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An Alternative Arterial Conduit for Totally Endoscopic Multivessel Coronary Artery Bypass

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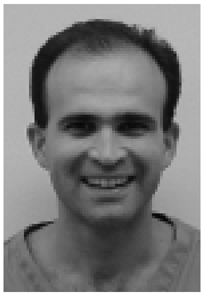

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ABSTRACT

Background: The ultimate goal of coronary artery bypass grafting (CABG) is the performance of a totally endoscopic procedure using multiple arterial conduits. At our center we have been routinely performing endoscopic robotic harvesting of internal thoracic arteries (ITAs) for use in minimally invasive CABG. The right gastroepiploic artery (RGEA) has been shown to be a reliable and versatile arterial conduit for bypass to coronary vessels not easily accessible by an ITA. The RGEA has already been harvested less invasively through a small laparotomy. This procedure could be made even less invasive by harvesting the RGEA laparoscopically, but this procedure has not yet been reported. The purpose of this study was to develop an endoscopic technique for harvesting the RGEA and demonstrate the safety and efficacy of this less invasive approach.

Methods: Twenty Duroc X Hampshire swine were administered general anesthesia and intubated. Ten mm and 5 mm trocars were then inserted. A 10 mm, 30-degree endoscope was adapted to a voice-activated robotic arm (AESOP), and the RGEA was harvested totally endoscopically using 5 mm harmonic scalpel shears. Intraoperative events and RGEA harvest times were recorded, and RGEA flows were measured after harvest. RGEA was delivered into the pericardial sac endoscopically.

Results: All RGEAs were successfully harvested without injury. Harvest time averaged 29.9 ± 10.9 min. The harvested conduits averaged 24.7 ± 2.37 cm in length. Flows were excellent in all harvested conduits, averaging 81.1 ± 31.8 cc/min. The harmonic scalpel controlled all RGEA branches with excellent hemostasis.

Conclusion: The RGEA can be harvested safely through port access with robotic assistance. This conduit is of sufficient length to be used as an alternative arterial conduit for totally endoscopic multivessel coronary artery bypass.

INTRODUCTION

Each year more bypasses are being performed on the beating heart without cardiopulmonary bypass [Subramanian 1995, Acuff 1996, Calafiore 1996a, Calafiore 1996b, Granjean 1996, Mack 1997, Mohr 2001]. The ultimate goal of minimally invasive coronary artery surgery is performing a totally endoscopic procedure using multiple arterial conduits. In order to achieve totally endoscopic multivessel coronary artery bypass, it is crucial to be able to harvest multiple arterial conduits endoscopically.

The left internal thoracic artery (LITA) has been used routinely as the arterial conduit of choice to bypass the left anterior descending artery (LAD) [Stanbridge 1995, Calafiore 1996a, Calafiore 1996b, Buffolo 1996]. Recent success with computer-enhanced robotic systems in the performance of endoscopic, single-vessel coronary artery bypass has paved the way for developing techniques for multivessel coronary artery bypass [Mohr 1998, Ducko 1999, Loulmet 1999, Boyd 2000, Kiaii 2000, Mohr 2001]. At our center, we have been routinely performing endoscopic robotic harvesting of ITAs since 1998 [Kiaii 2000, Boyd 2001].

The right gastroepiploic artery (RGEA) has been shown to be a suitable and reliable arterial conduit for bypass of coronary vessels not easily accessible by an ITA [Mills 1993, Granjean 1994]. When the RGEA is used in coronary artery bypass grafting (CABG), operative mortality between 0.4% to 3.3% has been reported [Suma 1991, Mills 1993, Nishida 1994, Jegaden 1995, Suma 1996], with patency rates of 96% at two months, 92% at two years [Granjean 1994], and 82% at five years [Voutilainen 1996]. The RGEA has also been used for minimally invasive coronary artery bypass grafting [Suma 1993, Voutilainen 1998]. In these cases, the RGEA is anastomosed to the right coronary artery (RCA) or the posterior interventricular branch (PIV) through a small laparotomy incision with removal of the xiphoid [Suma 1993, Voutilainen 1998]. This procedure could be even less invasive if the RGEA were to be harvested laparoscopically.

For patients with multivessel disease, it would be beneficial if another arterial conduit could be harvested endoscopically. Our goal in this study was to develop a technique to successfully and reproducibly harvest the RGEA endoscopically.

