive movement and surgeon independence, more precise lymph-node dissection, a short learning curve, and more extended application in minimally invasive surgery (MIS) (1). On the other hand, disadvantages also exist: increased costs, the necessity of a spatial footprint for the apparatus, the complexity of inserting robotic arms in the chest of patients, and the distance of the console from the operative table, which could generate anxiety in some surgeons and require time to gain confidence (1).

Nevertheless, the technique has been lauded as comfortable, precise, and safe, especially in cases of long surgical operations, in which fatigue can reduce the efficacy of a surgeon's skills (1). In the current era, changes are rapidly occurring for two reasons (2). First, the constant challenge to miniaturised electronic components has resulted in more efficient circuitry that can be fitted into smaller and more versatile robotic arms. Accordingly, this also induced an expansion in the range of procedures (for example, increased accessibility of narrow anatomical places) and, consequently, the market as well. Second, many companies are actively working on introducing their own machines into the field. Here, we describe the most significant innovations in the field of robotic surgery and postulate what the future of robotics may be.

New robots

As technology advances and the market continue to expand, new devices are rapidly being developed by several companies attempting to make an impact in this new robotic landscape.

One robotic devise in an advanced phase of development by the British company Cambridge Medical Robot (CMR) is called "Versius". It differs from the Industry-standard DaVinci® robot by having the arms attached to their own unique bases. In addition, Versius' arms are light and small enough to be positioned around the operating table according to the surgeon's preference, and from one operating room to another, so that the number of the arms can be tailored according to the procedure. This also abolishes the need for a specific place or a dedicated room to use the robot. Lastly, Versius' arms are modelled after a human arm, mimicking the shoulder, elbow, and wrist articulations, with the aim of creating a familiar movement for the surgeon, instead of adapting to a robot-friendly procedure (2).

Next, there is Medical Micro-instruments (MMI), based in Pisa (Italy), which has created a robot for reconstructive microsurgery with a pair of 3-millimeter wrists at their tips. This robot does not use a console, but instead, is manipulated directly by a surgeon with a pair of joysticks. This provides the advantage of having the surgeon near the operating table, so that they can perceive the anatomic structures as they appear through the microscope, which is especially useful in paediatric surgeries.

Another company, Auris Robotics, is attempting to develop a system of flexible arms equipped with a camera and instruments, which could enter a patient's body orally. According to their announcement, this robot could be used to remove lung tumors by introducing surgical instruments into the trachea precisely where the tumor is located, and then removing only as much tissue as required. In fact, they are "developing targeted, minimally invasive therapies, that treat only the diseased cells in order to prevent the progression of a patient's illness" (2). However, this technique, developed to avoid opening a patient's chest, is feasible only for small tumors or slow-growth tumors. Here, these first examples represent an attempt from smaller start-ups to compete against the giants of the Medical Industry, such as Medtronic® and Johnson and Johnson®, which are currently building their own surgical robots (2).

Arriving to the scene about three years ago, Medtronic is now at its tenth prototype. The Company has created many partnerships, the largest of which is with the German Aerospace Agency. As such, Medtronic licensed a robot called MIRO, characterized by light and independent arms, equipped with force sensors, and created for remote control of the arms in space. The project aims to create a robot based on MIRO, which would potentially allow surgeons to rely on touch as much as sight, in an effort to overcome the criticism of the lack of haptic feedback in currently available robots. The company is planning to launch the system first in India, because of the regulatory restrictions in US (2,3).

In 2015, the union of Ethicon, a medical device company of the Johnson and Johnson's family, and Verily (formerly Google Life Science) founded Verb Surgical. Their focus is to create a digital platform that combines robotics, advanced visualisation, instrumentations, data analytics, and connectivity to allow their robots to learn from one another through inter-robot connectivity via the internet (4). As a surgeon uses the robot, data is recorded and introduced to machine-learning algorithms for analysis. This information helps surgeons distinguish between pathologic and healthy tissue, decide where important structures like nerves and vessels are, and consequently plan a better procedure (2). As more data is collected, the robot's ability to guide surgeons in decisions increases.

