Robotics Applied to Minimal Invasive Surgery in Latin America.

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Abstract:

The application of robotics in minimal invasive surgery (MIS) has boomed on a worldwide level because of the advantages that it offers to the patient: reduction of the size of the incisions and the risk of hemorrhages and complications, decrease in hospital costs and inpatient convalescence, permitting the patient to return quickly to preoperative activity. The participation of Latin America in this field of study has been initially through the training of medical personnel in USA and Europe and the subsequent utilization of commercial robots in Mexico, Argentina and Brazil. Additionally, countries like Mexico and Colombia have advanced research projects in robotics, aiming to develop systems for future applications in laparoscopic surgery and sterotaxy. The problem for the development of research projects in the medical robotic area in Latin America has been economic; nevertheless, the employment of advanced technology would provide better quality service and therefore a healthier population.

Index Terms:

Computer - guided surgery, Robotic surgery, Stereotactic surgery, Telepresence, Telesurgery

Zastosowanie robotyki w chirurgii małoinwazyjnej w Ameryce Południowej.

Streszczenie:

Ogromny postęp w rozwoju i stosowaniu chirurgii małoinwazyjnej (MIS) na całym świecie wynika z zalet wynikających z ich stosowania dla pacjentów jak: znaczne zmniejszenie inwazyjności procedur chirurgicznych przez redukcję wymiarów nacięć w skórze, zmniejszenie ryzyka zakażeń i komplikacji, zmniejszenie kosztów poprzez szybszy proces gojenia i wymagany czas przebywania pacjenta w szpitalu. Rozwój tej dziedziny w Ameryce Południowej to przede wszystkim szkolenie kadry medycznej w USA i Europie oraz pojedyncze ośrodki wyposażone w komercyjne telemanipulatory dla wspomagania MIS, w Meksyku, Argentynie i Brazylii. Dodatkowo w Meksyku i Kolumbii realizowane są zaawansowe projekty badawcze w dziedzinie roboty medycznej dla ich przyszłych zastosowań w chirurgii. Główna przyczyna zbyt wolnego rozwoju tych dziedzin w Ameryce Płd. to wciąż aspekty ekonomiczne, jednak wprowadzanie zaawansowanych technologii w całym społeczeństwie poprawi jakość projektów i powstałych w ich wyniku produktów co powinno sprzyjać podniesieniu poziomu zdrowia.

I. INTRODUCTION

The study and application of minimal invasive surgery (MIS) grow everyday in the international scientific community. Comparative studies show the advantages of traditional surgery: reduction of incision size, decrease in pain and in the risk of hemorrhages and complications, diminution of inpatient convalescence and rehabilitation, permitting the patient to return quickly to preoperative activity[1-6].

Nevertheless, there are some troubles with traditional MIS including stiff and inflexible surgical instruments, difficulties in tactile and force feedback, limits in the degrees of freedom, inadequate precision, poor ergonomics and problems of visualization, which arise when attempting to project two-dimensional images of a three-dimensional field [5-8].

The use of robotics offers solutions to some problems mentioned of traditional MIS and has additional advantages [9-11]:

- Smaller number of people in the operating room.
- Improvement of surgeon's skills, eliminating trembling and permitting work scale planning.

- Three-dimensional viewing in comparison with the two-dimensional viewing that traditional MIS offers.
- The learning curve for robotic surgery is shorter in comparison with the conventional laparoscopic surgery.
- The instruments used by robotic devices have the possibility to be completely sterilized and they are resistant to radiation and infection, providing security to the patient, hospital and medical personnel.
- A partial or total registration of surgical procedures that permits evaluation and training contributing to the quality of service; moreover, with the registered information, it is possible to detect error sources and perform corrective actions in subsequent practices.

The first attempts to apply robotics in medicine occurred during World War II. Today, many laparoscopic procedures have been carried out with the aid of robotics in the USA, Canada and Europe [7, 12].

Latin America began the process of incorporating robots in surgery later than those countries, but its interest in this area grows in spite of its healthcare and economical problems. Initially, the integration of robotic surgery has been through the training of medical personnel in surgical procedures with robotic assistance in the United States and Europe as are the cases of the Colombian, Juan Carlos Góngora [13], the Argentinian, Santiago Horgan [14], and the Mexican, Adrián Carvajal Ramos [4, 15]. Subsequently, there has been widespread use of commercial robots in Mexico, Argentina and Brazil. Finally, research projects in robotics in countries such as Mexico and Colombia have developed systems for future applications in laparoscopic surgery and sterotaxy. The present article reviews the incorporation of this technology and the projects developed in Latin America.

