Facilitated endoscopic beating heart coronary artery bypass grafting using a magnetic coupling device

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Background: Suturing of a coronary anastomosis in totally endoscopic coronary artery bypass grafting on the beating heart is technically demanding. The potential benefits of the endoscopic Magnetic Vascular Positioner device (Ventrica, Inc, Fremont, Calif) to facilitate construction of a coronary anastomosis in a closed chest environment were evaluated.

Methods: Totally endoscopic coronary artery bypass grafting on the beating heart was performed in 8 foxhound-beagle inbred dogs with the da Vinci telemanipulation system (Intuitive Surgical, Mountain View, Calif). A prototype of the endoscopic Magnetic Vascular Positioner device was used to facilitate construction of the coronary anastomosis. One pair of magnets was inserted in the internal thoracic artery and left anterior descending artery using robotic instruments to guide and place the endoscopic delivery platform. All animals underwent angiography; gross inspection of the anastomotic site was performed after excision of the hearts.

Results: The procedure was accomplished in all animals in 169 minutes (155-190 minutes). Dissection of the left anterior descending coronary artery (6.5 minutes; 1-20 minutes), positioning of the stabilizer (8.5 minutes; 7-16 minutes), placement of occlusion tapes (6 minutes, 3-10 minutes), and arteriotomy 5.5 minutes (3-30 minutes) was achieved without problems. By use of the Magnetic Vascular Positioner device, the anastomosis at the graft site was performed with the graft still in situ. Except for 1 premature deployment, all other deployments were easily accomplished in 3 minutes (1-28 minutes). The following adverse events were encountered: bleeding from the right ventricle caused by occlusion tape (1), anastomotic leakage on reperfusion requiring repair stitches (2), and anastomotic occlusion as a result of thrombus (1). All except 1 animal with a patent graft and anastomosis survived the procedure. The overall patency was 7 of 8.

Discussion: The combination of robotic technology allowing for dexterous manipulation in a closed chest environment and a simple yet effective and timesaving technique for anastomotic coupling may facilitate beating heart totally endoscopic coronary artery bypass grafting.
come some of the limitations of conventional endoscopic instruments, TECAB has been performed consistently on the arrested and the beating heart.\textsuperscript{2-6} Although the total number of endoscopic internal thoracic artery (ITA) take-downs has continuously increased, the total number of successfully completed TECAB procedures is still small. Among the challenges are limited working space, indirect visualization, and the difficulty of maintaining insufflation. On the beating heart, the lack of effective stabilization and hemodynamic impairment complicate construction of a coronary anastomosis despite the enhanced endoscopic dexterity provided by contemporary telemanipulation systems. Only recently, a number of devices have been developed to facilitate construction of a distal graft to coronary anastomosis.\textsuperscript{7} To evaluate the potential synergistic effect of these new technologies, an endoscopic beating heart canine study was performed using the prototype of an endoscopic magnetic vascular positioning device to facilitate the construction of a distal graft to coronary anastomosis.

**Methods**

After approval of the study by the governmental offices (Regierungspräsidium), 8 foxhound-beagle inbred dogs (30-40 kg) underwent operations. Premedication included levomethadone-chloride (0.3 mg/kg intramuscularly [IM]), atropine (0.02 mg/kg IM), ketamine (3 mg/kg IM), and xylazinehydrochloride (0.7 mg/kg IM). After induction with ketamine (10 mg/kg intravenously [IV]) and diazepam (0.5 mg/kg IV), endotracheal intubation was performed. Pancuronium was administered at a dose of 0.13 mg/kg IV. Inhalational anesthesia was maintained with isoflurane 1.5% to 2.5% in oxygen, fentanyl was administered at a dose of 25 μg · kg \(^{-1}\) · h, and midazolam was administered at a dose of 0.2 mg · kg \(^{-1}\) · h continuously. Amiodarone (150 mg) was administered to prevent arrhythmias, and acetylsalicylate (500 mg IV) was used for antiplatelet therapy. An arterial line was placed in the right femoral artery, and a central venous line was placed in the right jugular vein. The animals were placed in the right lateral decubitus position. Monitoring included electrocardiography, arterial blood pressure, central venous pressure, and oxygen saturation. Intermittent positive-pressure ventilation was used. Normal saline solution was administered at a maintenance dose of 10 to 20 mL · kg \(^{-1}\) · h. Volume boluses and dopamine infusion were given as needed. The da Vinci telemanipulation system (Intuitive Surgical, Mountain View, Calif) has been described in detail elsewhere.\textsuperscript{2,3} A vacuum-assisted endoscopic stabilizer including an irrigation channel was used (Intuitive, not approved by the Food and Drug Administration). The surgical approach has been described.\textsuperscript{8} In brief, the entire operation was performed through a total of 5 thoracoscopic ports for the left (8 mm midaxillary seventh intercostal space) and right instruments (8 mm midaxillary third intercostal space), the scope (12 mm midaxillary fifth intercostal space), the stabilizer (12 mm subxiphoid), and the coupling device (12 mm fourth or sixth intercostal space below the midaxillary line).

Carbon dioxide insufflation was not applied. Motion scaling was set to 3:1. A 30° scope was used angled up for manipulation of the ITA and angled down when working on the heart. The endoscopic Magnetic Vascular Positioner (MVP) System (Ventrica, Inc, Fremont, Calif) consists of 4 magnetic implants and a delivery system. The external measurements of the magnets used in this study were 6.8 mm and 2.3 mm on the major and minor axes, respectively, with internal dimensions of 4.0 mm and 1.4 mm on the major and minor axes, respectively. The resulting orifice area was 6.0 mm\(^2\).

