Multivessel beating heart robotic myocardial revascularization increases morbidity and mortality

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Objective: The vast majority of reports describing beating heart robotic myocardial revascularization (total endoscopic coronary artery bypass) contain very small numbers of patients undergoing single-vessel bypass. We present a large series of patients undergoing multivessel total endoscopic coronary artery bypass.

Methods: We performed a retrospective clinical review of 106 patients undergoing total endoscopic coronary artery bypass (72% multivessel) at 1 institution by 1 experienced cardiac surgeon/physician assistant team. These results were compared with the expected clinical outcomes from conventional coronary artery bypass grafting calculated using the Society of Thoracic Surgeons risk calculator.

Results: Of the 106 patients, 1% underwent quadruple total endoscopic coronary artery bypass, 8% triple, 63% double, and 28% single. The emergent conversion rate for hemodynamic instability was 6.6%. The postoperative renal failure rate (doubling of baseline serum creatinine or dialysis required) was 7.5%. Overall, 23 patients (21.7%) exhibited at least 1 major morbidity/mortality (4 deaths). The number of vessels bypassed (single/double/triple/quadruple) correlated positively with the surgical/operating room time, the lung separation time, vasoactive medication use, blood use, a postoperative ventilation time longer than 24 hours, intensive care unit length of stay, and hospital length of stay. An increased surgical time was significantly associated with major morbidity ($P = .011$) and mortality ($P = .043$). A comparison with the Society for Thoracic Surgeons expected outcomes revealed a similar hospital length of stay but an increased incidence of prolonged ventilation ($P = .003$), renal failure ($P < .001$), morbidity ($P = .045$), and mortality ($P = .049$).

Conclusions: Our results suggest that addressing multivessel coronary artery disease using total endoscopic coronary artery bypass offers no obvious clinical benefits and might increase the morbidity and mortality. (J Thorac Cardiovasc Surg 2012;143:1056-61)

Minimally invasive surgery has potential benefits (facilitated rehabilitation/discharge) but also has potential risks (increased complexity).¹ Total endoscopic coronary artery bypass (TECAB) is performed using a robotic system that allows the surgeon to operate through a series of small thoracic incisions. Such surgery was first performed in humans in 1998,² ushering in a new era in cardiothoracic surgery.^{3,4}

Most reports using robotic technology during cardiac surgery have done so with some form of minithoracotomy and/or cardiopulmonary bypass (CPB), with or without myocardial arrest.⁵⁻¹⁰ The few reports describing TECAB (without minithoracotomy/CPB) have contained small numbers of patients undergoing single-vessel coronary artery bypass

grafting (CABG).¹¹⁻¹⁶ We report our experience with multivessel TECAB and compared the outcomes with the expected outcomes from conventional CABG calculated using the Society of Thoracic Surgeons (STS) risk calculator. The use of robotic assistance in cardiac surgery remains controversial.¹⁷⁻²⁰ Our analysis has helped to clarify the potential benefits and risks associated with this technology.

METHODS

The University of Chicago institutional review board approved the present study and informed consent was waived. We retrospectively reviewed the records of all 106 patients who had undergone TECAB from July 2007 to February 2009 at our institution. One cardiac surgeon/physician assistant (CS/PA) team performed every TECAB, with 1 of 6 experienced cardiac anesthesiologists. All were scheduled for off-pump beating heart 1- to 4-vessel TECAB using the da Vinci robotic system (Intuitive Surgical, Sunnyvale, Calif). Clinically important right coronary artery disease thought amenable to percutaneous coronary intervention was scheduled for stent placement after TECAB (before hospital discharge).

After application of standard monitors, anesthesia was induced with intravenous midazolam, fentanyl, propofol, and vecuronium, and the patient was intubated with a left-sided double-lumen endotracheal tube. A radial arterial line and a right internal jugular vein introducer were inserted. A pulmonary artery catheter and transesophageal echocardiographic probe were used in all patients. External defibrillation patches were appropriately placed. Surgery was performed with single-lung ventilation (when

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Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CPB	= cardiopulmonary bypass
CS/PA	= cardiac surgeon/physician assistant
euroSCORE	= European System for Cardiac Operative Risk Evaluation
HLOS	= hospital length of stay
ICU	= intensive care unit
LAD	= left anterior descending
LIMA	= left internal mammary artery
pRBCs	= packed red blood cells
RIMA	= right internal mammary artery
STS	= Society of Thoracic Surgeons
TECAB	= total endoscopic coronary artery bypass

requested by the surgeon for exposure), and the patient was positioned supine. Intravenous nitroglycerin (5 µg/min) and lidocaine (1 mg/min) were administered to attenuate coronary artery spasm and prevent reperfusion arrhythmias.

