Totally endoscopic robot-assisted transmyocardial revascularization

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Objective: Laser transmyocardial revascularization is an emerging therapy for intractable angina stemming from diffuse, small-vessel coronary disease not amenable to percutaneous coronary intervention or coronary bypass grafting. Presently, this therapy is delivered through a median sternotomy or left thoracotomy. In this pilot study, we sought to combine the advantages of a dexterous robotic surgical platform with a flexible fiberoptic laser to develop a minimally invasive approach toward transmyocardial revascularization.

Methods: A flexible fiberoptic holmium:yttrium-aluminum-garnet laser probe (CardioGenesis Corporation, Foothill Ranch, Calif), deployed with the da Vinci surgical robotic system (Intuitive Surgical, Sunnyvale, Calif), was used to create transmyocardial channels through all left ventricular wall regions in 5 canine subjects. The channels were localized, quantified, and histologically analyzed to assess distribution, dimensions, and transmurality.

Results: Transmyocardial channels were successfully created in all 6 defined left ventricular wall segments by using this minimally invasive approach without port repositioning, instrument exchange, or probe modifications. Gross pathologic and histologic analyses confirmed the uniform distribution of 1.0-mm transmural channels in all left ventricular regions. No direct pressure, topical hemostatic agents, or suture repairs were required for hemostasis. No significant hemodynamic instability or sustained arrhythmias were encountered at any time during the procedures.

Conclusions: We report the first use of a prototype flexible fiberoptic laser probe deployed by the da Vinci surgical robotic system to successfully perform totally endoscopic off-pump transmyocardial revascularization in a canine model, demonstrating the feasibility, precision, and safety of this approach. Refinement of this minimally invasive technique may reduce the morbidity of open-chest transmyocardial revascularization and facilitate its use as sole therapy or as an adjunct to percutaneous coronary interventions.

Although coronary artery bypass grafting (CABG) and percutaneous coronary interventions (PCIs) are proven therapies for relief of angina stemming from ischemic heart disease, there exists a subset of “no-option” patients with intractable angina caused by diffuse, small-vessel coronary disease not amenable to these modalities. Transmyocardial laser revascularization (TMR) has shown some clinical promise in substantially reducing anginal symptoms in these patients either as sole therapy or in conjunction with CABG. 1-5 Most recently, Allen and colleagues’ 6 also demonstrated a significantly reduced risk of late death for no-option patients treated with sole-therapy TMR compared with maximal medical therapy. TMR is currently delivered mainly through a median sternotomy or left thoracotomy. In this study, we sought to combine the unique dexterity afforded by the da Vinci surgical robotic platform with a prototype flexible fiberoptic holmium:yttrium-
aluminum-garnet (Ho:YAG) laser TMR device (CardioGenesis Corporation, Foothill Ranch, Calif) to perform totally endoscopic off-pump TMR in a canine model. We hypothesized that the dexterous characteristics of these 2 systems would facilitate the minimally invasive creation of TMR channels in all segments of the left ventricle.

Materials and Methods
Adult mongrel dogs of either sex (n = 5), weighing between 35 and 40 kg, were used in this experiment under a protocol approved by the Johns Hopkins University Animal Care and Use Committee (Protocol No. DO04M125) on May 11, 2004. All animals received humane care in compliance with the “Principles of Laboratory Animal Care” formulated by the National Society for Medical Research and the “Guide for the Care and Use of Laboratory Animals” prepared by the National Academy of Sciences and published by the National Institutes of Health (National Institutes of Health Publication No. 85-23, revised 1985). Anesthetic induction was composed of intravenous thiamylal 10 mg/kg followed by Kottmeier double-lumen endobronchial intubation (Rusch, Duluth, Ga) and inhalational anesthesia with isoflurane (1%-2%). Each animal was placed in a modified right lateral decubitus position and subjected to selective right-lung ventilation. Systemic arterial pressure was monitored with a femoral arterial line, and venous access was obtained peripherally. Continuous electrocardiographic telemetry and pulse oximetry (V3404 Plus, SurgiVet Inc, Waukesha, Wis) were used.

The da Vinci surgical robotic system (Intuitive Surgical, Sunnyvale, Calif) was used to perform the endoscopic TMR operations. A 0-degree videoscope was introduced into the left thoracic cavity through a 12-mm port (United States Surgical Corp, Norwalk, Conn) placed in the seventh intercostal space along the midscapular line. Two 5-mm da Vinci instrument ports were
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municate freely with the ventricular cavity. That led to the development of TMR as a means of revascularizing ischemic myocardium by channeling oxygenated blood within the left ventricular cavity into sinusoidal networks serving ischemic regions. Although this mechanism has largely been disproven, significant angina relief observed in nonrandomized TMR trials led to several prospective, randomized 1-year follow-up studies demonstrating angina relief, improved exercise tolerance, decreased rehospitalizations, and improved event-free survival for no-option patients with disabling angina refractory to medical management and not amenable to CABG or PCI. Recently, in a 5-year prospective, randomized, multicenter trial, Allen and colleagues demonstrated sustained long-term angina relief and increased survival in no-option patients receiving primary TMR versus medical therapy.