The magnets were 0.4 mm thick. One pair of elliptical magnets created an anastomotic port in the graft and the coronary artery, respectively. One magnet of each pair was placed within the vessel lumen at the incision site (intravascular magnetic implant), and the other was held in place on the external surface of the vessel (extravascular magnetic implant) by magnetic attraction. The 2 ports were connected by magnetic force and formed a side-to-side (functional end-to-side) anastomosis.

The left ITA was harvested, and the most distal portion was skeletonized. The pericardium was opened, and the left anterior descending (LAD) coronary artery was identified. Heparin (100 U/kg IV) was administered, and the activated clotting time was maintained at greater than 300 seconds. The ITA was occluded using a vascular occluder (Scanlan, St Paul, Minn). The distal end was clipped. A sharp arteriotomy of 3 to 3.5 mm in length was made in the distal portion of the ITA, and the magnetic vascular coupling device was inserted. For this study, the prototype of a cable-mounted endoscopic delivery system with an external trigger was used (Figure 1). The device was grabbed with robotic instruments, and the intravascular implant was guided into the target vessel. On correct seating of the internal magnet, the external magnet was released.

The target site (mid-portion of the LAD artery between the first and second collateral branch) was then immobilized by the vacuum-assisted stabilizer, which was inserted through a subxiphoid port. The LAD artery was occluded proximally and distally to the anastomotic site using 2 self-locking silicone rubber bands (Intuitive). A 3 to 3.5 mm arteriotomy was made in the LAD artery. Directed irrigation of the operating field was provided through a separate channel of the stabilizer. A second pair of magnets was then introduced and placed in the LAD artery using robotic instruments (Figure 2). The anastomosis was completed by detaching the ITA from the chest wall and connecting the outer magnets of the graft and the target vessel, respectively (Figure 3). The silicone occlusion tapes were released, and all instruments were withdrawn. After the procedure, all animals underwent angiography using a fluoroscopy unit (Sieremobil 2000; Siemens, Munich, Germany), after which they were killed. Because of the radiopaque nature of the magnets, quantitative angiographic analysis was not possible. Graft flow was assessed in 3 angles: anteroposterior, left anterior oblique, and right anterior oblique. After angiographic control, flow measurements were performed through a lateral thoracotomy. Postmortem gross inspection of the anastomotic site was performed after excision of the hearts. End points of the study were the technical feasibility of the construction of a magnetic port anastomosis, anastomotic patency (qualitatively), anastomotic construction time, and graft flows post-anastomosis.

All animals received humane care in compliance with the “Principles of Laboratory Animal Care” formulated by the National Society of Medical Research and the “Guide for the Care and Use of Laboratory Animals” prepared by the Institute of...
Results

The procedure including placement of the magnets and construction of a graft to coronary connection was accomplished in all animals in 169 minutes (155-190 minutes). ITA takedown was completed in 44 minutes (32-67 minutes). The time for skeletonization of the most distal portion of the vessel, distal ITA occlusion by clips, and placement of bulldog clamps for temporary proximal vascular occlusion was 23 minutes (16-35 minutes). The lack of countertraction and inefficiency of the clamps used were responsible for some delays during this part of the operation. Pericardiotomy and identification of the LAD coronary artery was readily accomplished in all animals (7.5 minutes; 3-10 minutes). LAD coronary artery dissection using a blunt knife (6.5 minutes; 1-20 minutes), positioning of the stabilizer including creation of a subxiphoid port (8.5 minutes; 7-16 minutes), and placement of the silicone rubber occlusion tapes proximally and distally of the target site (6 minutes, 3-10 minutes) were achieved without problems, except for 1 dog in which the occlusion tape caused bleeding from the right ventricle that required repair stitches. The...
TABLE 1. Angiographic and morphologic findings at anastomotic site

<table>
<thead>
<tr>
<th>Animal no.</th>
<th>Survival</th>
<th>Angiographic result</th>
<th>Gross inspection of anastomotic site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>Patent good run-off</td>
<td>No excess tissue</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>Patent good run-off</td>
<td>No excess tissue</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>Patent good run-off</td>
<td>No excess tissue</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>Occluded</td>
<td>Thrombus at anastomotic site, no excess tissue</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>Patent medium run-off</td>
<td>No excess tissue</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>Patent good run-off</td>
<td>No excess tissue</td>
</tr>
<tr>
<td>7</td>
<td>No</td>
<td>Patent (postmortem angio)</td>
<td>No excess tissue, no thrombus, Cause of death unresolved</td>
</tr>
<tr>
<td>8</td>
<td>Yes</td>
<td>Patent, medium run-off (D2)</td>
<td>No excess tissue</td>
</tr>
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</table>
factors that set the limits of surgical performance, the use of a telemanipulation system leads to additional delays in response time and decreases the geometric accuracy of the operator.11 This has been demonstrated by comparing manually and robotically constructed anastomoses.12 Although this difference may not be clinically relevant on the arrested heart, system-related prolongation of motor response caused by mechanical inertia, electronic, and optic delays may render endoscopic suturing on the beating heart inaccurate. By using a standardized coupling device, some of the difficulties of constructing an anastomosis remotely can be eliminated.

Given the good patency results with the MVP reported for the first experimental and clinical trials,13 it seems justified to conclude that the combination of robotic technology allowing for dexterous manipulation in a closed chest environment and a simple yet effective and timesaving technique for anastomotic coupling may facilitate endoscopic beating heart bypass grafting and accelerate the adoption of this procedure.

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References