The paper is organized as follows: section II presents the description of the principal systems for robotic surgery (AESOP™, Zeus™ and daVinci) and its introduction in Latin America; section III presents the research in Mexico; section IV presents the research projects in Colombia; and section V are the conclusions.

II. ANTECEDENTS IN LATIN AMERICA

Historically, there have been many telesurgical systems used in Latin America:

A. AESOP™

Automated Endoscopic System for Optimum Positioning, shown in Fig. 1, is a robotic arm that holds the laparoscope during surgery and responds to surgeon’s commands. AESOP was the first commercially available system, that was approved by the FDA in 1994, to guide the endoscope. This device is fixed to the operating table, in such a way that a change in the surgical environment does not require repositioning of the equipment. The robot is controlled by the surgeon through a pedal or manual control and in the last versions by voice prompts [15, 16]. The control system carries out some important functions: avoids trembling, stabilizes the image, moves in different directions according to surgeon's commands, and saves in memory some selected positions so that the surgeon can return to them when necessary[17].

Many procedures and some research projects in Latin America have been developed with the different versions of AESOP.

In 2002 the Heart Institute, Rio Grande do Sul, Brazil, carried out an investigation, in which AESOP functioned as the assistant to thoracoscopy to dissect the internal thoracic artery of 9 patients. The study verified the stability of the video and the control and allowed a decrease in operating times when the surgeon was adapted to the system. Furthermore, there was a left ventricle epimyocardial electrodes implantation for multiple site heart stimulation with a multi-chamber pacemaker. [18, 19].

Zorrón et al. published in 2005 the results of an investigation conducted on 15 patients in 2004 undergoing laparoscopic cholecistectomy. In this research, developed in the Hospital Universitário Clementino Fraga Filho-UFRJ, Rio de Janeiro, the surgeon learning curve was measured, with the purpose of studying the characteristics of abdominal robotic video surgery. The results of this investigation showed that the operating time was greater than with traditional surgery, but the stability of the camera and the precision were better [20].

Fig. 1. AESOP robot

Taken from: Robotics: the Future of Minimally Invasive Heart Surgery [in line] <http://biomed.brown.edu/Courses/BI108/BI108_2000_Groups/Heart_Surgery/Robotics.html>. [Consult: Dicember 25th 2006]

However, in many countries the access to AESOP is limited. The Prates et al. studies [18] doubt the cost-effectiveness of the system in Brazil and Latin-America. The article states that, although the procedures are cheaper than traditional surgery, the initial system (console, control of video and instruments) are very expensive and the investment can only break even after many procedures.

B. Zeus^{TM}

It is a robotic device developed by Motion Computer Incorporated, the same company that developed AESOP. It has 5 degrees of freedom (DOF) with the possibility of adding a DOF in the wrist. It has three arms: one is the AESOP endoscope and the other two manipulate the surgical instruments, see Fig. 2. The system offers viewing options in two or three dimensions with different sizes of telescopes [3, 4, 8, 10, 12]. Nevertheless, Zeus has some weaknesses: its arms work independently and there does not exist a reference system in the three-dimensional space for the integrated system [8]. An additional control pedal ceases all movements thereby avoiding accidents by inadvertent actions.

Fig 2. Zeus robot
Taken from: Robotics: the Future of Minimally Invasive Heart Surgery [in line]
< http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=227l>.
[Consult: Dicember 25th 2006]

The Zeus system was used by the Colombian Juan Carlos Góngora who took part in the team of surgeons that performed the first transatlantic telesurgery in 2001. The French surgeon Jacques Marescaux directed the procedure transmitting the signal by optical fiber 15000Km away [13].

C. Da Vinci®

This device, developed by Intuitive Surgical®, is the only robotic system that is currently in production applied for telesurgery. In 2003 Intuitive Surgical bought Computer Motion and suspended the production of the Zeus system.

The da Vinci system, see Fig. 3, consists of three fundamental parts: (a) the console as an interface between the surgeon and the robot, (b) the laparoscopic tower with a monitor to view the procedure, light source, control of the cameras, electrocautery and insufflator and (c) three fixed arms and one extra for some procedures. One of them holds the laparoscope and the others manipulate the instruments. At the end of each arm, da Vinci includes the Endowrist devices, developed and patented by Intuitive Surgical Incorporated [21].

