BRIEF COMMUNICATIONS

COMPUTER-ENHANCED CORONARY ARTERY BYPASS SURGERY

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The development of closed chest cardiopulmonary bypass systems has potentially opened the door for totally endoscopic coronary artery bypass graft surgery. Because of the limited range of motion of conventional endoscopic instruments with only 4 degrees of freedom, complex surgical tasks like suturing an anastomosis are difficult and time consuming. Thoracoscopic techniques are currently limited to harvesting of the internal thoracic artery (ITA).^{1,2} Computer-enhanced surgery has been developed to overcome the limitations of conventional endoscopic instruments.^{3,4}

Patients and methods. As opposed to off-line pre-programmed robotic systems, the endoscopic instrument control system (Intuitive Surgical, Mountain View, Calif) is a supervised on-line robotic system with 3 robotic arms of serial articulating joint architecture. The surgeon operates from a

control console that provides a 3-dimensional thoracoscopic image and is in steady control of the system via a human-machine interface. Surgical tasks like suturing or cutting are performed by the surgeon acting on master manipulators at the console that remotely control the motions of surgical instruments (effectors) via a computer interface (Fig 1). The surgical manipulators (2 designed to hold surgical tools and 1 designed to hold a 3-dimensional videoscope) that are mounted to a central column have 3 degrees of freedom (pitch, yaw, and insertion) and provide motion coupling for the end-effectors. These instruments add another 3 degrees of freedom by means of a mechanical wrist that allows the tip of the instrument to be articulated in all directions. Including 1 motion for tool actuation, the system offers a total of 7 degrees of freedom inside the chest. A tremor filter and motion scaling to adjust for the high magnification enable the surgeon to precisely manipulate the tissue and eliminate inadvertent motions.

After approval by the university's institutional ethical committee, the system was used in 5 patients with isolated stenosis or obstruction of the left anterior descending coronary artery to perform total videoscopic remote coronary artery bypass grafting starting May 25, 1998. After the patient had been positioned with the left side of the chest slightly elevated, 3 ports were created in the third, fourth, and sixth intercostal spaces to endoscopically harvest the left ITA remotely from the console. To improve visualization, the chest was

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Fig 1. Schematic illustration of operative setup. Surgeon seated at console operating on the master manipulator controlling motions of the robotic arms via computer interface.

insufflated with carbon dioxide up to an intrathoracic pressure of 10 mm Hg. A 30-degree scope was used. As required by the ethical committee, a small anterior thoracotomy as for minimally invasive direct coronary artery bypass (MIDCAB) surgery was made in the fourth intercostal space to provide immediate access to the heart. After final preparation of the pedicle under direct vision, Port-Access femoro-femoral cardiopulmonary bypass (Heartport, Inc, Redwood City, Calif) was established. A high resolution 0-degree 3-dimensional videoscope was attached and the camera guiding arm was repositioned and placed through the thoracotomy. The pericardium was opened remotely and the target artery was identified. The Endoclamp device was then inflated and the heart arrested with antegrade crystalloid cardioplegic solution. Both the arteriotomy and the coronary anastomosis were performed remotely from the console. The anastomosis was performed in a modified parachute technique with no assistance by means of custom-made double-armed 7-0 Prolene sutures (Ethicon, Inc, Somerville, NJ) 7 cm in length. After completion of the anastomosis, the robotic arms were removed from the table. Thermal coronary angiography and transit-time flow measurements were performed to document graft patency.⁵

Results. Setup time for the system (sterile draping, port placement) was 35 to 50 minutes. In 3 of the 5 patients the procedure could be completed. The ITA was harvested partially from the fifth to the second intercostal region using the system. In 1 patient the graft was damaged and the operation was converted to a standard MIDCAB procedure. In 1 patient advancement of the Endoclamp device was not possible and the patient underwent a standard MIDCAB procedure. In the remaining 3 patients both the arteriotomies and the anastomoses were performed remotely through ports without assistance. Intraoperatively, all anastomoses were patent (flow 22-36 mL/min) and there was no leakage from the anastomotic site. Weaning from cardiopulmonary bypass was uneventful. The time for the anastomosis was in the range of 15 to 22 minutes. Ischemic and cardiopulmonary bypass times ranged from 47 to 80 minutes and 76 to 123 minutes, respectively. All 5 patients were extubated on the day of the operation and transferred to the ward on postoperative day 1. Postoperative electrocardiograms and cardiac enzyme levels were within normal limits. Besides skin emphysema in 1 patient, no complications occurred. All patients were discharged between days 6 and 9. Postoperative angiograms demonstrated optimal patency of both the graft and the anastomoses with no stenosis in any patient. At 3 months' follow-up all patients are free from angina and have normal exercise capacity.

Discussion. This is the first report of successful remote coronary artery bypass grafting using computer-enhanced endoscopic instruments. Because of the high magnification and Endowrist technology, precise suturing allowed for a safe anastomotic technique. High-resolution 3-dimensional visualization compensated for the loss of tactile feedback associated with telesurgery. Some internal and external conflicts between the robotic arms of this prototype left ITA harvesting incomplete in this series. In 2 of the 5 patients the operation had to be converted to a standard MIDCAB procedure. In 1 patient the ITA was injured and had to be ligated. This com-

Fig 2. Intraoperative picture of surgeon's console (A) and draped manipulator (B).

plication is considered to be procedure related. In the other patient placement of the Endoclamp device was not possible and conversion to standard MIDCAB was not device related. In this early experience, a minithoracotomy was performed in all patients to allow for safe and quick access. However, the coronary anastomoses were performed completely through ports only (true endoscopic suturing). The time for anastomosis exceeded those times needed for a conventional or MIDCAB approach. This may be attributable to a learning curve for this new technique. In a porcine model the time to perform an anastomosis currently is in the range of 12 to 16 minutes. In contrast to a beating-heart MIDCAB approach, cardiopulmonary bypass and cardiac arrest were applied to facilitate the operation and to allow enough time for the anastomosis. However, it seems possible in the future to perform an anastomosis endoscopically on the beating heart, if perfect stabilization of the anastomotic site can be achieved through ports. The use of computer-controlled remote endoscopic surgical techniques may stimulate the future development of MIDCAB surgery.

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