Surgery was performed as previously described by Srivastava and colleagues.¹⁷ After single-lung ventilation was achieved, intercostal incisions were made (variations determined from revascularization schemes). Carbon dioxide was used to insufflate the chest (usually 10–15 mm Hg), and the robotic arms were placed. With the CS at the console and the PA scrubbed and in the field controlling the robotic instrumentation, the left internal mammary artery (LIMA) and, if needed, the right internal mammary artery (RIMA) were harvested. Pericardiotomy was performed, the target sites were identified, and a cannula was inserted through a subcostal port. Systemic intravenous heparinization (100 U/kg) was achieved (target activated clotting time, 250 seconds). A myocardial stabilizer was used to minimize movement of the target vessels. When all anastomotic sites appeared satisfactory, intravenous protamine (10 mg/kg) was administered. A Doppler probe was used to assess the flow measurements. A chest tube drain was inserted behind the left lung, followed by gentle reinflation of the left lung. The thoracic incisions were then surgically closed.

The patients were transported to the intensive care unit (ICU), usually with a single-lumen endotracheal tube or spontaneously ventilating after extubation in the operating room (OR). The goal was extubation 2 to 4 hours after ICU arrival. Mobilization by physical therapists occurred on the second postoperative day (POD), and the lines were removed. The patients were transferred to the rehabilitation floor when clinically appropriate.

The preoperative records (anesthesia, surgery) were reviewed for demographic data, comorbid conditions, number of diseased vessels, and severity of ventricular dysfunction. The OR records (surgery, nursing, perfusion) revealed the number of grafts performed, surgical time, and OR time. The anesthesia records provided the total lung separation time, use/nonuse of vasopressors (continuous infusion of dobutamine, epinephrine, neosynephrine, norepinephrine, and/or vasopressin), urine output, and any clinical problems. The postoperative records (ICU, floor notes) were reviewed for the interval to extubation, ICU length of stay (ILOS), hospital length of stay (HLOS), morbidity, and mortality.

The logistic version of the European System for Cardiac Operative Risk Evaluation (euroSCORE) was used to calculate the predicted perioperative mortality for each patient.²¹ Postoperative renal failure was defined as the doubling of the preoperative serum creatinine or new requirement for

postoperative dialysis. Bleeding was considered “excessive” if transfusion of 6 or more units of packed red blood cells (pRBCs) occurred within 24 hours after the surgical incision. Major morbidity was defined as ventricular trauma, emergent conversion, excessive bleeding, renal failure, acute graft failure, incomplete revascularization (inability to perform surgical bypass, inability to insert a coronary stent, or unaddressed disease found by postoperative angiography), or gross stroke.

The demographic, disease, and surgical characteristics and outcomes are summarized using the mean, standard deviation, and range or frequency counts and percentages. Comparisons across the groups were made using the Wilcoxon rank-sum test for continuous variables or chi-square tests (or Fisher’s exact tests, as appropriate) for categorical variables. When comparing the 2 series of patients, 2-sample *t* tests were used for continuous variables because the raw data from Srivastava and colleagues¹⁷ were unavailable. The correlations between the continuous or ordinal (eg, number of vessels bypassed) were assessed using Spearman rank correlation coefficients. The Cochran-Armitage trend test was used to examine whether the proportion of patients with morbidity, mortality, pRBC use, vasoactive medication use, or prolonged ventilation increased with an increasing number of vessels bypassed. Logistic regression models were fit to assess the likelihood of certain outcomes (eg, pRBCs or vasoactive medication use) stratified by the surgical time. In addition, 1 degree of freedom goodness of fit chi-square tests were performed to compare the number of patients with a particular outcome in the present series with that expected according to the STS risk calculator. A 2-sided *P* < .05 was considered statistically significant. No adjustments for multiple comparisons were made. All analyses were performed using Stata, version 11 (StataCorp, College Station, Tex).

