

# Beating Heart Totally Endoscopic Coronary Artery Bypass

Sudhir Srivastava, MD, Suresh Gadasalli, MD, Madhava Agusala, MD, Ram Kolluru, MD, Reyna Barrera, PAC, Shaune Quismundo, RN, BSN, Usha Kreaden, MS, and Valluvan Jeevanandam, MD

Cardiac Surgical Associates of West Texas and Alliance Hospital, Odessa, Texas; Intuitive Surgical Inc, Sunnyvale, California; and University of Chicago Medical Center, Chicago, Illinois

**Background.** Graft patency and clinical freedom from graft failure remains a subject of investigation in beating-heart totally endoscopic coronary artery bypass.

**Methods.** A total of 214 patients underwent successful beating-heart totally endoscopic coronary artery bypass from July 2004 to June 2007. Single-, double-, and triple-vessel beating-heart totally endoscopic coronary artery bypass was performed in 139, 68, and 7 patients, respectively. Fifty patients underwent planned hybrid revascularization. Eighty percent of patients (172 of 214) underwent computed tomography angiography or conventional angiography within 3 months from the time of surgery. On computed tomography angiography, the analysis included gross patency, stenosis within the graft, and contrast in the grafted coronary artery. A FitzGibbon score was used to analyze graft patency and anastomosis in patients undergoing conventional angiography. Clinical follow-up was done in all patients for any major adverse cardiac event in relation to the revascularized coronary arteries.

**Results.** There was no myocardial infarction, operative mortality, or conversion to cardiopulmonary bypass. All patients who had computed tomography angiography were found to have grossly patent graft without stenosis and demonstrated opacification of the grafted coronary artery. Fifty-seven grafts were studied in 39 patients by conventional angiography postoperatively during hybrid revascularization. At the time of study, all grafts except one had FitzGibbon grade A anastomosis and Thrombolysis In Myocardial Infarction grade 3 flow. Three patients (1.4%) required reintervention at 2, 3, and 13 months after initial beating-heart totally endoscopic coronary artery bypass.

**Conclusions.** The clinical freedom from graft failure noted in 98.6% patients appears to be excellent. Further angiographic and clinical follow-up is required to determine the long-term results.

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Beating-heart (BH) coronary artery bypass graft (CABG) techniques were introduced in the 1950s before the advent of cardiopulmonary bypass (CPB) [1, 2]. With the introduction of CPB and cardioplegia, arrested-heart (AH) CABG became the gold standard in coronary revascularization [3]. Benetti and colleagues [4] and others [5–7] have revived the interest in BH CABG through less invasive approaches. Since then, numerous studies of less invasive CABG graft patency have been reported [8–10].

The superiority of the left internal thoracic artery (ITA) as a conduit has been well established for long-term patency and event-free survival [11–13]. The da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA) offers three-dimensional magnified vision with wristed instrument tips that enables performance of totally endoscopic coronary artery bypass (TECAB) [14]. Loulmet and associates [15] reported the first AH TECAB utilizing peripheral CPB. With the introduction of the

endoscopic stabilizer, BH TECAB became feasible. However, earlier reports were associated with technical challenges and relatively high conversion rates [16–18]. In July 2004, after a multicenter trial of robotically assisted TECAB on an arrested heart, the da Vinci robotic surgical system received approval from the Food and Drug Administration in the United States for coronary anastomosis [19].

Graft patency and clinical freedom from graft failure has remained a major concern in less invasive off-pump approaches for CABG. This study reports a single-center, single-surgeon, nonrandomized retrospective study of early graft patency and clinical freedom from graft failure in 241 consecutive patients who underwent attempted BH TECAB with the da Vinci robotic surgical system.

## Material and Methods

The Western Institutional Review Board in compliance with the Health Insurance Portability and Accountability Act regulations and the Declaration of Helsinki approved

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Address correspondence to Dr Srivastava, Peachtree Cardiovascular and Thoracic Surgeons PA, 5665 Peachtree Dunwoody Rd NE, Ste 150, Atlanta, GA 30342; e-mail: sudhirprsvastava@mac.com.

