New technology

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This section is designed to bring forward some of the latest innovative technology with explanations in terms that will clarify their importance to the discipline of surgery. Through the efforts of the Innovative Technology Committee of the Society of American Gastrointestinal Endoscopic Surgeons (SAGES), leading experts in various areas will be invited to present a summary of new technology, often including their pioneering work.

Robotically assisted laparoscopic surgery

From concept to development

J. M. Sackier[1], Y. Wang[2]

[1] Department of Surgery, University of California, San Diego Medical Center, 225 Dickinson Street, 8891, San Diego, CA 92103-9981, USA
[2] Computer Motion, Inc., 250 Storke Road, Suite A, Goleta, CA 93117, USA

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Abstract. The evolution of laparoscopy from a monocular view to the video screen has enabled all in the operating room to see the procedure. This has meant the surgeon must rely on an assistant to hold the scope, which has many drawbacks. Robotic enhancement technology creates a symbiotic relationship between the surgeon and robot and leads to great improvement in the performance of the case.

Key words: Robot – Laparoscopy – Concept

Laparoscopy was conceived at the turn of the century [4, 5] but found few early supporters. Its value as a diagnostic modality was promoted by Kalk [3], Ruddock [7], Cuschieri [2], and Berci [1], but the use of monocular vision made it an uncomfortable procedure to perform. Certainly, advances in instrumentation and techniques led to its widespread adoption for gynecological operations, as proposed by Steptoe [11] and Semm [10]. However, it was the addition of the video camera to the laparoscope that surely formed the progenitor of the "laparoscopic revolution."

This simple addition meant that all on the operating team could follow the performance of an operation on a large television screen placed at a comfortable viewing distance. However, there were certain prices to pay for this advance. The two-dimensional (2-D) representation of the three-dimensional human anatomy on a TV screen led to problems with depth perception which have been accommodated for by either experience or the use of expensive 3-D TV systems. With the absence of direct tissue contact, the surgeon has had to develop subtle modifications in technique to obtain tactile feedback, which the experienced laparoscopist can master.

Probably the most significant change, though, has been the requirement that someone else control the laparoscope: One's vision is effectively delegated to another individual. This means that one has to develop a "language" to command this individual to move the scope to the area under consideration. Invariably, the smallest movements of the scope-holding assistant — even the tremor from a heart beat, when great magnification is being used — can lead to motion-induced nausea amongst the surgical team, as any surgeon who has performed laparoscopy can confirm.

In these times of financial constraint, it is becoming progressively less likely that surgical assistance will be reimbursed. Therefore, one must employ an additional operating-room technician or nurse to hold the camera, which leads to significant expense and the use of sometimes-ill-trained personnel for this very important job. All in all this leads to frustration on the part of the surgeon and to delays in completing the operation. Additionally, if the person holding the telescope does not understand the importance of following instruments in and out of the abdomen through accessory cannulae then the potential for iatrogenic injury exists.

Some surgeons who operate single-handed control the telescope themselves. This means that they do not have another hand free for the more important job of manipulating tissue graspers, and this becomes extremely frustrating during delicate maneuvers such as suturing.

Mechanical scope holders were created in order to address these problems. These devices typically attach to the side of the operating table and reach up and over the surgical field through a series of mechanical linkages. The more advanced holders have pneumatically locking joints; all the joints are simultaneously held rigid or relaxed according to the press of a button.

Correspondence to: J. M. Sackier

Fig. 1. A photograph of AESOP demonstrating the positioning arm holding the laparoscope, the computer control unit, the foot switch (bottom left) and the hand switch (bottom center)

When the joints are rigid the scope is held in a fixed position without any assistance. When the joints are relaxed the surgeon can move the scope to a new viewing location. With a mechanical scope holder, if the surgeon wishes to change the current view, he or she releases the surgical instruments, disengages the locking mechanism, moves the scope to a new position, reengages the locking mechanism, picks up instruments, and resumes the procedure. While this technique does eliminate the need for extra personnel to hold the scope and allows the surgeon to directly control the view, it requires a cumbersome, disruptive, and time-consuming process for the surgeon to change the field of vision.

A solution to these problems has been developed. A computer-controlled robot named AESOP (Automated Endoscope System for Optimal Positioning) holds the laparoscope and moves under direction of the surgeon (Fig. 1).

Mere teleoperation duplicates a physical action; AESOP, on the other hand, improves the fashion in which the laparoscope is controlled. By returning control of vision to the operator, robotic assistance enhances a surgeon's abilities to operate in a safe and expenditious fashion.