RESULTS

From July 2007 to February 2009, 106 patients underwent TECAB. The preoperative demographic and intraoperative data are listed in Table 1.

A total of 39 patients (36.8%) experienced morbidity or mortality (Table 2). Some patients were counted more than once in Table 2 (eg, emergent conversion with postoperative pneumothorax). One intraoperative RIMA-obtuse marginal tear resulted in cardiac arrest and emergent thoracotomy (with CPB) for revision. The patient then returned to the OR the next day for additional revision (median sternotomy). A patient with right ventricular trauma returned to the OR for repair of bleeding from the LIMA-left anterior descending (LAD) anastomosis and right ventricular tear site. Left ventricular trauma in 1 patient was caused by the myocardial stabilizer and required emergent sternotomy. Four patients underwent elective intraoperative conversion by way of a thoracotomy (not considered a morbidity). All required elective conversion because of surgical technical difficulty. Seven patients underwent emergent perioperative conversion because of hemodynamic instability. Five required sternotomy (2 intraoperative, 3 requiring a return to the OR) and 2 required thoracotomy (both intraoperative). Of the 3 intraoperative CPB initiations, 2 were emergent. The 1 elective CPB initiation (closed chest) was required for hemodynamic instability (the patient also experienced postoperative stroke). Eight patients developed postoperative renal failure, of whom, 3 required dialysis. Seven patients had incomplete

TABLE 1. Preoperative demographics/intraoperative data (n = 106)

Variable	Value
Age (y)	
Mean $\pm$ SD	63.6 $\pm$ 11.5
Range	38–87
Female gender (n)	27 (25.5)
Body mass index (kg/m ²)	
Mean $\pm$ SD	30.4 $\pm$ 6.2
Range	17.6–58.0
Hypercholesterolemia (n)	78 (73.6)
Hypertension (n)	98 (92.5)
Diabetes mellitus (n)	36 (34.0)
History of smoking (n)	29 (27.4)
Peripheral vascular disease (n)	5 (4.7)
Cerebral vascular disease (n)	10 (9.4)
Preoperative creatinine >2.0 mg/dL (n)	2 (2.2)
Ejection fraction <50% (n)	24 (23.8)
Previous myocardial infarction (n)	30 (28.3)
Triple-vessel coronary artery disease (n)	76 (71.7)
Left ventricular ejection fraction (%)	
Mean $\pm$ SD	53.9 $\pm$ 13.0
Range	16–76
Repeat coronary artery bypass grafting (n)	2 (1.9)
euroSCORE	
Mean $\pm$ SD	3.2 $\pm$ 3.5
Range	0.9–24.4
“Low-risk” euroSCORE (<3) (n)	69 (65.1)
“Moderate-risk” euroSCORE (3–5) (n)	24 (22.6)
“High-risk” euroSCORE ($\geq$ 6) (n)	13 (12.3)
Four-vessel TECAB (n)	1 (0.9)
Three-vessel TECAB (n)	8 (7.5)
Two-vessel TECAB (n)	67 (63.2)
One-vessel TECAB (n)	30 (28.3)
LIMA/RIMA (n)	55 (51.9)
Total surgical time (min)	
Mean $\pm$ SD	326 $\pm$ 139
Range	125–876
Total lung separation time (min)	
Mean $\pm$ SD	269 $\pm$ 123
Range	0–660
Total operating room time (min)	
Mean $\pm$ SD	451 $\pm$ 142
Range	240–1007
Total urine output (mL/kg/hr)	
Mean $\pm$ SD	0.7 $\pm$ 0.4
Range	0.1–2.0
Vasopressor infusion required (n)	55 (51.9)

Data in parentheses are percentages. euroScores calculated as described by Nashef et al.²¹ SD, Standard deviation; euroSCORE, European System for Cardiac Operative Risk Evaluation; TECAB, total endoscopic coronary artery bypass; LIMA/RIMA, left internal mammary artery/right internal mammary artery (dissection).

revascularization, and 3 experienced graft failure during the postoperative period (one 80% RIMA graft stenosis assessed through angiography; 2 required LIMA-LAD stent). Four returned to the OR for excessive bleeding (3 sternotomies and 1 thoracotomy).