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**Abbreviations and Acronyms**

AH	= arrested heart
BH	= beating heart
CABG	= coronary artery bypass graft surgery
CPB	= cardiopulmonary bypass
CT	= computed tomography
CTA	= computed tomography angiography
DX	= diagonal branch
ITA	= internal thoracic artery
LAD	= left anterior descending artery
OM	= obtuse marginal branch
PCI	= percutaneous coronary intervention
RCA	= right coronary artery
RITA	= right internal thoracic artery
SVG	= saphenous vein graft
TECAB	= totally endoscopic coronary artery bypass
ThoraCAB	= CABG completed through lateral thoracotomy

this retrospective study. Two hundred forty-one patients were considered candidates for BH TECAB between July 2004 and June 2007 at Alliance Hospital, Odessa, Texas (currently known as Odessa Regional Medical Center). Two hundred fourteen patients (111 male and 103 female) successfully underwent BH TECAB. The mean age was 67.9 ± 11.8 years (range, 35 to 91). Preoperative risk factors are listed in Table 1. Single-, double-, and triple-vessel BH TECAB was performed in 139 (65%), 68 (32%),

*Table 1. Patient Demographics and Preoperative Characteristics (n = 214)*

Characteristic	Mean ± SD (Range)	Percent
Male	111	52
Female	103	48
Age, years	67.9 ± 11.8 (35-91)	
Body mass index, kg/m <sup>2</sup>	30.7 ± 7.6 (17-47)	
Smoking	86	40.2
Hypertension	180	84.1
Diabetes mellitus	79	37
Family history of coronary artery disease	135	63.1
Dyslipidemia	71	33.2
Myocardial infarction	72	15
Arrhythmia	18	8.4
Cerebrovascular disease	30	14
Peripheral vascular disease	21	9.8
Chronic renal failure	6	2.8
Chronic obstructive pulmonary disease	11	5.1
Angina	182	85
Reoperations	8	3.7
Left ventricular ejection fraction	53.87 ± 9.07 (20-80)	

*Table 2. Revascularization Schemes*

Revascularization	Number (%)
Single-vessel TECAB, n = 139	
LITA-LAD	117 (84)
RITA-RCA	9 (7)
LITA-OM	8 (6)
LITA-DX	3 (2)
RITA-DX	2 (1)
Double-vessel TECAB, n = 68 (%)	
LITA-OM, RITA-LAD	27 (40)
LITA-LAD, RITA-DX	19 (28)
LITA sequential DX and LAD	7 (10)
LITA-DX, RITA-LAD	3 (4)
LITA-LAD, RITA-RCA	3 (4)
LITA-LAD, T-graft RITA-OM	3 (4)
LITA-RB, RITA-LAD	2 (3)
LITA sequential proximal and distal LAD	2 (3)
LITA-LAD, RITA-OM	1 (1)
LITA sequential mid and distal LAD	1 (1)
Triple-vessel TECAB, n = 7 (%)	
LITA sequential DX and OM, RITA-LAD	2 (29)
LITA sequential OM1 and OM2, RITA-LAD	1 (14)
LITA sequential ramus and OM1, RITA-LAD	1 (14)
LITA sequential DX1 and DX2, RITA-LAD	1 (14)
LITA-DX2 composite graft SVG-LAD, RITA-DX1	1 (14)
LITA-DX, Y-graft SVG-OM, RITA-LAD	1 (14)

DX = diagonal branch; LAD = left anterior descending; LITA = left internal thoracic artery; OM = obtuse marginal branch; RB = ramus branch; RCA = right coronary artery; RITA = right internal thoracic artery; SVG = saphenous vein graft; TECAB = totally endoscopic coronary artery bypass.

and 7 (3%) patients, respectively. In all, 296 grafts were constructed in 214 patients, with an average of 1.4 ± 0.5 grafts per patient (range, 1 to 3). Two hundred ninety-four bypass conduits were single ITA or bilateral ITA. In 2 patients, saphenous vein graft (SVG) was used in a composite fashion (1 patient) or Y fashion (1 patient). The right ITA (RITA) was used as a free graft in a T or Y fashion in 4 patients. An intracoronary shunt was used in a total of 12 of 296 coronary anastomoses (4%). Detailed revascularization schemes are listed in Table 2.

Fifty patients (23.4%) underwent planned hybrid coronary revascularization. Of these 50 patients, 11 (22%) presented with acute coronary syndrome and underwent urgent percutaneous coronary intervention (PCI) followed by elective BH TECAB; and the remaining 34 patients (68%) had planned PCI after BH TECAB. Simultaneous planned hybrid coronary revascularization was performed in 5 patients (10%). The BH TECAB could not be performed in 27 of 241 patients (11.2%) for the reasons listed in Table 3. Of these, 10 (4.1%) were excluded intraoperatively and 17 (7.1%) required intraoperative conversion. The CABG was completed through a lateral thoracotomy (ThoraCAB) in 26 patients and a median sternotomy in 1 patient.