Lastly, Intuitive Surgical recently introduced to the market—the DaVinci X®, a low-cost version of the DaVinci Xi. Positioned between the Si and the Xi models, the DaVinci X maintains the thinner and more capable arms and instruments of the Xi version, but with the moving cart of the Si model. While this design loses the versatility of the flagship model, it guarantees a low-price point (5). Though useful for abdominal surgery, The DaVinci X is also adaptable for various other procedures. As such, the Intuitive Surgical Endoscopic Instrument Control System (DaVinci X Surgical System Model IS4200) was created to assist in the accurate control of Intuitive Surgical Endoscopic Instruments during some urologic, general and gynaecologic laparoscopic, thoracoscopic surgical procedures, and trans-oral otolaryngology resection of benign and malignant tumors classified as T1 and T2 (6).

New devices

The introduction of the EndoWrist Stapler signalled an increase in both the precision and safety of modern robotic techniques (7). In fact, in previous robotic thoracic procedures, staplers were used to section vessels, bronchus, and incomplete fissures, and were introduced directly through one of the ports after removal of a robotic arm. In a recent report, Pearlstein *et al.* described the use of these new devices, underlining the early experience using the robotic staplers and providing techniques, that have maximized efficiency and safety (7,8). These staplers are introduced into the operative field through a 12 mm port, controlled by a surgical console, and guarantee a maximum of 108° side-to-side and 54° up-and-down articulation (7,9). The system is equipped with a SmartClamp feedback software, that recognizes, through a microchip installed on the cartridge, if the instrument's jaws are adequately closed on the anatomical structure (7,9). In fact, three different reloads are available (white, blue and green), which correspond to the same closed-staple heights of the equivalent reload colours currently available on the market (7).

Another device compatible with the DaVinci System technology is the EndoWrist sealer, an instrument that has independent cutting and sealing functions complete with dual-hinged jaws. It features a 50° articulation, can cut and seal vessel or bundles of tissue up to 7 mm with orthogonal transection, and is manipulated directly by a surgeon utilizing a console (6). In addition, it features Ultrasound technology, a system using a curved probe, to guarantee a realistic 3D visualisation with an easy plug-and-play system of imaging integration (9). Furthermore, thanks to the ERBE VIO system, a generator inserted in the vision cart of DaVinci system, the energy and bipolar effect can be regulated, as with other instruments (6,9).

Fluorescence

Fluorescence, also known as the Firefly Imaging System in the case of the DaVinci robot, is used to shine a near-infrared laser with the ability to switch on white and infrared lights using dedicated commands. This offers the opportunity to perform fluorescence-guided surgery, taking advantage of the indocyanine green (ICG) vital dye, which absorbs light between 600 and 900 nm, exhibits an excellent tolerability, and adheres well to plasma proteins, joining all body regions (9). This technique has multiple applications in robotic surgery, for example: fluorescent cholangiography, evaluation of bowel perfusion, identification of sentinel lymph nodes, cases of thoracic procedures, and the identification of lung segments, when performing an anatomic lung segmentectomy (9,10).

Simulators

Simulation is valued as an important component in understanding how to use a surgical robot.

Currently, the leading firm for surgical robotic simulators is MIMIC™ (11). In 2007, MIMIC produced dV-Trainer, an original robotic simulator, joining the most realistic and life-like simulation available (12). Then, in 2010, they collaborated with Intuitive Surgical to create a simulation software for the DaVinci Surgical System, called the Skill Simulator®, which can be attached to the primary or secondary robotic console (11). Generally, a second console is used as a device to watch the operative field and have the same immersive feel as the primary surgeon. With both consoles connected, the trainee can participate at the appropriate time, while the primary surgeon can regain control as necessary (11). The advantage of the Skills Simulator is that it receives the input directly from the surgeon's console, meaning hardware fidelity is 100%. On the other hand, Skills Simulators are almost always located in the operating room and not always accessible (11). MIMIC also collaborates with C-SATS Inc., an online service via inter-operative video review, that started as a research project of the University of Washington (12). The surgeon can attempt different procedures, which are video-recorded and sent via safe connection. After being reviewed by qualified reviewers, it is returned with a score value and some recommendations on how to improve the technique (12). Performance can also be judged by tele-mentoring, a one-to-one virtual access, which puts the trainer in contact with specialized surgeons (12).

