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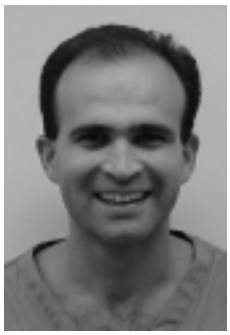
Robot-Assisted Computer Enhanced Closed-Chest Coronary Surgery: Preliminary Experience Using a Harmonic Scalpel® and ZEUS™



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(#2000-18998)

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ABSTRACT

Background: Successful endoscopic harvesting of arterial conduits is critical to the performance of totally endoscopic bypass grafting. Recent success with computer-enhanced robotic systems in the performance of endoscopic single vessel coronary artery bypass (ENDOCAB) has paved the way for developing techniques for multivessel ENDOCAB. The Harmonic Scalpel® (Ethicon Endo-Surgery, Cincinnati, OH) has previously demonstrated versatility and efficacy in manual endoscopic internal thoracic artery (ITA) harvesting. This study was undertaken to determine the feasibility of adapting this technology to a robotic telemanipulation system and its safety and efficacy in telerobotic ITA harvesting.

Methods: The Harmonic Scalpel® was adapted to the ZEUS™ robotic surgical system (Computer Motion, Goleta, CA) and used to harvest the ITA in 19 patients undergoing multivessel off-pump coronary artery bypass (OPCAB) surgery. With the left lung collapsed, the ITA was harvested in all patients with CO_2 insufflation through three 5 mm ports in the left chest. Postoperative angiography and transthoracic Doppler studies were performed in all patients.

Results: There were no ITA injuries and patients tolerated insufflation without hemodynamic compromise. Side branches were controlled easily without bleeding. Average ITA harvest time was 65 ± 21 minutes. All vessels were patent after harvesting and demonstrated no angiographic evidence of injury.

Conclusions: This paper demonstrates a technique by which the Harmonic Scalpel® can be readily adapted to the ZEUS™ robotic telemanipulation system. Using this system, ITA's can be safely harvested totally endoscopically within a reasonable time frame for patients undergoing ENDOCAB.

INTRODUCTION

The ultimate goal of minimally invasive coronary artery surgery is the performance of a fully endoscopic coronary artery bypass (CAB) using multiple arterial conduits on the beating heart [Ducko 1999]. In the march toward total endoscopic multivessel CAB, it is crucial to be able to harvest arterical conduits endoscopically. The recent introduction of computer-enhanced telemanipulation systems has addressed several limitations posed by conventional endoscopic instruments that have previously prevented totally endoscopic bypass procedures up to now [Mohr 1998, Ducko 1999, Loulmet 1999, Tabaie 1999]. Robotic telesurgery systems have now been proven to enable mammary artery harvesting through endoscopic means [Falk 2000]. To date, there have been no reports of the Harmonic Scalpel® (Ethicon Endo-Surgery, Cincinnati, OH) being used in conjunction with these computer enhanced systems. Furthermore, there are few reports of multiarterial conduit harvesting with telepresence surgery.

Several authors, including us, have shown that the Harmonic Scalpel® is safe and efficacious for thoracoscopic ITA harvest [Ohtuska 1997, Boyd, in press]. It has been suggested that the lack of articulated motion at the instrument tip of the ZEUS™ system (Computer Motion, Goleta, CA) may be a major disadvantage in performing totally robotic ITA dissection [Chitwood 1999]. The purpose of