Table 3. Intraoperative Conversion and Exclusion (n = 241)

Reasons	Number (%)
Intraoperative exclusion	10 (4)
Intramyocardial LAD	6
Less than 3cm intra thoracic space	2
Pleural adhesions	2
Conversion to minithoracotomy	16 (6.6)
Less than 1 mm size of LAD	4
Intolerance to single lung ventilation + hemodynamic instability	4
Hemodynamic instability	2
Lateral rotation of heart	2
Intolerance to ischemia + arrhythmia	1
Suspected dissection of LIMA to OM graft	1
Tension RIMA to LAD graft	1
Heavily calcific and fragile coronary artery with bleeding anastomotic site	1
Conversion to sternotomy	1 (0.4)
Revision of grafts due to spasm	1
Cases completed successfully	214

LAD = left anterior descending artery; LIMA = left internal mammary artery; OM = obtuse marginal artery; RIMA = right internal mammary artery.

#### Inclusion/Exclusion Criteria

Patients with single or multivessel coronary artery disease were considered for BH TECAB with or without planned hybrid coronary revascularization. Target coronary arteries for BH TECAB included the left anterior descending (LAD), diagonal branch 1 or 2 (DX1, DX2), ramus branch, obtuse marginal branch 1 or 2 (OM1, OM2), and the right coronary artery (RCA). Patients with prior thoracic surgery, history of thoracic trauma with chest tube insertion, empyema, or pleural effusion, severe chronic obstructive pulmonary disease and inability to tolerate one-lung anesthesia, acute myocardial infarction, acute cerebrovascular accident, and unstable hemodynamics were excluded preoperatively. Relative contraindications included body mass index of greater than 35 kg/m<sup>2</sup> and prior radiation therapy to the chest wall.

#### Surgical Technique

Routine hemodynamic, electrocardiography, and continuous pulse oximetry was used for intraoperative monitoring. Single-lung ventilation was achieved by the use of a double-lumen endotracheal tube. External defibrillator

patches were placed on the interscapular area and anterior chest wall. Continuous intravenous nitroglycerin drip was used during the procedure and for 24 hours postoperatively. Intravenous lidocaine infusion was used during pericardiotomy and coronary anastomosis to minimize ventricular arrhythmias.

Patients were placed in a supine position with the operative side elevated from 15 to 30 degrees. The camera and two instrument arm ports were placed 3 to 5 cm medial to the anterior axillary line in the third, fifth, and seventh intercostal spaces based on the body habitus. Port positions were based on revascularization schemes (Fig 1). Carbon dioxide insufflation was initiated, and the intrathoracic pressure was maintained between 10 to 15 mm Hg. Skeletonized single ITA or bilateral ITA was harvested from the first rib to the distal bifurcation. The prepericardial and mediastinal fat was dissected, followed by anterior pericardiotomy. Pericardiotomy was done 2 cm posterior to the phrenic nerve in patients requiring grafts to the OM branches.

After establishing the feasibility of completing the procedure as TECAB, a stabilizer port was inserted in the subcostal region with endoscopic guidance. Heparin, 2 mg/kg, was given intravenously to achieve an activated clotting time of more than 300 s, which was monitored every 30 minutes for satisfactory anticoagulation.

The distal end of the ITA was partially spatulated, and five S18 U-Clips (Medtronic, Minneapolis, MN) were passed through the ITA from the heel to the apex (Fig 2). For a sequential graft, the proximal ITA arteriotomy was prepared in the same manner. The Y-graft construction with RITA as a free graft was achieved by anastomosing RITA to the proximal LITA using S18 U-Clips.

An Octopus TE stabilizer (Medtronic) was used in 199 patients; and in 15 patients, an EndoWrist stabilizer (Intuitive Surgical, Sunnyvale, CA) mounted on the fourth arm of the da Vinci-S system was used. A fifth port was placed posterior at the mid axillary line between the camera and left instrument arm ports for stabilization of the OM branches in 10 patients. After securing proximal and distal control of the target coronary artery with two silastic saddle loops (Quest Medical, Allen, TX), the previously placed U-Clips in ITA were passed sequentially through the appropriate coronary artery wall, and the artery was parachuted down. Additional U-Clips were placed to complete the anastomosis. In the event of a sequential anastomosis, a side-to-side anastomosis between ITA and coronary artery was performed first. Flow

