Total Arterial Off-Pump Coronary Revascularization Using Bilateral Internal Thoracic Arteries in Triple-Vessel Disease: Surgical Technique and Clinical Outcomes
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Total Arterial Off-Pump Coronary Revascularization Using Bilateral Internal Thoracic Arteries in Triple-Vessel Disease: Surgical Technique and Clinical Outcomes

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Background. This was a single-institutional study about total arterial off-pump coronary artery bypass graft surgery (OPCABG) using bilateral internal thoracic arteries in triple-vessel disease.

Methods. We retrospectively reviewed the records of 569 multivessel CABG patients (10% female) who underwent total arterial (bilateral internal thoracic arteries) OPCABG between January 2002 and December 2006. Mean age was 63.9 ± 8.9 years. All patients included underwent OPCABG as an elective procedure. Postoperative angiograms were evaluated during a postoperative follow-up period. Early and midterm outcomes, including overall patient survival, freedom from readmission and reintervention, freedom from the combined endpoint of cardiac events and quality of life, were evaluated. Multivariate analysis was used to find determinants of late death. Overall survival and freedom from combined endpoints were determined by the Kaplan-Meier method.

Results. The average number of distal anastomoses per patient was 3.18 ± 0.4. The average operation time was 209.7 ± 41.7 minutes. Thirty-day mortality was 0.88% (5 of 569). Overall patency rate for all grafts studied was 94.3% (632 of 670). Mean follow-up time was 810 days (range, 8 days to 61 months). Cumulative patient survival at 4 years was 93.3% ± 1.9%. Significant predictors of late mortality were age (hazard ratio, 1.06; 95% confidence interval: 1.01 to 1.12), previous stroke (hazard ratio, 6.5; 95% confidence interval: 1.8 to 23.5), and moderate to severe left ventricle ejection fraction (hazard ratio, 3.3; 95% confidence interval: 1.2 to 8.8). Freedom from hospital readmission and reintervention at 4 years was 91.7% ± 3.5%. Freedom from combined endpoint (death, hospital readmission, and reintervention) at 4 years was 86.9% ± 3.6%. There was a marked improvement in patients’ quality of life at follow-up (Duke Activity Status Index score > 45 in more than 70% patients).

Conclusions. Total arterial (bilateral internal thoracic arteries) OPCABG is feasible with a safe outcome in terms of hospital mortality. At follow-up the incidence of death, hospital readmission and reintervention and patients’ quality of life are acceptable with favorable graft patency rates.


Beat-to-beat surgery (off-pump coronary artery bypass graft surgery [OPCABG]) has enjoyed resurgence in interest and technology, and that has allowed surgeons to perform high-quality reproducible anastomoses and has established its place as a good method for multivessel coronary revascularization. Early results after myocardial revascularization without cardiopulmonary bypass (CPB) show, in the great majority of reports, a decrease in postoperative morbidity [1–7].

Recently, bilateral internal thoracic artery (BITA) grafting was applied to gain further beneficial long-term results. Several reports have indicated that BITA grafting gives better survival rates and higher rates of freedom from cardiac-related events than does single ITA grafting, although no randomized trials have been published [8–10]. In addition, it was reported that skeletonized harvesting of ITA offer more conduit length and was associated with a lower incidence of sternal infection [11, 12].

The aim of this study was to investigate the incidence of in-hospital mortality and morbidity and to report early and late follow-up in terms of survival and cardiac-related events in total arterial off-pump coronary artery surgery in triple-vessel disease.

Patients and Methods

This is a retrospective analysis of prospectively gathered data over a 5-year period of patients undergoing OPCABG at the Instituto Cardiovascular de Buenos Aires. The Insti-
tutional Ethical Committee approved the trial, and surgical consent was obtained from each patient with respect to surgical method and postoperative evaluations.