TABLE 2. Morbidity/mortality

Period	Patients (n)
Intraoperative	
RIMA trauma	1
Ventricular trauma	2
Cardiac arrest	1
Emergent conversion	4
CPB initiation	3
Death	1
Postoperative	
New-onset atrial fibrillation	17
Pneumothorax	2
Renal failure	8
New-onset dialysis	3
Incomplete revascularization	7
Acute graft failure	3
IABP insertion	3
Cardiac arrest	1
Reintubation	2
Stroke	2
Excessive bleeding	7
Return to operating room	4
Death	3

RIMA, Right internal mammary artery; CPB, cardiopulmonary bypass; IABP, intra-aortic balloon pump.

Seven patients were extubated in the OR. Of the remaining 99, 86 were extubated within 24 hours of ICU arrival, and 13 were extubated more than 24 hours after ICU arrival. The mean ILOS was 2.3 days (range, 0–22), and the mean HLOS was 5.2 days (range, 2–24).

Of the 106 patients, 23 (21.7%) exhibited major morbidity. The surgical time for the patients with major morbidity was significantly longer than that for the patients without major morbidity (414 $\pm$ 191 minutes vs 302 $\pm$ 111 minutes, respectively, $P = .011$). The decrease in the major morbidity/mortality rates over time (ie, with more experience) was not statistically significant. The rate was 35% among the first 26 patients, 19% among the next 27 patients, 22% among the next 27 patients, and 12% among the last 26 patients (Cochran-Armitage trend test, $P = .071$).

Four patients died. The first was a 69-year-old woman (ejection fraction, 51%; euroSCORE, 3.79) scheduled for 2-vessel TECAB. Elective conversion (thoracotomy) was required. A LIMA-LAD graft was performed; however, the right coronary artery was not revascularized. Postoperative infarction (right coronary artery territory) required intra-aortic balloon pump insertion, and renal failure (dialysis) preceded death on POD 4. The second was a 58-year-old woman (ejection fraction, 40%; euroSCORE, 1.85) scheduled for 2-vessel TECAB. LIMA-obtuse marginal and RIMA-LAD grafts were performed. Ventricular fibrillation immediately after surgery led to emergent sternotomy/initiation of CPB. Additional revascularization was performed; however, this patient was unable to be weaned

TABLE 3. Comparison of revascularization groups (n = 106)

Variable	One-vessel TECAB	Two-vessel TECAB	Three/four-vessel TECAB	P value
Total patients (n)	30 (28)	67 (63)	9 (9)	
euroSCORE	3.3 ± 2.6	3.3 ± 3.9	1.7 ± 1.4	.144
Lung separation time (min)	174 ± 73*	283 ± 99	464 ± 136	<.001
Surgical time (min)	220 ± 102*	342 ± 100	564 ± 150	<.001
Operating room time (min)	346 ± 107*	466 ± 101	695 ± 160	<.001
Vasoactive medications (n)	11 (36.7)*	37 (55.2)	7 (77.8)	.019
pRBC use (n)	1 (3.3)	3 (4.5)	3 (33.3)	.021
Renal failure (n)	3 (10.0)	5 (7.5)	0 (0.0)	.364
Postoperative ventilation >24 h (n)	1 (3.3)	9 (13.4)	3 (33.3)	.018
ILOS (d)	1.7 ± 1.3	2.4 ± 3.0	3.6 ± 1.5	.002
HLOS (d)	4.2 ± 1.7*	5.3 ± 3.4	7.2 ± 3.3	.004
Major morbidity (n)	7 (23.3)	12 (17.9)	4 (44.4)	.522
Mortality (n)	1 (3.3)	2 (3.0)	1 (11.1)	.481