Da Vinci translates the surgeon's hands movements into precise manipulator movements. It is not fixed to the operating table and, therefore, it is necessary to change its position by varying the operating environment. It has been utilized in abdominal, cardiac and urological procedures [1, 2, 8, 22, 23].

Da Vinci includes algorithms of very accurate control to perform different functions: the transformation of surgeon's hand movements into movements of the robot joints, the change of movement scale and filtering of trembling to provide security for the patient [9, 24].

Fig. 3. Da Vinci robot

Taken from: Robotics: the Future of Minimally Invasive Heart Surgery [in line]
< http://www.intuitivesurgical.com/corporate/newsroom/mediakit/product_images.aspx>.
[Consult: Dicember 25th 2006]

Da Vinci robot has been utilized in Argentina since 2005, where the surgeon Santiago Horgan with the aid of two other Argentinian doctors, carried out esophagus surgery on a 34-year-old patient [14].

III. RESEARCH IN MEXICO

Mexico is the Latin American country that has had more contact with the advances of robotics applied to MIS. It has played an important role during the FDA approval phases of robotic telesurgery systems and has had its own developments in this area.

In 1996, Mosso et al. developed a software that permitted the adaptation of a robot, PUMA 6000 of Unimation, to hold the laparoscopic camera for procedures in animals. Three cholecystectomies were performed utilizing this robot, which was telemanipulated 10m away[15].

Additionally, test phases of the Zeus Project took place in the Hospital Torre Médica of Mexico in 2001. A research study conducted on 222 patients established a comparison between traditional versus robotically assisted laparoscopy in two different procedures: Nissen funduplicature and cholecystectomies. The results showed that the morbidity rate was 0.9%, the learning curve was the same, the quality of the image was better in the robotic surgery and the time of procedure was shorter with traditional surgery [25].

Subsequently, after considering the high import costs factor of a robot and the commercial limitations in applying it to other fields, there was a decision to develop and construct a robot completely in Mexico. This project began in 1997 and today, after several versions, this robot, Tonatiuh, has been utilized successfully in more than a hundred procedures on a pediatric level in Mexico City [15, 16, 26].

Tonatiuh is a robot with five DOF, designed to hold a 10mm laparoscopic camera. The design of the system, includes three types of user interfaces: (1) an optoelectronic interface, that responds to the movements of the surgeon's head; (2) an interface by voice recognition that responds to 6 basic commands and another 2 to confirm the movement; and (3) an interface by a manual control which controls independently the movement of each joint using a computer keyboard as a positioning system and later, when the laparoscope is inside the abdominal cavity, a physical manual control. [16]. Fig. 4 shows Tonatiuh robot.

The test phases in animals were carried out in 2001 [27] analyzing the behavior of the system with real needs. In the same year, the first test on human beings was performed; it was a hysterectomy on a 36-year-old patient with uterine myomatosis [28], showing the utility of the robot in this type of gynecological procedures.

Fig 4. Tonatiuh robot, 2002. Taken from: [15]

Moreover, in 2002, a breakthrough from the point of view of communications was achieved when two laparoscopic cholecystectomies were performed in Chiapas. The procedures were assisted by Tonatiuh teleoperated 4m away. The transmission was broadcasted directly to medical personnel in 19 telediagnostic centers and auditoriums around the country. Doctors in Mexico City, located 1.277Km away were able to advise and provide information during the procedure. In this case the surgical times were longer than in conventional laparoscopies and permitted the analysis of some important requirements of the robot's location during surgery and, additionally, determined some advantages and disadvantages of involving the instructions of surgeons at a distance [29]
Finally, a hands-free navigation system design for surgeons has been worked out. The design frees the robot from the operating table and is attached to the doctor's thorax, allowing for shorter operating times, but fatiguing the surgeon [15].

IV. RESEARCH IN COLOMBIA

Several research groups in Colombia have been working on robotics projects applied to surgery. The Robotics and Automation Group in The Universidad Pontificia Javeriana in Cali in cooperation with the "Centro Médico Imbanaco" is working on a project to design and develop a stereotaxic robotic computational system prototype to improve greatly the precision and quality of transpedicular instrumentation surgeries. This project seeks to demonstrate the viability of this application on patients [30].
At the same time, the "grupo de I+D en Automática Industrial" of the Universidad del Cauca is beginning some investigations in robotics applied to surgery. This group is working on projects for the creation of a simulated environment for laparoscopic procedures, the definitions of trajectories on a laparoscopic cholecystectomy and the idea of translating that simulation to three dimensions.