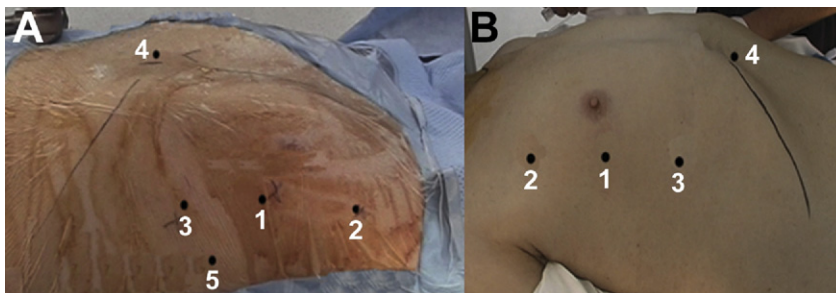
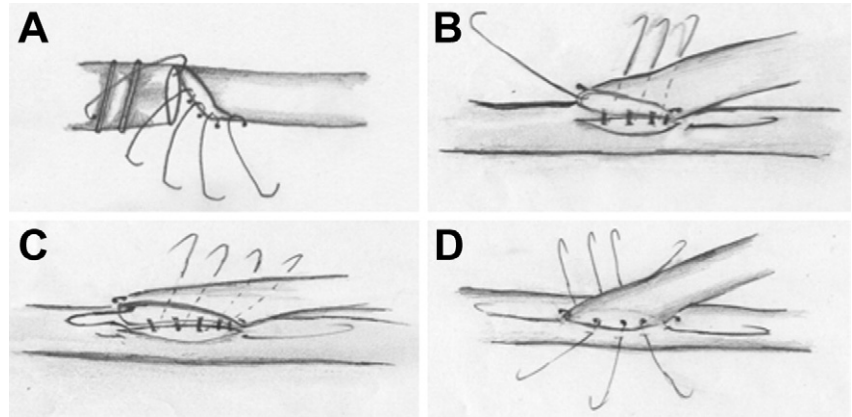


Fig 1. (A) Left-side ports and (B) right-side ports for beating-heart totally endoscopic coronary artery bypass.

Fig 2. Internal thoracic artery (ITA) preparation and anastomosis with U-Clips (Medtronic, Minneapolis, MN). (A) Insertion of 5 U-Clips with internal mammary artery (IMA) attached to chest wall. (B) Inserting previously placed U-Clips through coronary arteriotomy. (C) Parachuting IMA onto coronary artery. (D) All U-Clips inserted.



measurement was done in 129 patients using an endoscopic MediStim VeriQ flow meter (MediStim AS, Oslo, Norway). The appropriate dose of protamine was given to reverse the heparin after completion of all anastomoses.

Eighty percent of patients (172 of 214) underwent computed tomography angiography (CTA) or conventional angiography within 3 months from the time of surgery. Of all grafts performed, 239 of 296 (81%) were studied. A 16-slice CTA was done in 123 patients between July 2004 and December 2006; and 10 patients underwent a 64-slice CTA from January 2007 to June 2007. The total number of grafts studied by CTA was 182 of 239 (76%). Multiplanar three-dimensional reconstruction was done to assess gross graft patency, stenosis within the graft, and the target coronary artery beyond the anastomosis (Fig 3). In 39 patients, 57 of 239 grafts (24%) were studied by conventional angiography postoperatively during planned hybrid revascularization

(Fig 4). A FitzGibbon score was used in patients who underwent conventional angiography.

Clinical follow-up using a questionnaire was done for all patients to assess any major adverse cardiac event in relation to the revascularized target coronary arteries. The questionnaire included occurrence of myocardial infarction, repeat angiography, PCI, or surgical intervention in the grafted coronary artery and mortality.

### Results

There was no myocardial infarction, operative mortality, or conversion to CPB. One patient (0.5%) who underwent BH TECAB to LAD followed by planned simultaneous hybrid coronary revascularization had a CVA after the procedure. Two patients (1%) required reexploration for postoperative bleeding. Eight patients (4%) remained on