From January 2002 to December 2006, a total of 569 elective patients (according to The Society of Thoracic Surgeons guidelines) underwent total arterial OPCABG in multivessel disease using exclusive BITA, representing the 40% (569 of 1410) of the total OPCABG institutional experience. This surgical technique had been selectively and sporadically during the first year, and from December 2002 onward, OPCABG was routinely used in all coronary surgical cases. Finally, from November 2003, all consecutive patients with multivessel disease received total arterial off-pump coronary revascularization using BITA.

All patient data were prospectively collected by using our custom-made database (Microsoft Access; Microsoft Corp, Redmond, Washington), which is used daily for clinical data management.

Complete arterial revascularization was defined as all diseased coronaries systems (stenosis > 70%) receiving at least one ITA graft insertion. Preoperative and operative data were obtained by retrospective review of clinical and pathology reports from the database and were cross-checked with all medical charts. The data collected included the following: demographics; comorbidity risk factors; operative data; periprocedural mortality (death within 30 days); and postoperative complications. Two-dimensional biplane echocardiography was utilized for left ventricular function (LVF) evaluation. Moderate/severe LVF was defined following Simpson’s rule (ejection fraction < 35%). Postoperative complications were defined as myocardial infarction (new Q wave or loss of R-wave progression across the chest leads or creatine kinase myocardial band enzyme > 10%), low cardiac output (a newly placed intra-aortic balloon pump or the use of inotropic drugs for > 48 hours), malignant ventricular arrhythmias, bleeding requiring a rethoracotomy, respiratory insufficiency (mechanical ventilatory support > 48 hours), renal failure (creatinine value > 2 mg/dL or 100% increase of the preoperative value, with or without the need of dialysis), mediastinal infection and cerebrovascular accident, defined as a central neurologic deficit persisting for more the 72 hours or confirmed by computed tomography. In patients with preoperative stroke, postoperative stroke was defined as a worsening of neurologic deficit with new radiology findings (Table 1). All the patients in this group were operated on with the intention of carrying out the OPCABG (intention to treat), and the criteria used for conversion to on-pump CABG were hemodynamic or electric instability and calcified or intramyocardial coronary arteries, or both.

**Operative Technique**

All patients included in this study underwent surgery with the purpose of obtaining complete myocardial revascularization using more than two grafts and following Tector’s (T graft) surgical technique [13]. The conduits used for coronary revascularization were both internal thoracic arteries (left ITA–right ITA [LITA-RITA]). No other types of venous or arterial conduits were used; only in few cases (n = 27) when the heart was severely enlarged, it was necessary to use a short segment of radial artery (<8 cm) in end-to-end fashion, to increase the length of the RITA to reach the distal branches of the right coronary artery. Most of the ITA grafts were harvested skeletonized although some, in the beginning, were dissected as a pedicle. The skeletonized method allows obtaining the maximum length of the arterial conduit. During both ITA preparations, no intraluminal infusion of any kind of solutions was used.

<table>
<thead>
<tr>
<th>Table 1. Baseline Patient Characteristics</th>
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<tbody>
<tr>
<td>Patient Characteristics</td>
</tr>
<tr>
<td>Number of patients</td>
</tr>
<tr>
<td>Average age (years)</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
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<tr>
<td>Hypertension</td>
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<td>Smoking</td>
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<tr>
<td>Lipid disorders</td>
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<tr>
<td>Previous myocardial infarction</td>
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<tr>
<td>Previous percutaneous coronary intervention</td>
</tr>
<tr>
<td>Previous coronary artery bypass graft surgery</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
</tr>
<tr>
<td>Previous renal disease</td>
</tr>
<tr>
<td>Previous stroke</td>
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<tr>
<td>EuroSCORE</td>
</tr>
<tr>
<td>Left main trunk disease</td>
</tr>
<tr>
<td>Number of vessels</td>
</tr>
<tr>
<td>Moderate/severe left ventricular function</td>
</tr>
<tr>
<td>Asymptomatic</td>
</tr>
<tr>
<td>Stable chronic angina</td>
</tr>
<tr>
<td>Unstable angina</td>
</tr>
<tr>
<td>Aspirin preoperatively</td>
</tr>
<tr>
<td>Clopidogrel preoperatively</td>
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</tbody>
</table>