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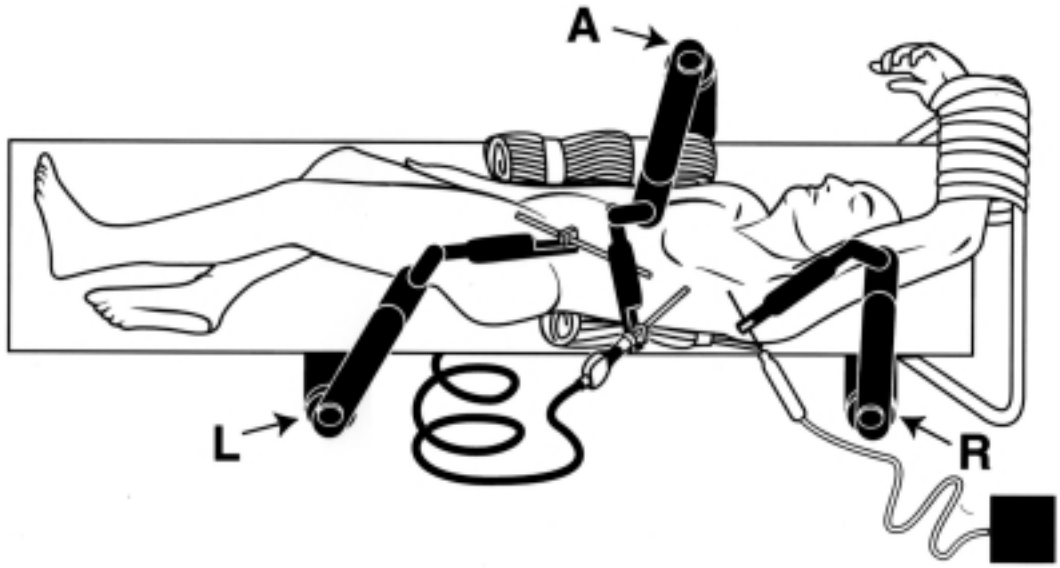

Figure 1. Robotic arm placement diagram for robotically assisted ITA takedown. A is AESOP® (endoscope arm). L is Left arm. R is Right arm.

this paper is to validate that totally robotic arterial conduit harvesting can be safely accomplished with the ZEUS™ telemanipulation system and the Harmonic Scalpel®.

MATERIALS AND METHODS

In this report, ITA's were harvested endoscopically through the left chest using the Harmonic Scalpel® and a computer-enhanced telesurgical system ZEUS™. The Harmonic Scalpel® has interchangeable tips. The tips used in the ITA harvesting included the straight hook blade and the curved blade. Patients underwent pulmonary function testing prior to surgery in order to confirm sufficient pulmonary reserve to tolerate isolated right lung ventilation during ITA dissection.

Anaesthetic Considerations/Surgical Technique

After establishment of general anaesthesia with a double-lumen endotracheal tube, and allowing complete collapse of the left lung, each patient was placed in the 45-degree right lateral decubitus position. The left arm was abducted for sufficient exposure of the axilla to allow placement of the access ports and avoid external robotic arm collisions. The left arm was also draped to allow increased mobility during the procedure. After internal thoracic harvesting was completed, the arm was returned to the patient's side. External defibrillation pads were placed on the patient. A warming blanket was used to prevent hypothermia.

The ZEUS™ robotic system has three robotic arms. One robotic arm, which is the voice activated robotic assistant (AESOP® 3000, Computer Motion, Goleta, CA), was used to hold the endoscope and was positioned on the right side of the operating table directly opposite to the proposed camera port-access site (Figure 1, ◎). The other two robotic arms were the right and left arms used for positioning the instruments. The right arm was mounted opposite the patient's head on the left side of the operating table. The left arm was mounted at the level of the patient's mid thigh on the left side of the operating table. Thoracoscopic ITA harvest was performed using three 5 mm incisions. A 5 mm 30-degree video thoracoscope was first placed through an insufflation port in the fifth intercostal space in the mid to anterior axillary line and adapted to the voice activated robotic arm. In the third intercostal space in the mid to anterior axillary line a second 5 mm port was inserted for the Harmonic Scalpel®. The Harmonic Scalpel® was then attached to the right robotic arm (Figure 2, ◎). A third 5 mm port was placed in the sixth or seventh intercostal space in the mid to anterior axillary line for a Kittner dissector (Ethicon Endo-Surgery, Cincinnati, OH), which was adapted to the left robotic arm. The surgeon, seated at the console away from the operating table, performed the harvesting by controlling the endoscope with voice commands and the instruments with handles that resemble conventional surgical instruments. During the procedure, warm carbon dioxide gas was insufflated into the pleural cavity to a pressure of 5 to 10 mmHg. A veress needle was inserted near the camera port and vented under suction when higher CO_2 flows were used to clear intra thoracic vapour created by the Harmonic Scalpel®. The patient was monitored with radial arterial and pulmonary arterial catheters. The cardiopulmonary bypass pump was on standby in the operating room. The left internal thoracic artery (LITA) was then identified and dissected as a pedicle from the first to sixth rib with voice-activated robotic and video assistance using the straight hook blade of the Harmonic Scalpel® (see Movie, ◎). The parietal pleura were