Construction

Figure 2 shows a picture of AESOP in the operating-room environment and specifies the location of each component. The complete system is composed of the following parts. The chassis is an enclosure which houses the control computer, power system, system indicator lights, and power switch. The chassis plugs into a standard wall socket, which provides all of the power necessary to operate AESOP. The control computer is connected to all of the sensors and actuators of the system and is responsible for interpreting the commands from the surgeon (who has a foot controller and a hand controller) into action by applying power to the actuators which position the robot. The program for the system is contained in "READ-ONLY MEMORY" (ROM), which is a form of semiconductor device which provides unchangeable program storage. After these programs are initially entered at the factory, the program content remains unchanged even when the power is turned on and off.

The AESOP positioner is an electromechanical device which attaches to the rail of the surgical table. This is the device which is attached to the laparoscope by a collar and collar holder (Figs. 1 and 2) and holds and moves the laparoscope. The main structure of the positioner is made of machined and cast aluminum, and the joints include components such as bearings and gears which are made of steel and plastic (Fig. 3). The positioner at its greatest diameter is 15 cm, where it attaches to the table, and at the narrowest is 3 cm, where it connects to the laparoscope. The device provides 14 inches of vertical movement and 27 inches of reach (Fig. 3).

The laparoscope is attached to the positioner by a disposable collar which is placed as close to the top of the laparoscope shaft as possible and snugly fits the instrument. It is made of a combination of sterilized plastic and stainless-steel components. The collar holder is a sterilized jaw which snaps into the positioner and clicks to the collar and is made of stainless steel.

In order to retain sterility once the positioner has been attached to the operating table, a disposable plastic gown is passed over the scope. A hole in the gown allows the insertion of the sterile collar holder while maintaining the integrity of the sterile field. The AESOP positioner is controlled by the surgeon by means of either a foot or hand controller. Since the hand controller is in the sterile field, it is made of a hermetically sealed plastic such that it may be sterilized by soaking.

Mode of operation

There are a number of ways in which AESOP may be used by the surgeon to position the scope. Grasping the positioner and depressing the "disable" button causes AESOP to function as a manual scope holder. When the disable button has been pressed, the joints become passive and the surgeon can easily move the positioner to any location. After releasing the disable button the positioner becomes rigid once again. By using the foot or hand controller the surgeon can move the laparoscope in, out, left, right, up or down by applying pressure to the corresponding place on the controller. An important consideration is that all the commands are executed relative to the field of view of the video