Data presented as numbers of patients, with percentages in parentheses, or mean ± SD. *P* values from Spearman rank correlation analysis for continuous variables and Cochran-Armitage trend tests for dichotomous variables. *TECAB*, Total endoscopic coronary artery bypass; *SD*, standard deviation; *pRBC*, packed red blood cells; *ILOS*, intensive care unit length of stay; *HLOS*, hospital length of stay. **P* < .05 compared with patients undergoing multivessel TECAB using Wilcoxon rank-sum tests for continuous variables and chi-square tests (or Fisher's exact test, as appropriate) for dichotomous variables.

from CPB secondary to myocardial dysfunction. The third patient was an 85-year-old man (ejection fraction, 62%; euroSCORE, 4.79) scheduled for 2-vessel TECAB. Elective conversion (thoracotomy) allowed surgery to be performed uneventfully (LIMA-LAD, vein graft-diagonal). However, postoperative myocardial failure (postoperative ejection fraction 10%), and renal failure (dialysis) preceded death on POD 6. The fourth was a 71 year-old female (ejection fraction, 55%; euroSCORE, 2.68) scheduled for 4-vessel TECAB, which was performed uneventfully (LIMA-obtuse marginal/ramus, RIMA-LAD, vein graft-diagonal). However, the patient returned to the OR because of excessive bleeding (emergent sternotomy) after cardiac arrest in the ICU. Subsequent stroke preceded death on POD 8. The surgical time in patients with mortality was significantly longer than in patients without mortality (506 ± 190 minutes vs 319 ± 132 minutes, respectively, $P = .043$).

The comparison of the revascularization groups is given in Table 3. An increasing number of vessels bypassed was significantly associated with increased vasoactive medication use ($P = .019$), pRBC use ($P = .021$), the occurrence of postoperative ventilation times longer than 24 hours ($P = .018$), and ILOS ($P = .002$). The number of vessels bypassed also correlated positively with lung separation time ($r = 0.615$; $P < .001$), surgical time ($r = 0.686$; $P < .001$), OR time ($r = 0.669$; $P < .001$), and HLOS ($r = 0.279$; $P = .004$). Compared with patients undergoing 1-vessel TECAB, patients undergoing multivessel TECAB had significantly prolonged surgical and OR times ($P < .001$ for both) and HLOS ($P = .027$). An increased surgical time was significantly associated with increased lung separation time ($r = 0.782$; $P < .001$), HLOS ($r = 0.332$; $P < .001$), an increased likelihood of vasoactive medication use (odds ratio, 1.80 per standard deviation increase in surgical time; 95%

confidence interval, 1.14–2.84; $P = .011$), pRBC use (odds ratio, 2.68 per standard deviation increase in surgical time; 95% confidence interval, 1.34–5.35; $P = .005$), and prolonged postoperative ventilation time (odds ratio, 1.80 per standard deviation increase in surgical time; 95% confidence interval, 1.07–3.04; $P = .028$).

The observed outcomes in our patients compared with the expected outcomes from conventional CABG using the STS risk calculator (available from www.sts.org) are listed in Table 4. Our patients had a significantly greater incidence

TABLE 4. Observed versus expected outcomes

Outcome	Observed (n)	Expected (n)*	P value†
Prolonged ventilation	13	5.94	.003
Short length of stay	71	63.36	.130
Long length of stay	2	3.57	.398
Renal failure	8	2.55	<.001
Stroke	2	0.85	.209
Reoperation	4	3.85	.939
Morbidity	16	9.96	.045
Mortality	4	1.56	.049

*Expected outcomes calculated from Society of Thoracic Surgeons risk calculator (available from: www.sts.org), which allows a user to calculate a patient's risk of morbidity and mortality. The risk calculator incorporates the Society of Thoracic Surgeons risk models, which are designed to serve as statistical tools to account for the effect of patient risk factors on operative morbidity and mortality. STS outcomes definitions include prolonged ventilation (tracheal extubation >24 hours), short length of stay (hospital discharge <6 days), long length of stay (hospital discharge >14 days), renal failure (serum creatinine increase to >2.0 mg/dL, doubling of preoperative creatinine, or new requirement for dialysis); stroke (confirmed neurologic deficit of abrupt onset that does not resolve within 24 hours); reoperation (for bleeding/tamponade, valvular dysfunction, graft occlusion, other cardiac or noncardiac reasons); morbidity (composite endpoint of operative mortality, permanent stroke, renal failure, prolonged ventilation >24 hours, deep sternal wound infection, and reoperation); mortality (death during hospitalization, even if after 30 days or deaths after hospital discharge but within 30 days of procedure unless the cause of death was clearly unrelated to the operation). †From 1 degree of freedom chi-square goodness of fit test.

of prolonged ventilation, renal failure, morbidity, and mortality.