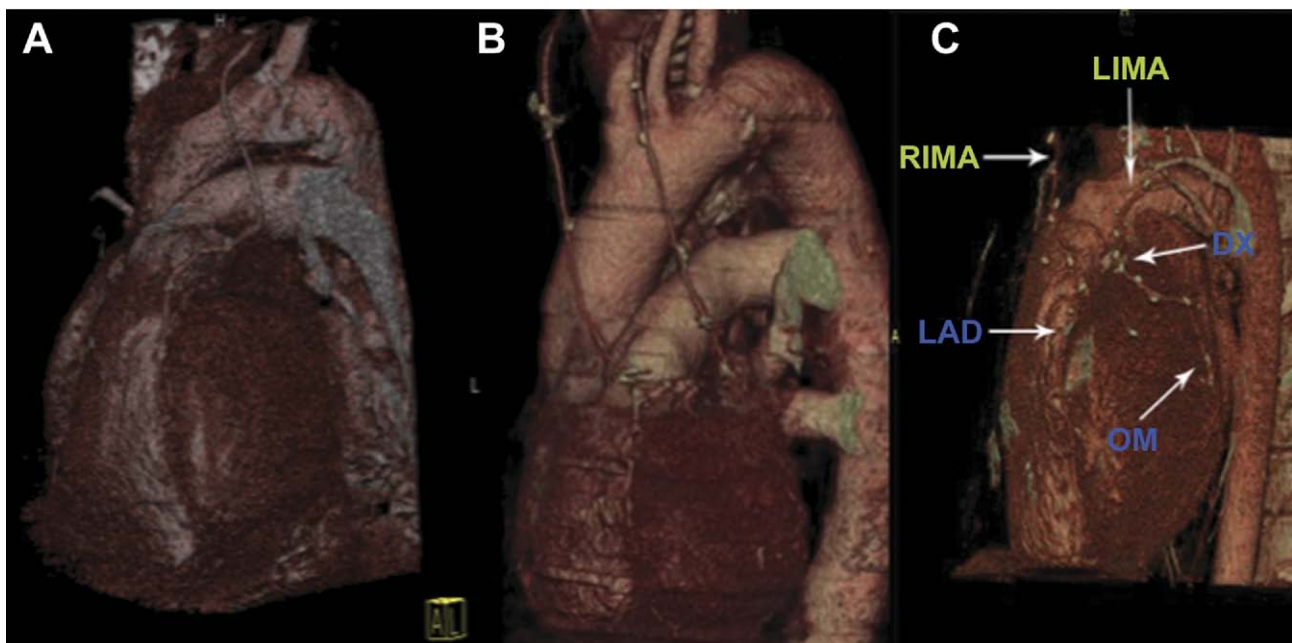


Fig 3. Computed tomography angiography of single and multivessel beating-heart totally endoscopic coronary artery bypass. (A) Left internal mammary artery (LIMA) to left anterior descending artery (LAD); (B) Right internal thoracic artery (RITA) to LAD, left internal thoracic artery (LITA) to obtuse marginal branch (OM); (C) RITA to LAD, LITA to diagonal branch (DX) to OM.

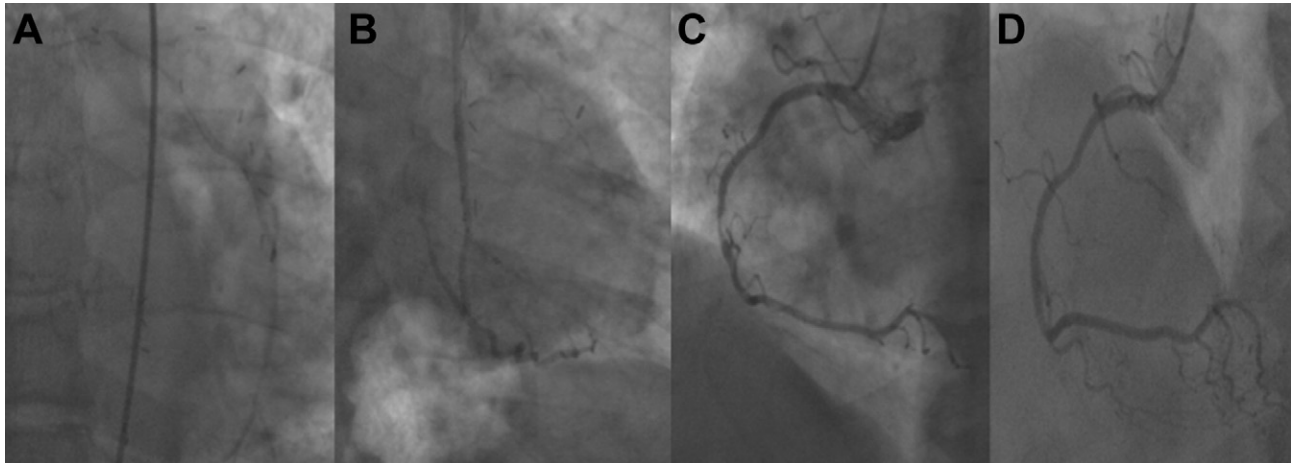


Fig 4. Angiography results of left anterior descending artery (LAD) and obtuse marginal branch (OM) grafts during percutaneous coronary intervention (PCI) to right coronary artery (RCA [hybrid]). (A) RITA to LAD; (B) LITA to OM; (C) pre-PCI to RCA; (D) post-PCI to RCA.

ventilatory support for more than 48 hours. Prolonged ventilation did not correlate with longer operative times. One patient (0.5%) had a transient rise in serum creatinine after intravenous ketorolac tromethamine that was resolved after discontinuation of the drug. New-onset atrial fibrillation was noted in 22 patients (10%).

The intraoperative data are listed in Table 4. Two hundred eighty-six ITAs were used to construct 294 arterial grafts. All ITAs were harvested without any incidence of injury and were found to be suitable for BH TECAB. All except 5 patients (2.3%) received in-situ ITA grafts. In these 5 patients, RITA was used as a Y-graft in 3. In 1 patient, a small segment of SVG was used to extend LITA, and in another patient it was used as a Y-graft to the DX 1.