MATERIALS AND METHODS

Twenty Duroc X Hampshire swine of either sex weighing 30-40 kg were studied. All animals were cared for according

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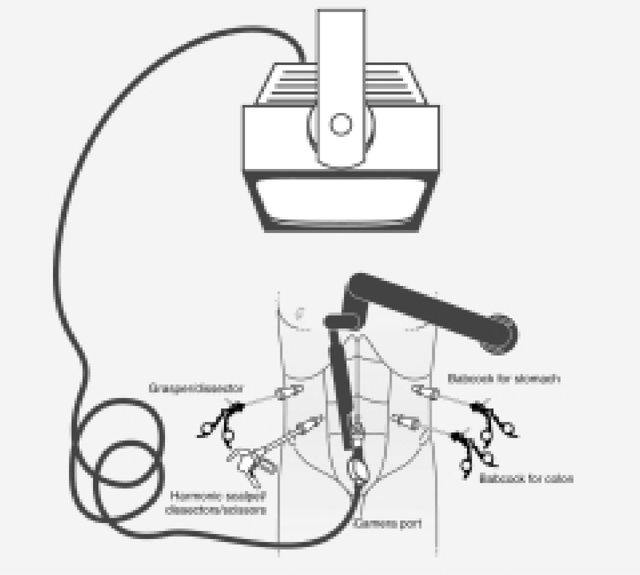

Figure 1. Robotic arm placement diagram for the robotically assisted RGEA Harvesting.

to guidelines of the University Council on Animal Care of the University of Western Ontario. The animals were given general anesthesia with thiopental sodium, 12 mg/kg intravenously, and maintained with isofluorane by inhalation. Animals were intubated with a cuffed endotracheal tube, and volume-cycled mechanical ventilation was begun at tidal volume of 10 ml/kg, FiO_2 0.50, and positive end expiratory pressure of 5 cm H_2O. Neuromuscular blockade was achieved with intravenous pancuronium, 0.1 mg/kg, which was repeated at necessary intervals to eliminate spontaneous breathing. One 10 mm trocar (Ethicon Endo-Surgery, Cincinnati, OH) was positioned at the umbilicus and four other trocars (5 and 10 mm) were inserted laterally to the rectus muscle with two on each side of the rectus muscle. See Figure 1 (◎). A 10 mm, 30-degree endoscope (Karl Stortz, Tuttlingen, Germany) was inserted in the 10 mm port at the umbilicus. The endoscope was adapted to a voice-activated robotic arm (AESOP 3000, Computer Motion, Goleta, CA). Through this port, pneumoperitoneum of 10-14 mm Hg was created using CO_2. A harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH) and a dissector (Ethicon Endo-Surgery) were inserted through the left side trocars. The two remaining ports on the right were used for a Babcock and a grasper (Ethicon Endo-Surgery). See Figures 1 and 2, ◎.

Once adequate pneumoperitoneum was achieved, the stomach was grasped using the Babcock and reflected upwards, and the transverse colon was reflected downwards. This maneuver permitted exposure of the RGEA. Once adequate visualization of the gastroepiploic artery was obtained, it was dissected from the mid-aspect of the greater curvature of the stomach to the pyloris. All arterial and venous branches were controlled with the harmonic scalpel. After full mobilization of the artery (Figure 3, ◎), flows were measured into a beaker and compared with flows measured with a transit-time ultrasonic flow probe (Transonic Systems, Ithaca, NY).

Figure 2.

The length of the RGEA pedicle was then measured. The RGEA pedicle was tunneled into the mediastinum through a small incision created endoscopically in the diaphragm over the dome of the liver. The animal was euthanized with an intravenous injection of potassium chloride.

RESULTS

All RGEAs were safely and successfully harvested without injury. Robotic assistance facilitated total endoscopic dissection of the RGEA. The operative data is recorded in Table 1 (◎). The RGEA harvest time averaged 29.9 ± 10.9 min. (range 15-48 min.). Free graft flow averaged 81.1 ± 31.8 ml/min. (range 36-120 ml/min.) and Doppler-measured flow averaged 99.8 ± 49.0 ml/min. (range 45-210 ml/min.).

In each case the laparoscopic approach enabled complete dissection of the RGEA without injury to the stomach or other internal organs. All RGEA pedicles were of sufficient length to allow endoscopic delivery into the pericardial cavity without tension. In all cases the harvesting was performed with video assistance using only port access with the harmonic scalpel. The division of all vascular branches was accomplished hemostatically with the harmonic scalpel.