DISCUSSION

TECAB for multivessel disease has been described as “uncharted territory.”¹⁸ Our series represents the largest reported pool of patients undergoing multivessel TECAB. We found that increasing the number of vessels bypassed significantly increased the surgical/OR time, lung separation time, vasoactive medication use, pRBC use, postoperative ventilation time, ILOS, and HLOS. Furthermore, the increased surgical time was significantly associated with major morbidity and mortality. Finally, a comparison with the STS expected outcomes revealed a similar HLOS but a significantly increased incidence of prolonged ventilation, renal failure, morbidity, and mortality. Our results suggest that addressing multivessel disease by way of TECAB offers no obvious clinical benefits and might increase the morbidity and mortality.

The vast majority of reports using robotic technology during cardiac surgery have done so with some form of minithoracotomy and/or CPB (with/without myocardial arrest) and usually describe single-vessel revascularization (LIMA-LAD).⁵⁻¹⁰ All have reported prolonged surgical/OR times—perhaps the “payoff necessary to avoid sternotomy or thoracotomy.”⁸ However, elective conversion rates (to sternotomy/full thoracotomy) hover around 20%.^{5,6,8} Potential benefits include enhanced postoperative recovery⁷ and decreased postoperative atrial fibrillation.⁹ Perioperative blood use might be decreased⁹ or increased.⁵ Unresolved issues include increased costs⁷ and increased technical difficulty.^{5,6} All have described a substantial learning curve.^{6,10}

The few reports describing TECAB (without minithoracotomy/CPB) involve small numbers of patients undergoing single-vessel revascularization.¹¹⁻¹⁶ We also found many of the same concerns listed previously. Falk and colleagues¹⁶ described 12 patients (all with single LIMA-LAD) and the “substantial learning curve.” Katz and colleagues¹⁵ and Gao and colleagues¹² reported on 27 patients and 4 patients (all with single LIMA-LAD), respectively, undergoing combined TECAB and percutaneous coronary intervention for multivessel disease. Gao and colleagues¹² reported that TECAB “is very demanding.” All reported long operation times and a substantial learning curve and believed this technology should be reserved for single-vessel revascularization in healthy patients.¹¹ de Canniere and colleagues,¹⁴ in a multicenter report (5 centers, 74 patients, 90% single-vessel disease), found that target vessel reintervention was greater than that reported for conventional CABG and stated that TECAB had “difficulties that must not be underestimated.” Others have questioned the issue of graft patency. Bonatti and colleagues²⁰ detailed 40 patients undergoing single-

TABLE 5. Comparison of studies by Srivastava et al¹⁷ and present study

Variable	Srivastava et al ¹⁷	Present study
Total patients reported (n)	93	106
Study period	Jul 2004–Dec 2005	Jul 2007–Feb 2009
Mean age (y)	67.4 ± 12.3	63.6 ± 11.5*
Number of vessels†		
One-vessel TECAB (n)	54 (58)	30 (28)
Two-vessel TECAB (n)	35 (38)	67 (63)
Three-vessel TECAB (n)	4 (4)	8 (8)
Four-vessel TECAB (n)	0 (0)	1 (1)
Multivessel TECAB (n)	39 (42)	76 (72)†
LIMA/RIMA (n)	38 (41)	55 (52)
Perioperative sternotomy (n)	0 (0)	5 (5)
Emergent conversion (n)	0 (0)	7 (7)*
CPB required (n)	0 (0)	3 (3)
Mean operating room time (min)	272 ± 128	451 ± 142†
Stroke (n)	0 (0)	2 (2)
Return to operating room (n)	0 (0)	4 (4)
In-hospital mortality (n)	0 (0)	4 (4)
Mean hospital length of stay (d)	3.4 ± 2.0	5.2 ± 3.1†