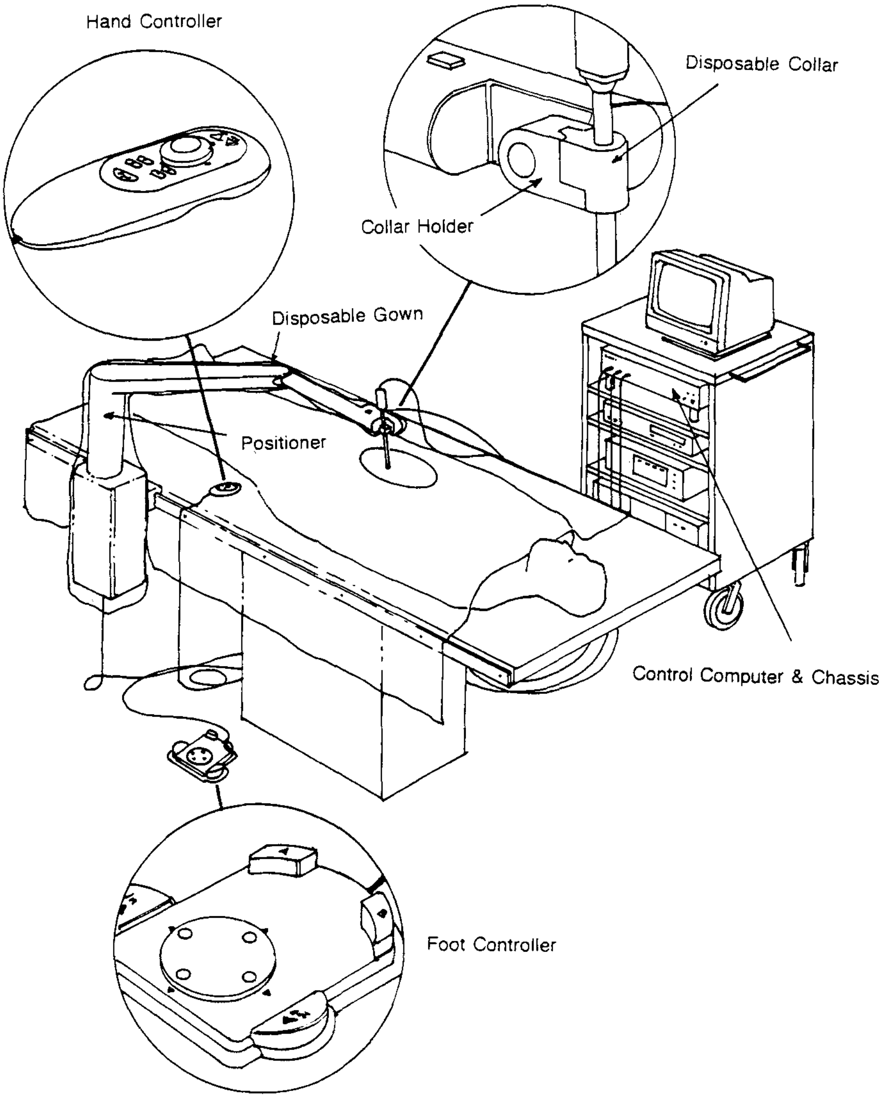

Fig. 2. The operating room environment showing the positioner arm of the robot attached to the table, the hand and foot controls, and the computer which integrates all the functions of AESOP

screen. Consequently, the commands are given with respect to the most natural and intuitive reference frame. The foot pedal is pressure sensitive; maximum speed governs. Therefore commands are determined by how much pressure is exerted, as well as the direction indicated by the command. As pressure on the pedal is increased, the speed with which the device moves is increased. If the maximum allowed speed of 3 inches per second is reached, increasing the pressure on the pedal has no further effect. Additionally, commands can be combined so that by applying pressure appropriately, the surgeon can, for example, move the laparoscope diagonally up and to the left in one motion.

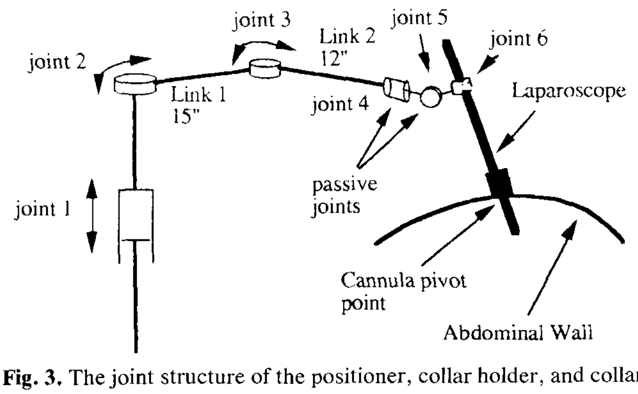

Fig. 3. The joint structure of the positioner, collar holder, and collar

Another method of controlling the laparoscope is with memory buttons located on both the hand controller and foot controller. If during the performance of the procedure the surgeons locates a view that is particularly useful, such as a panoramic view of the abdomen and all accessory cannulae insertion points, the push of a button will cause the position to be "remembered." Then at any time during the procedure, by hitting the appropriate button, the laparoscope will automatically return to that programmed position. These buttons can be programmed and reprogrammed as many times as desired during a procedure.

This device is extremely simple to use, as has been seen in training-box and experimental animal trials. The movement of the robot becomes intuitive after a sort familiarization phase, and a number of surgeons have commented on the benefits of pre-programmed positions, the stable view and the elegance of use.

The device has a number of built-in safety points such as limitation of how far joints can move. The surgeon is alerted to the fact that the scope can move no further by a "chirping" sound. These limitations are controlled by a mixture of mechanical and software programs.

Conclusions

The AESOP positioning system allows for smooth, fast, and efficacious control of the laparoscope during complex surgical procedures. It eliminates the need for one additional person at the operating table and helps ensure the safety of the patient by allowing the surgeon to follow surgical instruments in and out of the field.

Since the first appearance of the term "Robot" in Capek's play *Rossum's Universal Robots* in 1920, from the Czechoslovakian *Robota*, meaning "forced labor," we have been intrigued and infatuated by a superficially human automaton — an intelligent and obedient but impersonal machine. This concept is particularly appealing in the operating room, where we frequently have to deal with communication problems with our assistants. Recently, the late Hap Paul described the use a supervised robotic device to create the medullary cavity for a cementless hip prosthesis [6]. Although enthusiasm greeted the introduction of this "robo-doc" there was some trepidation as well. This is understandable. Neither surgeons nor patients wish to have a machine perform what are deemed to be delicate medical interventions. However, the appeal of the AESOP device is that it actually returns to the surgeon control of her or his faculties and *enhances* the doctor's work rather than detracting from it. AESOP *robotically enhances* the surgeon such that with AESOP she or he is more capable; in essence AESOP gives the surgeon a third arm. Dr. Richard Satava recently published his view of future trends in surgery [8, 9]. It is our feeling that the AESOP positioning device is the first step along the exciting road he has charted.

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