One patient had diffuse ischemic changes at the end of two-vessel BH TECAB (RITA to RCA and LITA to LAD) and

required intraoperative conversion to sternotomy for resuscitation. Severe spasm of BITA just proximal to the anastomotic sites was noted. Both anastomoses were revised off pump after transecting the spastic segments of BITA. Pre-discharge CTA in this patient showed patent grafts.

Intraoperative flow measurement was done in 129 patients. In 1 patient with a LITA sequential graft to LAD and DX, absence of flow between DX and LAD was noted during flow measurement. Transection of the distal LITA showed an intraluminal hematoma causing the occlusion. The occluded segment was removed after clipping the distal end of LITA. A segment of SVG to extend LITA was anastomosed to a new arteriotomy site on LAD, with the procedure was completed as BH TECAB.

Two hundred thirty-nine grafts (81%) were studied by CTA (182) and conventional angiography (57). All 182

Table 4. Intraoperative Outcomes (n = 214 Completed Cases)

Intraoperative Outcome	Single Vessel Mean/SD [Range]	Double Vessel Mean/SD [Range]	Triple Vessel Mean/SD [Range]
Exclusion	6 (2.5%)	4 (1.6%)	0
Conversion	5 (2.1%)	12 (5%)	0
Operative time, minutes	177.3 ± 52.5 [84–466]	318.5 ± 97 [161–616]	523.6 ± 112.3 [337–682]
SITA takedown, minutes	34.5 ± 13.2 [16–110]	33.2 ± 8.5 <sup>a</sup> [23–51]	NA
BITA takedown, minutes	NA	63.7 ± 14.5 [40–110]	65.9 ± 13.1 [44–82]
Occlusion time/graft, minutes	20.3 ± 9.9 [9–64]	21.32 ± 13.19 [12–73]	24 ± 8.1 [13–50]
Anastomotic time/graft, minutes	12.5 ± 5.5 [6–38]	13 ± 4.4 [7–27]	13.1 ± 3.9 [8–27]
Pulsatility index	3.6 ± 3.5	3.8 ± 1.8	3.3 ± 1.4
Mean flow, mL/minute	18.6 ± 13.7	27.7 ± 19.3	26.2 ± 18.9
Hybrid	32 (15%)	16 (7.4%)	2 (1%)
Mortality	0	0	0

<sup>a</sup> Left internal thoracic artery sequential to left anterior descending artery and diagonal artery.

BITA = bilateral internal thoracic artery; SITA = single internal thoracic artery.

grafts (100%) studied by CTA were found to be grossly patent. There was adequate visualization of the grafts, anastomotic sites, and the target coronary artery distal to the anastomosis. In the hybrid coronary revascularization group, conventional angiography was performed postoperatively during planned PCI in 39 patients, and 57 grafts were studied. Fifty-six grafts (98.2%) were found to have a Thrombolysis in Myocardial Infarction (TIMI) flow grade 3 and FitzGibbon A score. One patient (1.8%) for planned hybrid coronary revascularization, LITA to LAD graft and PCI to RCA, was found to have an acute occlusion of a LIMA to LAD graft. This patient had presented with myocardial infarction and a totally occluded LAD preoperatively. During BH TECAB, the native LAD was found to be very short, the lumen was less than 1 mm in size and had a fresh intraluminal thrombus that had to be extracted.

During the clinical follow-up period of  $528 \pm 697$  days, patients were reviewed for occurrence of major adverse cardiac effects. Two patients with double-vessel BH TECAB had recurrence of angina at 2 and 3 months postoperatively. In the first patient, who underwent sequential LITA anastomosis to proximal and distal LAD, a repeat coronary angiography showed occluded LITA segment to distal LAD. A CABG through a ThoraCAB with an SVG jump graft from proximal LITA to distal LAD was then performed. During the follow-up period, the patient remained free of angina, and follow-up CTA after 3 weeks showed patent distal LAD graft as well. The second patient who had two-vessel BH TECAB with RITA to LAD and LITA to OM was found to have spasm of the distal RITA during conventional angiography and underwent PCI to reopen RITA. The third patient with LITA to LAD BH TECAB presented with chest discomfort 1 year postoperatively. The conventional coronary angiography showed new occlusive disease in DX 1 and OM 1. A ThoraCAB approach using SVG to DX 1 and OM 1 was performed in this patient. All 3 patients (1.4%) requiring reintervention have remained free of major adverse cardiac events during the follow-up period. Thus, the overall clinical freedom from graft failure and reintervention was 98.6%.