DISCUSSION

For the past ten years, the right gastroepiploic artery has been used in coronary artery bypass grafting with excellent results [Galbut 1990, Perrault 1993, Suma 1993, Pym 1995, Voutilainen 1996]. It has been shown to be a reliable and versatile arterial conduit for bypass to coronary vessels not easily accessible by an ITA [Granjean 1994, Mills 1996]. The use of the RGEA in coronary surgery has been associated with acceptable morbidity and mortality [Suma 1991, Nishida 1994, Jegaden 1995, Mills 1996, Suma 1996]. Patency rates of 92% at two years [Granjean 1994] and 82% at five years [Voutilainen 1998] have been reported. Already the RGEA has been harvested through a small laparotomy in minimally invasive bypass procedures [Suma 1993, Voutilainen 1998].

Figure 3.

However, endoscopic harvest of the RGEA with robotic assistance has not yet been reported.

Beating heart endoscopic coronary artery bypass grafting is a procedure in the process of development. Closed-chest coronary artery bypass techniques require the development of new procedures for harvesting arterial conduits endoscopically. A technique for harvesting the ITA endoscopically has already been described [Ohtusko 1997, Boyd 2001]. This conduit has primarily been used in single-vessel, totally endoscopic coronary artery bypass procedures, although multiarterial bypass grafts have been performed [Mohr 1998, Loulmet 1999, Boyd 2000, Falk 2000, Mohr 2001]. In order to perform fully endoscopic multivessel coronary artery bypass, arterial conduits other than the ITA also have to be harvested endoscopically [Cichon 2000]. Two recent technological advances, robotic assistance and the harmonic scalpel, have opened new prospects for endoscopic harvesting. It has been demonstrated that robotic telesurgery systems have further facilitated mammary artery harvesting through the endoscope [Falk 2000, Kiaii 2000].

The use of robotics to enhance minimally invasive operations has been previously described in other disciplines [Geis 1996]. We describe a new application of robotic technology for the performance of laparoscopic RGEA harvesting. The surgical robot used in this series, the Automated Endoscope System for Optimal Positioning (AESOP), is capable of positioning a laparoscope in response to a surgeon's verbal commands. AESOP approximates the form and function of a human arm and provides the surgeon with direct control of the endoscope. In our initial experience, the use of the AESOP 3000 robot assistant allowed the surgeon to safely perform laparoscopic RGEA harvesting comfortably without prolonging operative time and without additional equipment. The benefits of robotic assistance include greater image stability and consistency in the quality of assistance. By providing instantaneous "surgeon-brain-camera" positioning, accurate instrument tracking, and optimal magnification, the robot markedly increased the surgeon's video-dexterity and lessened fatigue.

Because of concern about potential thermal injury with the use of diathermy as the method of hemostatic control of collateral branches during dissection of the RGEA, we adopted the harmonic scalpel for endoscopic conduit harvesting. Our group and others have shown that the harmonic scalpel is a safe and efficient means of dissection because it operates at a lower temperature than diathermy and does not require instrument transfers to control side branches [Ohtuska 1997, Boyd 2000].

Table 1. Operative data

Animal Number	RGEA harvest time (min)	RGEA Length (cm)	Free Flow (ml/min)	Doppler Flow (ml/min)
1	48	19	36	–
2	40	21	48	–
3	42	31	36	–
4	27	27.9	50	50
5	29	23.5	85	85
6	49	26.5	45	45
7	30	25	52	63
8	20	24.75	70	70
9	20	25.5	104	150
10	45	28	63	76
11	25	25	120	210
12	35	24	108	160
13	18	22	100	122
14	18	25	56	58
15	15	25.1	50	68
16	15	19	108	98
17	19	25.5	70	130
18	25	27	60	56
19	18	23	156	156
20	17	23.5	60	64

The results of this study confirm that endoscopic RGEA harvesting allows a complete, reliable dissection of the RGEA from the mid-aspect of the greater curvature of the stomach to the pyloris and permits clear, magnified views that are superior even to that of the open approach. A sufficient length of RGEA may be readily obtained without injury to the vessel or to the stomach. In addition, a small tunnel can be created in the diaphragm over the dome of the liver through the endoscope using the harmonic scalpel, thereby allowing the RGEA pedicle to be delivered directly into the pericardial sac.

CONCLUSION

Robotic-assisted, endoscopic RGEA harvesting using the harmonic scalpel greatly facilitates the harvesting procedure and has the potential to decrease the morbidity associated with graft harvesting. We have demonstrated that the RGEA can safely and reproducibly be harvested endoscopically through port access with robotic assistance. The RGEA is of sufficient length to be delivered into the pericardial sac and to be used as an alternative arterial conduit for totally endoscopic, multivessel coronary artery bypass.

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