EuroSCORE = European System for Cardiac Operative Risk Evaluation.
The most commonly used technical configuration was in-situ anastomoses of the LITA to the left anterior descending artery; and the RITA, after being divided at its origin and bifurcation, was connected end to side to the in-situ LITA as a sequential T graft to the circumflex and to the posterior descending coronary artery (Fig 1). To bypass all three coronary arteries with ITA grafts, it is essential to obtain maximum graft length. Some measures that help to accomplish this include dissection of the ITA from below its bifurcation into the superior epigastric and musculophrenic branches up the thoracic inlet, use of the skeletonized technique for harvesting both ITA, and placement of the anastomoses of the RITA to the attached LITA as a T graft, which is critical not only for enhancing its reach but also for preventing kinking at the anastomoses. We prefer localizing these anastomoses in the anterior aspect of the LITA at the level of the left atrial appendage or at the level in which the LITA enters the pericardial cavity through a small slit (Fig 1A). (If the LITA is lifted from the chest, it is the same site where it crosses the anterior table of the sternum.) These anastomoses are constructed with 8-0 monofilament suture. Constructing the T graft before touching the heart helps in the alignment of the limbs of the T graft to the obstructed coronary arteries. This T-graft configuration provides the shortest route to the first lateral coronary branch to be bypassed.

In addition to the left anterior descending and circumflex arteries, the right coronary artery was always bypassed unless it was not dominant or small. The posterior descending branch of the right or circumflex coronary arteries was bypassed in 61.5% of patients (350 of 569), and the distal right or the posterior marginal branch of the dominant circumflex in the remaining patient. Parallel and multiple sequential (side-to-side, diamond-shaped) anastomoses were constructed to the obstructed coronary arteries, maintaining them in a straight line and keeping the ITA loose between anastomoses. A suction stabilizer (Axius Vacuum 2 Stabilizer System; Guidant, Santa Clara, California; or Octopus 3; Medtronic, Minneapolis, Minnesota; or Estech equipment) was used to stabilize the coronary artery. Soft proximal coronary occlusion or intracoronary shunts, or both, were utilized when deemed necessary by the operating team. It must be stated that no proximal anastomoses in the aorta were carried out in any patient in this series. Finally, a vertical incision on the right pericardium, toward the inferior vena cava was done (b). (CX = circumflex artery; IVC = inferior vena cava; LAD = left anterior descending artery; LITA = left internal thoracic artery; PDA = posterior descending artery; RITA = right internal thoracic artery.)

Follow-Up

Follow-up was achieved by direct communication with the patients, their family, attending physician, or a combination of these during a 5-month closing interval ending in July 2007. The interview investigated survival, symptoms, long-term medical managements, the incidence

<table>
<thead>
<tr>
<th>Intraoperative Data</th>
<th>Left Internal Thoracic Artery</th>
<th>Right Internal Thoracic Artery</th>
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<tbody>
<tr>
<td>Number of distal anastomoses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>459</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>108</td>
<td>362</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total grafts</td>
<td>569</td>
<td>569</td>
</tr>
<tr>
<td>Total anastomoses</td>
<td>674</td>
<td>1133</td>
</tr>
<tr>
<td>Left anterior descending artery</td>
<td>569</td>
<td>10</td>
</tr>
<tr>
<td>Diagonal artery</td>
<td>100</td>
<td>107</td>
</tr>
<tr>
<td>Circumflex artery</td>
<td>4</td>
<td>659</td>
</tr>
<tr>
<td>Right coronary artery/posterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>descending artery</td>
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Anastomoses per patient = 3.18 ± 0.4.
idence of hospital readmissions and the need for reinter-
vention (percutaneous coronary intervention [PCI] and
redo CABG), and any operation-related complications.
Data collected for readmissions included recurrent an-
gina, new acute myocardial infarction, and congestive
heart failure. The preoperative and postoperative physi-
ological aspects of quality of life were assessed with the Duke
activity status index (DASI). The DASI is a disease-
specific quality of life questionnaire, validated for cardio-
vascular disease, that measures major activities of daily living (personal care, ambulation, household tasks, sexual
function, and recreational activities). Each item is
weighted on the known metabolic cost of each activity,
and weights of positive terms are summed to obtain the
DASI score for the patient. The DASI is measured on a
semicontinuous scale that allows for possible scores
between 0 and 58.2. High scores (≥45) represent good
physical functioning, scores close to zero reflect inability
to perform any basic activities, and in-between scores (25
to 45) reflect regular limitations [14].