Currently, most patients receive TMR in conjunction with CABG or after failed CABG through a median sternotomy or left thoracotomy, targeting myocardial regions not amenable to bypass grafting or PCI. Far fewer no-option patients undergo sole TMR as an initial surgical procedure, presumably because of a lingering, yet healthy skepticism as to the efficacy of TMR given the following: (1) the lack of a definitive mechanism of action, (2) a perceived placebo effect that has not been strictly excluded in past clinical trials, because of the impracticality of a true surgical “sham” group, and (3) no benefit seen in sham-controlled, randomized studies using percutaneous myocardial laser revascularization. Furthermore, diminished survivals have been observed with sole-therapy TMR applied to patients in congestive heart failure or with poor ventricular function. In this context, few cardiologists and cardiac surgeons are willing to impose the morbidity of a primary operation or even as an adjunct to PCI. To reduce the morbidity-to-benefit ratio of sole-therapy TMR, approaches for minimally invasive TMR have been proposed. deGuzman and colleagues described the conventional thoracoscopic application of CO2 laser TMR in pigs. Izutani and colleagues used the Zeus robotic surgical system (Computer Motion, Goleta, Calif) to perform excimer laser (Xe:Cl) TMR in pigs. Although successful to varying degrees, these early attempts could not deliver TMR to all left ventricular regions or required port relocation, instrument exchanges, and/or manual handpiece angle adjustments to do so.

We sought to develop a new minimally invasive, totally endoscopic off-pump approach to TMR, facilitated by a dexterous robotic surgical platform, to more easily deliver TMR to all left ventricular wall regions. The da Vinci surgical robotic system provides wrist-like dexterity and superb stereoscopic visualization within the chest cavity. We have modified the commercially available CardioGenesis SoloGrip III Ho:YAG fiberoptic laser probe, permitting it to be introduced into the chest cavity through a 5-mm thoracoscopic port and easily manipulated across a wide range of angles by the da Vinci instrumentation. We selected the Ho:YAG laser over other commercially available CO2 lasers because with the latter, laser energy is not transmitted fiberoptically, but rather through relatively fixed reflective elements. Combining the da Vinci system’s robotic dexterity with the Ho:YAG laser’s flexible fiberoptic conduit greatly facilitates positioning the probe at the precise location and perpendicular orientation to all left ventricular regions for optimal TMR channel creation. Although we believe this approach compares favorably with conventional thoracoscopic techniques in this regard, we did not perform the same procedure with standard thoracoscopic instruments to make objective comparisons.

Histologic and gross confirmation of transmural channel penetration and distribution in all left ventricular wall segments were achieved in this study. The excellent visualization and precise maneuverability afforded by this approach also reduces the chance of inadvertent injury to epicardial vessels. In more than 200 channels created in these experiments, no epicardial vessel was lacerated.

Single-lung ventilation with gentle CO2 insufflation greatly facilitates off-pump exposure of the heart for this totally endoscopic approach. In turn, avoiding heparinization associated with cardiopulmonary bypass greatly promotes hemostasis. In these pilot studies, uniform spontaneous channel hemostasis without the aid of direct pressure, topical hemostatic agents, or suture closure was achieved. Furthermore, no sustained arrhythmias or hemodynamic instability was noted in any of the preparations. We recognize that this stability may not always be afforded by an ischemic ventricle; therefore, we anticipate the mandatory use of external defibrillator pads and cardiopulmonary bypass standby for this closed-chest approach.

Finally, we recognize that most animal models do not anatomically replicate the human thorax; however, we did find that, in our canine preparation, the left ventricle lies within several centimeters to the chest wall, as it does in humans with dilated cardiomyopathies. Despite this, we were able to easily direct the TMR probe to all left ventricular regions. This is an advantage afforded by our robotic approach and may prove to obviate the need for additional exposure devices used in other off-pump operations.

In summary, we describe our early experimental experience with a totally endoscopic, robot-assisted off-pump approach for delivering TMR therapy. By combining the advantages of a dexterous robotic surgical system with a prototypic modification of a commercially available flexible fiberoptic Ho:YAG TMR system, we demonstrate the feasibility, precision, and safety of this approach. The targeted
aims of this strategy are to substantially reduce the morbidity of TMR therapies arising from open-chest approaches and to facilitate the minimally invasive application of TMR as initial sole therapy or as an adjunct to primary PCI, addressing ischemic myocardial regions supplied by non-stentable coronary arteries. Further developmental studies appear to be warranted.

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References