#### *Limitations of the Study*

This report represents a single-center, single-surgeon, nonrandomized retrospective analysis of a selected group of patients who underwent BH TECAB technique for the treatment of coronary artery disease. There was no core laboratory evaluation and reporting of CTA or conventional angiography that was done in 172 of 214 patients (80%). Qualitative assessment of the anastomotic site remains a limitation of CTA. There was no routine angiographic follow-up beyond the initial studies.

#### **Comment**

This report represents the largest experience of successfully completed BH TECAB utilizing da Vinci robotic assistance. Although in a recent editorial, Damiano [20] reported that robotic assistance is not optimal for surgical treatment of coronary artery disease, we were able to

demonstrate safety, efficacy, and excellent early graft patency in this group of patients.

We were able to complete the procedure as BH TECAB in 214 of 241 patients (89%). In the other 27 patients (11%), off-pump CABG was completed through a lateral thoracotomy (26 patients) and sternotomy (1 patient). Ten patients (4%) were intraoperatively excluded because of extensive pleural adhesions (2 patients), suboptimal intrathoracic space (2 patients), and intramyocardial LAD (6 patients). Dense and extensive pleural adhesions and an intrathoracic space of less than 3 cm made the endoscopic approach technically difficult. In BH TECAB, the authors considered it unsafe to dissect a deep intramyocardial LAD without tactile feedback associated with the robotic system. The intraoperative exclusion or conversion was not considered as failure of therapy as all these patients would have required an open approach. The intended target vessel revascularization with or without hybrid revascularization was achieved in all 214 patients (100%) undergoing BH TECAB.

Interrupted anastomosis with surgical U-Clips has been shown to be more compliant than those performed with running sutures on intravascular ultrasonography [21]. The interrupted anastomosis also reduces the possibility of purse stringing of a continuous suture and helps to overcome the lack of tactile feedback inherent with the da Vinci surgical system.

Optimum blood pressure will minimize occurrence of ischemia in the majority of the target coronary arteries with significant stenosis. An intracoronary shunt may be used to facilitate longer anastomotic time or in instances of less than 80% to 90% stenosis in a large proximal LAD and main RCA. A three-dimensional magnified view and EndoWrist instruments allow for very precise placement of the U-Clips. These steps facilitated a good quality anastomosis with an average anastomotic time of 13 minutes.

Multislice computed tomography was used to assess gross graft patency. This examination is easily tolerated and accepted by the patients. The radiologist and or the cardiologist evaluated the entire length of ITA graft, the anastomotic site, and visualization of the target coronary artery beyond the anastomosis. The 64-slice CT offers better spatial and temporal resolution as compared with 16-slice CT [22]. Patients with small distal target vessel, obesity, and motion producing artifacts may have less than optimum visualization of target vessels beyond the anastomosis. The three-dimensional reconstruction of CTA images allows for a multi-angle evaluation of grafts as well as external anastomotic site. In 4% to 10% of CTAs, the evaluation may be limited because of technical or patient reasons [23].

In this group of patients, our early graft patency of 99% and clinical freedom from graft failure of 98.6% over a mean follow-up period of  $528 \pm 697$  days are results comparable to numerous reported graft patency results for conventional CABG, off-pump CABG, and minimally invasive CABG. Of 42 of 214 patients (20%), angiography could not be performed in 7 patients owing to renal failure. In the remaining patients, other reasons included patient's refusal, institutional scheduling, and postdischarge access to CTA because of geographical location. In a review article by Mack and

coworkers [11], early (<1 month) LITA graft patency between conventional CABG and minimally invasive CABG ranged between 94% and 99%. In his own series of 103 patients, angiography done in 97% of patients, intraoperatively (38%) and immediately postoperatively (62%), Mack reported 99% graft patency; 8 patients had FitzGibbon B score, with 3 patients requiring revision of grafts [7]. De Cannier and associates [16] reported a multicenter European experience of 38 of 164 patients who underwent conventional angiography during hybrid coronary revascularization, with a graft patency of 92% and 97% overall efficacy of the BH TECAB group. In the prospective multicenter trial for AH TECAB, Argenziano and colleagues [19] reported an overall freedom from reintervention or angiographic failure of 91%. Somewhat lower than expected graft patency in other published studies of less invasive CABG approaches could be due to early evolution and the learning curve.

In conclusion, BH TECAB offers a safe, efficacious, and less invasive option for selected groups of patients with single and multivessel coronary artery disease with excellent early clinical and graft patency results. A hybrid coronary revascularization strategy for selected patients could offer complete revascularization. Early angiographic graft patency of 99% and clinical freedom from graft failure of 98.6% during the follow-up period appears to be excellent. These results were achieved by following a methodical protocol and dedicated commitment by the surgical team and the institution. Long-term clinical and angiographic follow-up and wider adoption of the technology is necessary to further evaluate this promising technique.