Angiographic Study
Postoperative angiography was performed to assess graft
patency, only in patients who gave informed consent,
during the same interval ending in July 2007. When
patients were symptomatic during follow-up, diagnostic

angiography was performed at that time. The Fitzgibbon
classification was used for graft evaluation [15]. If a new
lesion of a native coronary artery or graft occlusion was
found, PCI was performed if possible. Angiographic
studies were reviewed and evaluated by surgeons and
interventional cardiologists.

Statistical Analysis
Categorical variables are expressed as percentages, and
comparisons were done with the χ² test. Continuous
variables are expressed as mean and standard deviation
or median and interquartile range, according to having

Table 3. Significant Predictors for Mortality at Follow-Up

<table>
<thead>
<tr>
<th></th>
<th>Cox Regression Analysis</th>
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<tr>
<td></td>
<td></td>
<td>p Value</td>
<td>HR</td>
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<tr>
<td></td>
<td></td>
<td>0.01</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.004</td>
<td>6.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.01</td>
<td>3.36</td>
</tr>
<tr>
<td>Age</td>
<td>0.01</td>
<td>1.06</td>
<td>1.01–1.12</td>
</tr>
<tr>
<td>Previous stroke</td>
<td>0.004</td>
<td>6.59</td>
<td>1.84–23.5</td>
</tr>
<tr>
<td>Moderate/severe LVF</td>
<td>0.01</td>
<td>3.36</td>
<td>1.28–8.81</td>
</tr>
</tbody>
</table>

CI = confidence interval; HR = hazard ratio; LVF = left ventric-
ular function.
normal distribution or nor; and comparisons were done with \( t \) test or Wilcoxon test, respectively.

Early and midterm outcomes, including overall patient survival, freedom from readmission and reintervention, and freedom from the combined endpoint of cardiac events and quality of life, were evaluated.

Associations between baseline characteristics and time to outcome are expressed as hazard ratios (HR) and corresponding 95% confidence interval (CI). Survival curves were constructed using the method of Kaplan and Meier and compared using the log-rank test. Multivariable Cox proportional hazards analysis was used to adjust for baseline differences between groups and to obtain independent predictors of outcomes. In all cases, a \( p \) value less than 0.05 was considered significant. Statistical analysis was done with STATA 9.0 (Stata Corp, College Station, Texas).

Results

In-Hospital Results

The average operation time (skin to skin) was 209.7 ± 41.7 minutes. The total number of distal anastomoses was 1,807 for the entire group, and mean number of distal anastomoses per patient was 3.18 ± 0.4 (Table 2).

Aortic calcification plaques were identified in 15 patients (2.64%). Complete revascularization was achieved in 100% the patients; and from the total number of our patients, 515 patients (90.5%) had been extubated in the operative room. In 4 patients (0.7%), conversion to cardiopulmonary bypass was required without serious postoperative complications. The overall 30-day perioperative mortality was 0.88% (5 of 569). Seven patients (1.23%) underwent a perioperative myocardial infarction; low cardiac output syndrome occurred in 11 patients (1.93%) and atrial fibrillation in 52 patients (9.14%). Rethoracotomy for bleeding was needed in 9 patients (1.59%). Stroke was present in 4 patients (0.70%), respiratory failure in 7 patients (1.23%), renal insufficiency in 32 patients (5.6%), and major wound infection (mediastinitis) in 10 patients (1.76%). The four major postoperative complications (perioperative myocardial infarction, redo for bleeding, stroke, low cardiac output) were present in only 28 patients (4.92%). Median operation-to-discharge length of stay was 5 days (interquartile range, 4 to 6).