Another competitor in this sector is RoSS™, a portable, stand-alone robotic simulator. In contrast to MIMIC and other simulators designed for the DaVicini system, this simulator is portable, and thus novices can use it outside the operating room (13). As of now, RoSS is the only simulator featuring a full-length surgical procedure in 3D, called hands-on surgical training (HoST) (13). With the use of haptics, the system guides the user's hands gradually during steps of a real surgical procedure, engaging the user to interact with the machine. As the program tracks the progress of the surgeon, the principle is that they can proceed only after having successfully learned and executed each step (13).

Single-port robotic surgery

The future of robotics is minimal and flexible devices designed to create smaller incisions and provide more comfort to the patient. Intuitive Surgical has created a DaVinci Single-port surgical robotic system, DaVinci Sp®, with a 2.5 cm cannula, including three articulated devices, at the moment specific for urological procedures. The DaVicini Sp can be used for single-port laparoscopy and is equipped with a five-lumen port, usually at the position of the umbilicus, in which optimized curved instruments and cannulae are introduced (6). Even though the Food and Drug Administration (FDA) has given clearance to the system, the Company wants to make it fully compatible with the DaVinci Xi, before definitively releasing it on the market (14). At the same time, an American medical device company, Transenterix, considered a pioneer in minimally invasive robotic surgery, is following this trend with particular attention to costs (15). The evolution of performing single-port robotic surgery relies greatly on technology, as there is the necessity to miniaturize the electronic components, without losing the precision, safety, and vision of conventional robots. One such example of this philosophy is the Transenterix SPIDER®, which has yet to be released on the market, but already seems to have great potential. The robot benefits from flexible arms, based on the Senhance technology system, that enter the patient through a single-port incision (15). This sensitive system adds the haptic force feedback in any degree of motion and for the whole length of the instrument. Another benefit is the eye camera control system (15). Equipped with special glasses, the surgeon controls camera direction with their eye movement, and can zoom in or out of the image by approaching or moving away from the screen. The Transenterix company is specialized in robotic abdominal surgery, but it seems that other medical companies have had the same idea in creating robotic devices to perform a single portal surgery in other fields, such as thoracic surgery.

Artificial intelligence (AI) and deep learning

The development of computers and robotics, for an integration between humans and machines in robotic surgery, will most certainly spur AI. Image-guided MIS could extend the panel of surgical conditions potentially managed with targeted non-invasive treatments (16-20). Image-guided hybrid MIS combines different technologies, preoperative surgical planning with simulation from personalized 3D modelling of patients, resulting in a virtual reality environment, in which the user is immersed and may use sensors to interact (16). This process allows surgeons to plan the surgical strategy and to choose the best treatment to apply, while, during the operation, the preoperative data of the patient can be superimposed with real-time patient images (16,17). This augmented reality clarifies a surgeon's vision of their patients (a "see-through" view), allowing them to track instruments and improve pathology targeting, through the acquisition of intraoperative 3D medical-images and the association of a non-rigid, temporal registration algorithm (18). Another innovative feature, that makes the most of the augmented reality, is an anatomical reconstruction of a body, by navigation "*in vivo*" with the integration of information, obtained from preoperative imaging in a 3D model, and the real anatomical variations, found during the surgical operation (interactive augmented reality) (17,18).

As such, AI will continue to develop in both virtual and physical branches (21). In the virtual world, there will be a deep learning algorithm in the management of health information and active guidance of surgeons in treatment decisions (21), while, concomitantly in the physical world, surgical and training robots will be used as new delivery systems of care. More sophisticated robots will be used as "carebots" for aging persons, patients with disabilities or cognitive decline (21). However, there are still two problems to solve before these robots can be available: ethical issues and standardizing a system of measurement of physiological changes and health indicators (21). Moreover, the cooperation between AI technologies and protected health informations will lead to societal and ethical problems of data security, real medical utility, and the necessity of an interdisciplinary collaboration for their wide applications with consequent evaluation of costs (20,21).

As exciting as this future scenario may seem, the reality most likely has many years to come. At the moment, the amount of resources used is still too high and unfortunately not available to each hospital. In addition, time is needed to create both more sophisticated robots and superior health algorithms. Due in part to this first phase of development, together with the progressive improvement of early detection and screening of lung cancer, in the future, this technology will be the main (if not only) method of surgical approach.

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