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## DISCUSSION

**DR THOMAS J. BERGER** (Arden, NC): Did any of the grafts that were patent have significant stenoses, over 50% stenoses, at the anastomotic site?

**DR SRIVASTAVA:** No.

**DR T. BRUCE FERGUSON** (Greenville, NC): Tell us about your learning curve for this. How did you start out and how long did it take you to get to 30 minutes per IMA and 20 minutes per anastomosis?

**DR SRIVASTAVA:** I think that's a great question. The scope of our report did not allow some of these discussions. We were doing a fair number of thoracotomy approaches and probably had done 600 or so ThoraCAB by the time we got onto the robotic platform. So it was easy for us to take the internal thoracic arteries down and use them through the thoracotomy approach.

As far as the ITA takedown times, it took us relatively small number of cases, I would say, probably 10 or 15 mammary takedowns. After 5 or 6 as pedicle, we switched to total skeleton-

ization and found out it really did not take additional harvesting time. If anything, it was safer because you don't run into a bleeding situation whereby the branch retracts into the muscle pedicle and then you're struggling.

In terms of getting onto the beating-heart platform, we were part of the initial trial of the arrested heart whereby we were required to, in fact, take 15 to 20 mammaries down whereby you can get your timings to about 30 to 45 minutes or so. Then we did pig heart anastomosis just to get comfortable with use of the da Vinci system as we recognized that there is no tactile feedback, so you almost have to develop a visual feedback. And I think once the stabilizers came along, we launched beating-heart TECAB. I would say the learning curve is very difficult to pinpoint, and will vary from surgeon to surgeon, but maybe 20 some cases or so.

**DR Y. JOSEPH WOO** (Philadelphia, PA): Can you describe the extent of your pericardiectomy and cardiac positioning for grafting the OMs from this approach.

**DR SRIVASTAVA:** The pericardiectomy for the obtuse marginal branch is done about 2 cm posterior to the phrenic nerve and extended parallel to the phrenic nerve. Obtuse marginal 1 and 2 are accessible through this approach. The best part of this approach is that there is absolutely no displacement of the heart. You take your camera and the instruments to the vessel instead of bringing the target vessel into your view as we do in open cases. Because of this, we have no hemodynamic instability in these patients.

**DR VALLUVAN JEEVANANDAM** (Chicago, IL): Could I just ask you to elaborate on why patients were converted. And also, what criteria were used to exclude patients from this procedure?

**DR SRIVASTAVA:** There were a variety of reasons. In 6 patients, the LAD was intramyocardial. And although we can handle subepicardial LAD, a deep intramyocardial LAD on a beating heart in an endoscopic setting, I feel it is not safe to dissect, and we would convert them to a left minithoracotomy.

Other reasons included patients with severe pulmonary insufficiency. Although up to a point these patients will tolerate

one-lung anesthesia, we found that in the later part of surgery there were oxygenation problems, particularly in multivessel cases. I think 2 patients had severely calcific target vessels. If you know this ahead of time, it is probably not a good idea to do them endoscopically.

In terms of preoperative exclusions, patients with acute myocardial infarction, acute cerebrovascular accident, known severe pulmonary insufficiency, prior thoracic surgery, and extreme obesity should be excluded.

**DR SOON J. PARK** (Rochester, MN): Can you elaborate a little bit more on pros and cons of minimally invasive CABG versus totally endoscopic approach? I think all of us believe that the da Vinci mammary takedown is a wonderful technique in the patients who needs a single-vessel LIMA to LAD surgery.

**DR SRIVASTAVA:** Yes, in fact, we did several hundred minimally invasive CABG and ThoraCAB before getting onto the TECAB platform. And I think these are great operations. But our goal has been to advance to a less invasive approach through ports. One has limitation on the number of vessels grafted through a minimally invasive CABG approach. Operative times for our single-vessel TECAB average around 1 and a half to 2 hours. So we're able to do the same thing in a closed chest manner.

TECAB allows us to do multivessel revascularization with bilateral ITAs in a closed chest manner.

**DR PARK:** No, I agree with the doability and it's good that we could do that. I want to know whether we can move beyond that. Doing TECAB, is it truly better than minimally invasive CABG, for patients? So I think whether patient comfort, length of stay, other things ought to be measured, because I believe the da Vinci takedown of mammary is wonderful and putting it to LAD is a great thing. And so I was wondering whether you had data beyond doability?

**DR SRIVASTAVA:** We have not actually compared the quality of life issues in terms of pain and functional recovery and length of stay between the two groups.