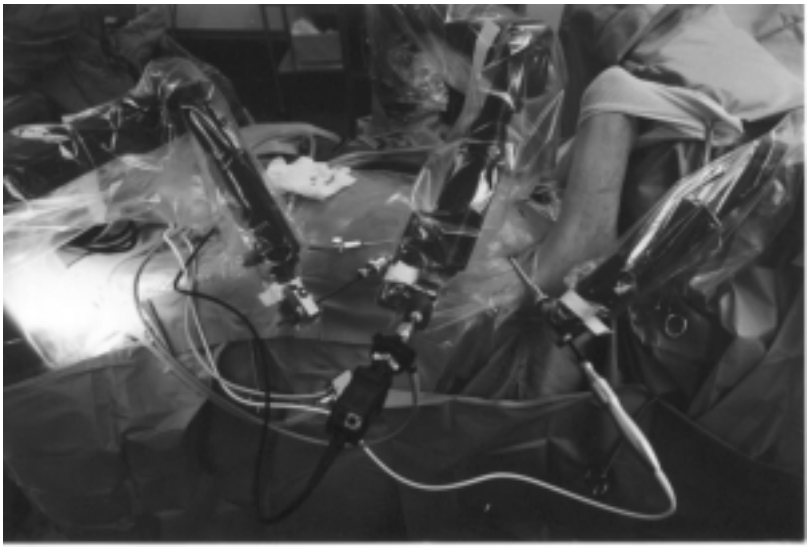

Figure 2. Intraoperative Harmonic Scalpel® orientation and robotic arm placement.

first scored 1 to 2 cm medial and lateral to the ITA from the first rib to the sixth intercostal space. Often, arterial pulsation observed through the soft tissue guided distal dissection, but on occasion no obvious pulsation was observed. In these cases, gentle distal compression of the soft tissues with the Kittner dissector augmented arterial pulsations, heralding the location of the ITA. Dissection of the ITA was usually started over the second rib, and progression of the dissection was always initiated over subsequent ribs which acted as "safe-zones" without intercostal vascular tethering. Once the ITA had been safely separated from the superior and inferior ribs, the intervening intercostal spaces were carefully dissected. The Kittner dissector was used to provide gentle counter traction during the dissection and was often positioned by rolling the Kittner on the ITA. When dividing the intercostal arteries and veins with the Harmonic Scalpel®, gentle pressure was applied with the blunt side of the blade with a power setting of three. During cutting and coagulation, Harmonic Scalpel® loiters times averaged five seconds, but varied with the size of the intercostal branches being divided. Occasionally it was necessary to interchange the Harmonic Scalpel® and the Kittner sites to complete the dissection.

In three patients, once LITA dissection was completed, the mediastinum was crossed and right pleura was entered. The right internal thoracic artery (RITA) was identified and dissected from the first rib to the sixth intercostal space similarly to the LITA as described earlier. Upon entering the right pleura, the insufflation pressure was increased to 10–15 mmHg in order to provide adequate exposure. This resulted in minor hemodynamic instability, which recovered after five minutes. The difference was that initially the pleura, on the medial aspect of RITA, was scored using the straight Harmonic Scalpel® blade. The straight blade was then exchanged for the curve blade for scoring the pleura on the lateral aspect of the RITA. After the lateral aspect was scored, the curve blade was exchanged back to the straight blade. The straight blade was used to completely free up the medial aspect of the RITA pedicle. Then the curve blade was used again to dissect the lateral aspect of the pedicle allowing the harvest of RITA to be completed. The patency of all internal thoracic arteries were checked by demonstrating adequate flow through the arteries with a transit time ultrasound flow probe (Transonic Systems, Ithaca, NY).