Follow-Up Data

Follow-up of hospital survivors (564) was 96.5% complete; 20 patients were lost to follow-up. The mean follow-up time for the 544 patients available was 810 days (range, 8 days to 61 months). During the follow-up period, there were 21 deaths (3.8%). Overall cumulative patient survival at 1 and 4 years was 98.4% ± 0.5% and 93.3 ± 1.9%, respectively (Fig 2). Of these 21 patients, only 6 (1.1%) died of cardiac causes at 4 years. Variables significantly correlated with late mortality on multivariate analysis are summarized in Table 3. From proportional hazards regression analysis, significant predictors of late mortality were age (HR 1.06; 95% CI: 1.01 to 1.12), previous stroke (HR 6.5; 95% CI: 1.8 to 23.5), and LVF moderate/severe (HR 3.3; 95% CI: 1.2 to 8.8).

Only 4 patients (0.7%), of the 544 patients available for follow-up, underwent hospital readmission for cardiac-related causes at 4 years. Nine patients (1.6%) underwent a new reintervention procedure (PCI, 8; CABG, 1) during the same follow-up period. Cumulative period of freedom from reintervention and hospital readmission at 1 and 4 years was 99.5% ± 0.2% and 91.7% ± 3.5%, respectively (Fig 3). Freedom from the combined endpoint of death, hospital readmission, and reintervention...
at 1 and 4 years was 98.0% ± 0.6% and 86.9% ± 3.6%, respectively (Fig 4).

There was a great improvement in patients’ quality of life reflected by significant differences in the postoperative DASI scores at follow-up (Fig 5). More than 70% of the patients had good (DASI score > 45) physical functioning.

Angiographic Results

After a mean of 37.7 ± 20.1 months, 250 patients (44%) underwent postoperative angiography. Overall patency rate for 670 grafts (Fitzgibbon A plus B; 250 of 670 = 2.68) was 94.32% (632 of 670). Table 4 shows the patency rates for the different types of conduits/coronaries anastomosis. The major reasons for not having all patients undergo postoperative angiogram were renal insufficiency (creatinine level > 2.5 mg/dL), other medical problems or social circumstances, and finally there was an important group of patients who refused follow-up angiography owing to an asymptomatic clinical condition.

Comment

The goal of the coronary surgery is to let the patient live as long as possible free from any coronary events, symptoms, and reinterventions. Arterial conduits utilization has better midterm long-term outcomes regarding recurrent of angina, incidence of myocardial infarction, and need for new reintervention (PCI and CABG) compared with conventional LITA to the left anterior descending artery plus additional saphenous veins grafts [9]. The objective of our study was to evaluate whether total arterial off-pump, using exclusive BITA, could be safely and effectively performed. The endpoints of the study were in-hospital death, complications, and late outcomes in terms of mortality and cardiac-related events. In our study, the OPCABG with BITA was feasible for all patients and was associated with a very low incidence of conversion to on-pump technique. Considering the proportion of patients with left main disease (13%) and with moderate/severe LVF (23%), our rate of in-hospital mortality, in this elective group of patients, was very low. Only 7 patients (1.23%) underwent a new perioperative myocardial infarction, confirming previous reports that despite cardiac elevation and transient hypotensive episodes, a beating-heart operation can provide adequate myocardial protection [16]. Although a possible limitation is the underestimation of neurocognitive deficits, in our study, cerebrovascular accident had a very low rate.