In the "Centro de Investigaciones en Bioingeniería" (GIBIOING) of the Universidad Pontificia Bolivariana, two prototypes of robots have been developed: ISOTAX and KIRUBOT.

A. ISOTAX

In 1997 by the initiative of neurosurgeon Carlos Jaime Yepes, the prototype "ISOTAX" was designed. It is a system for the execution of neurosurgical procedures. It is composed of two elements: a table of coordinates and a stereotactic framework in which a surgical arm is adjusted and where a stereotactic needle or an electrode is fixed.

Subsequently, other versions of the prototype and its automation have been developed, in search of an affordable system that can carry out the presurgical planning and can be adapted to the conditions and needs of the environment.

ISOTAX counts on a mechanical system, see Fig. 5, a movement control system based on power drives and data acquisition cards, and a software developed with virtual instrumentation as the user interface. The geometric study carried out on the prototype determined the orientation of the needle, which indicates the path that includes the incision point, the treatment point and the origin of coordinates (center of the circle), to guarantee that the principle of centered arc is complied with [31].

The doctor then inputs two points with Cartesian coordinates X, Y, Z, that represent the place of the incision and the location of the area to explore; the system indicates if the points are correctly located to respond to the conditions of centered arc and when this condition is met, automatically the set points for the different control loops are established, in this way moving the needle in the direction of penetration.

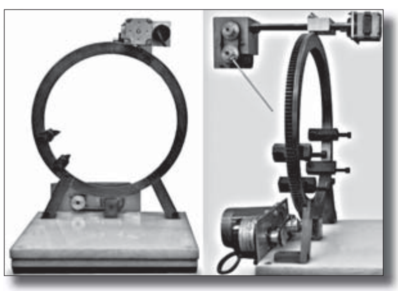

Fig 5. Prototype ISOTAX robot

A validation phase was carried out to determine the precision and accuracy of the system, as well as to evaluate the actual design characteristics and to anticipate any future design needs [31].

B. KIRUBOT

KIRUBOT is a prototype with four degrees of freedom with rotational joints for future applications in surgery, see in Fig. 6. The mechanical system is based on the adaptation of the worm gear mechanisms to every stepper motor in the manipulator [32, 33].

The automation of the prototype was programmed using movement control tools. Additionally, the automation software incorporates the performance of the robot in its environment. It has an initial positioning option and an autonomous movement option in a three-dimensional system. With this last option, the subsequent movements will be directed by the surgeon in the future with the aid of an optimum viewing system.

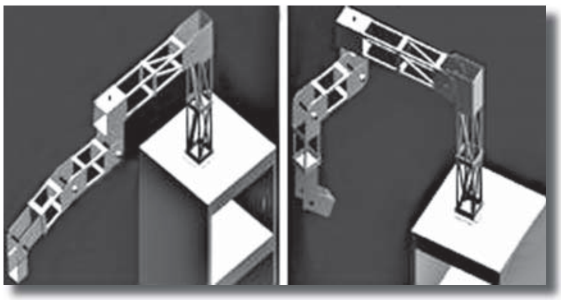

Fig 6. KIRUBOT prototype robot

V. CONCLUSIONES

In the last three decades there has been much work in the topic of robotics applied to MIS around the world. The AESOP™, Zeus™ and daVinci systems are in the last stage of the design process, because they have been already implemented with FDA approval. The applications of robotics to minimal invasive surgery in Latin America initially have been in the training of medical personnel for using the devices mentioned above. Nevertheless, the high cost to acquire those systems has created the need to evaluate the possibility of constructing devices in countries like Mexico and Colombia.

The implementation of new technologies implies during the initial phases high costs, limited security compared with previous technologies and doubts with respect to its operation, but these diminish when the technology is perfected, because the costs of the services will decrease and acceptance and credibility will grow. The robot Tonatiuh constructed in Mexico is in the final design, adjustments and implementation phases, since tests on animals and people have been carried out, while the systems in Colombia are in the early stages, the initial prototype and the evaluation phase. It is important to continue developing research projects that contribute solutions to the different problems present inside the operating room, especially those problems particular to Latin America.

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