RESULTS

Remote robotic telemanipulation facilitated total thoracoscopic dissection of the ITA with the Harmonic Scalpel®. There were no conversions to a standard approach because of an injury to the grafts and no reoperations for bleeding. In all cases, pedicles had sufficient length to allow anastomosis without tension. Postoperative angiography demonstrated all ITA's to be patent without injury. Patients tolerated insufflation without hemodynamic compromise even when crossing over into the right pleural space. The curved harmonic blade was useful when harvesting the right ITA to avoid injury to the vessel. From the total number of 19 patients, 16 were males and 3 females with average age 61 ± 12 years. The average length of time required to harvest the ITA's was 65 ± 21 minutes. Mean ITA flow was 31 ± 19 cc/min. Vascular branches were transected with excellent hemostasis and no hemoclips were required for side branch bleeding. There were no mortalities, perioperative myocardial infarctions or arrhythmias. There were no perioperative blood transfusions required. There was no evidence of conduit spasm or trauma after harvesting. All anastomoses were angiographically patent.

DISCUSSION

This paper describes the technique of harvesting arterial conduits using total robotic telemanipulation. In our experience and those of others, the Harmonic Scalpel® has been found to be a safe and efficacious tool in thoracoscopic harvest of the ITA [Ohtsuka 1997, Boyd, in press]. Other authors have suggested that one potential disadvantage of the ZEUS™ system is the lack of end-effector articulation making dissection of the ITA difficult [Chitwood 1999]. We have shown that the ZEUS™ robotic surgical system is readily adaptable to the Harmonic Scalpel® and that bilateral ITA's can be safely harvested through the left chest with robotic telemanipulation. This can be accomplished even when anterior-posterior working space is limited.

Robotic indexing allows surgeons to maintain a comfortable and ergonomic arm position while sitting at the console performing the ITA dissection, thus reducing fatigue [Reichenspurner 1999]. Moreover, robotic telemanipulation facilitates the training of this technique since it allows the mentor teaching the technique, to stand over the shoulder of the trainee, guiding him or her through the procedure while viewing the same picture. Hand motions with the telepresence surgical system are more natural and mimic the hand motions of the open technique, which shortens the learning curve of totally thoracoscopic ITA harvesting. It was clear that surgical endoscopic skills learned from prior experience of harvesting internal thoracic arteries with a voice-controlled robotic endoscope positioner (AESOP® 3000) and the Harmonic Scalpel® using manual techniques [Boyd, in press] greatly facilitated the transition to telerobotic ITA harvesting.

Remote robotic telesurgery can have potential drawbacks. It presently lacks the haptic feedback, which is present in the open method. Although haptic sensation is somewhat reduced in video-enhanced procedures using conventional endoscopic instruments, the operator has to rely solely on visual cues when performing telepresence surgery. The ideal visualization system would allow a three-dimensional view at high resolution using a 5mm endoscope. In this study, we also demonstrated the utility of the ZEUS robotic system by successful surgical dissection of the entire right internal thoracic artery through the same initial working ports. When performing this dissection of the RITA through the left-chest ports, the working angle between the chest wall and the Harmonic Scalpel® is very acute. This increases the risk of injuring the arterial conduit during the dissection. To avoid this complication, the medial aspect of the pedicle is dissected first and a curved blade instead of a straight blade is used when dissecting the lateral pedicle.

In conclusion, the ZEUS™ robotic telemanipulation system used in conjunction with the Harmonic Scalpel® enables safe remote endoscopic harvest of the ITA through three 5 mm incisions on the left chest. This allows bilateral arterial conduits to be harvested endoscopically, which is a crucial step in making totally endoscopic robotic telemanipulation coronary artery bypass grafting possible.

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