Data presented as mean ± standard deviation; data in parentheses are percentages. TECAB, Total endoscopic coronary artery bypass; LIMA/RIMA, left internal mammary artery/right internal mammary artery dissection; CPB, cardiopulmonary bypass. * $P < .05$. † $P < .001$.

vessel (LIMA-LAD) robotic revascularization (CPB, arrested heart), of whom 50% experienced “undesirable technical events” and 20% experienced “anastomotic problems.” Kappert and colleagues¹³ described 5-year follow-up data for 33 patients who underwent TECAB (95%, single; 5%, double) and found an unacceptably high (13%) LAD reintervention rate. They concluded that “clinical outcomes and need for reintervention of the target vessel leave room for improvement.”¹³

Two editorials have summed up the controversy surrounding TECAB.^{3,4} One is fairly optimistic: “The reality is, at present, no one can predict whether robotic technology is or is not going to play a major role in the future of cardiac surgery.”⁴ The other is not: “It is time to recognize that robotics are no longer a promising new technology but instead a technology that has been tried and has failed to demonstrate any clinical value, outside of its questionable use for marketing.”³

A comparison of our results with those of Srivastava and colleagues¹⁷ provides additional unique insight. These 2 series (Table 5) represent the largest reported number of patients undergoing multivessel TECAB and the same experienced CS/PA team performed all the surgeries (at 2 different institutions). This previous experience likely led to our inability to find strong evidence of a learning curve. Our patient population was quite different from that of Srivastava and colleagues¹⁷ (72% multivessel vs 42% multivessel TECAB, $P < .001$). Furthermore, Srivastava and colleagues¹⁷ reported a 13.8% exclusion/conversion rate

(all elective thoracotomy), no episodes of emergent conversion or a need for sternotomy and/or CPB, and 18 patients (19.4%) underwent planned hybrid revascularization (no failures reported).¹⁷ A comparison of these 2 series supports the notion that addressing multivessel coronary artery disease using TECAB might increase the morbidity and mortality. However, for a wide variety of reasons (different periods, different institutions, different perioperative personnel, and so forth), a comparison of these 2 studies might be inappropriate.

Intraoperative hemodynamic instability is a challenging clinical reality of TECAB.^{11,14,17,18,22} Carbon dioxide insufflation (essentially a pneumothorax) leads to cardiac displacement and decreased venous return, when coupled with potential hypoxemia/hypercarbia (prolonged single-lung ventilation), might lead to increased central venous pressure, increased pulmonary artery pressure, decreased cardiac output, and hypotension.^{11,14,17} Right ventricular dysfunction (single-lung ventilation-initiated atelectasis, hypoxic vasoconstriction) and/or left ventricular dysfunction (compliance changes) might also contribute.¹⁸ Such hemodynamic instability necessitates preload augmentation and/or the use of inotropes/vasoconstrictors. We hypothesized that increasing the number of vessels bypassed (thus increasing the single-lung ventilation time/surgical time) promotes greater hemodynamic instability (increasing vasoactive medication use) and might be the underlying etiology of the increased morbidity and mortality observed. Because of this procedure-induced hemodynamic instability, many have recommended TECAB only for single-vessel disease in patients with reasonable cardiopulmonary reserve.^{11,14,18}

Our study had all the inherent limitations associated with a retrospective analysis. Furthermore, one must remember that the predicted outcomes using the STS risk calculator are only an estimate. However, we specifically defined all major morbidities assessed. Additionally, the morbidities we believed were more along the lines of “clinical challenges” (elective conversion, new-onset atrial fibrillation) were not considered major morbidities. Also, to best compare the outcomes from TECAB versus conventional CABG, a randomized controlled trial would be ideal.

In conclusion, we have reported the largest series to date of patients undergoing multivessel TECAB by 1 CS/PA team at a single institution and compared the findings with expected outcomes from conventional CABG and with the same CS/PA team’s experience at another institution. Our analysis supported the concerns voiced by others, that addressing multivessel coronary artery disease with TECAB offers no obvious clinical benefits and might increase the morbidity and mortality. At present, until efficacy is proven through proper clinical trials, TECAB myocardial revascularization should be reserved for relatively healthy

patients (reasonable cardiopulmonary reserve) undergoing single-vessel revascularization.

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