Kouchoukos and colleagues [17] found BITA harvesting to be the strongest predictor of a sternal complication, especially among diabetic patients. On the contrary, Kai and colleagues [18] reported equivalent results in insulin-dependent diabetic patients using off-pump skeletonized BITA grafting. In our study, the incidence of deep sternal wound infection was low and comparable with our previous reports using on-pump technique [19]. In agreement with Puskas and colleagues [20], we observed a low incidence of atrial fibrillation. Only 7 patients (1.23%) underwent respiratory insufficiency after OPCABG, but in the majority of patients (90.5%), it was possible to extubate in the operating room following our postoperative fast-track protocols.

In triple-vessel disease patients, CABG exclusively using ITA T grafts with multiple sequential side-to-side ITA to coronary artery anastomoses introduces the concept of coronary arterial tree reconstruction by the most appropriate conduit. Adding off-pump techniques to this approach creates not only a more technically demanding procedure but also a more effective and durable one [21]. Nevertheless, this technique has not been widely adopted. Using this surgical approach, the total coronary bypass flow is dependent on the flow of the proximal LITA; this scenario has led to concern whether flow reserve in the LITA is sufficient to supply more than one coronary anastomosis. Several reports have already concluded that ITA T grafts allow complete myocardial revascularization with good perioperative results and that the flow reserve of the proximal LITA is adequate for multiple coronary anastomoses [22].

In our angiographic study, the flow in the proximal LITA allowed the complete perfusion of all bypassed coronary arteries. In our series of postoperative angiograms, 8 patients presented with competitive flow in the RITA to the right coronary artery or its branches. In these patients, the opacification of the native coronary arteries, visualized by retrograde flow, showed perfect patency of the RITA graft. This scenario was more frequent in case of a large dominant right coronary artery. However, these angiographic abnormalities had no postoperative consequences in our group of patients.

Another controversy still persists whether the RITA is long enough to reach the right coronary artery without stretch. Completely skeletonized harvesting of ITA is very important to provide enough length to reach the right coronary system. In our series, we were short in length to bypass the right coronary branches (right posterolateral or posterior descending arteries) in 27 patients owing to a very dilated right ventricle or to a short sternum length. We used a short segment of radial artery (<8 cm) to fill the gap with an end-to-end anastomosis with the distal RITA without difficulties. No angiographic evidence of traction or stretch at any point of conduits or coronary anastomosis was observed.

There has been a concern regarding the feasibility of performing a perfect multiple sequential side-to-side ITA to coronary anastomoses. Similar to several reports [23], in our study, postoperative angiograms allowed visual control of the quality of the ITA T graft anastomosis, the sequential side-to-side ITA–coronary anastomoses, and the distal runoffs in the native coronary arteries.

Survival at 4 years was good (93.3% ± 0.2%), and a significant clinical improvement was observed in the vast majority of the patients; moreover, freedom from cardiac-related events was more than 90%, similar to other groups [24–26]. In our experience, age, preoperative LVF, and previous stroke seemed to be the independent risks factors on proportional hazards regression analysis at 4 years of follow-up.

Quality of life measure reflects the patients’ perception of burden of disease and interest in not only survival and
relief of angina but also in resumption of their daily activities [15]. In our study, there was a significant improvement in the DASI score at follow-up, with more than 70% of the patients having high scores reflecting good physical functioning.

The limitations of this single-institution retrospective study are that the number of patient was small and the length of clinical follow-up was relatively short. Although our current practice is to use this surgical technique for all coronary patients, in this study, only elective patients were included.

In conclusion, total arterial OPCABG using exclusively BITA can be safely performed with low in-hospital mortality and complications rates. Surgical tricks and the new technology in coronary stabilizers allow surgeons to perform a complete myocardial coronary revascularization using the best available arterial conduit (BITA). Postoperative angiography allowed visual control of the quality of the revascularization. Clinical outcome and survival free of cardiac-related events at 4 years of follow-up confirmed the effectiveness of this surgical approach.

References

INVITED COMMENTARY
This single center observational study by Navia and colleagues [1] describes their experience with off-pump total arterial coronary artery revascularization. The results presented are indeed impressive. These surgeons report a perioperative mortality of less than 1%, with similarly low rates of major complications and graft
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