Intracoronary Shunt Prevents Ischemia in Off-Pump Coronary Artery Bypass Surgery

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Background. **The purpose of this study was to evaluate the role of intracoronary shunt during off-pump coronary artery bypass surgery.**

Methods. **Fifty-six patients undergoing off-pump coronary artery bypass using the left internal mammary artery to bypass the left anterior descending coronary artery were randomly assigned to have the bypass performed with intracoronary shunt or by occlusive snaring. Ischemia during grafting was monitored by tissue Doppler. Hemodynamic status and indicators of ischemia were monitored, and on-table and postoperative angiography were performed.**

Results. **In patients with retrograde filling of the left anterior descending coronary artery, ischemia did not develop, but occlusion of antegradely perfused vessels caused ischemia in 26 of 33 patients. Ischemia was reversed in 14 of 16 shunted patients, and in 3 of 17 nonshunted cases ($p = 0.004$). Angiography showed a trend toward improved on-table angiographic results in shunted patients. After 3 months, graft patency was 100%, but 1 patient treated without shunt required reintervention and 15 patients had new angiographic lesions, equally distributed between shunted and nonshunted patients.**

Conclusions. **Intracoronary shunt prevents ischemia during grafting of the left anterior descending coronary artery and provides satisfactory immediate- and short-term graft patency.**

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An important challenge during off-pump coronary artery bypass graft surgery (OPCABG) is avoidance of ischemia, especially during grafting of the left anterior descending coronary artery (LAD) [1]. Temporary occlusion of the LAD is tolerated in many patients, but may cause hemodynamic collapse and conversion to cardiopulmonary bypass (CPB) [2]. Intravascular shunts are used in vascular [3–5], neurosurgical [6], and cardiac surgery [7, 8]. Such shunts may reduce ischemia [9], but may cause endothelial damage [10, 11].

The aim of this study was to evaluate risks and benefits of intracoronary shunt during grafting of LAD.

Material and Methods

Patients scheduled for OPCABG were randomly assigned to two groups. In the no-shunt group, left internal mammary artery (LIMA) grafting to the LAD was performed with proximal occlusion. In the shunt group, an intracoronary shunt was utilized. Transesophageal ultrasonography with tissue Doppler was used to detect ischemia in the interventricular septum. Potential damage from the shunt or from snaring was monitored by clinical follow-up, monitoring of cardiac enzymes, electrocardiography (ECG), and on-table angiography immediately after surgery. Clinical examination and repeat coronary angiography were performed 3 months after surgery.

Selection and Randomization

Fifty-six patients scheduled for OPCABG were randomly assigned to shunt or no-shunt groups by block randomization. Patients with significant stenosis or occlusion of LAD were included. Left ventricular function was above 25% in all cases, and the patients were clinically stable at the time of operation. Preoperative data are shown in Table 1.

The study was approved by the Regional Ethics Committee. Patients signed informed consent before the operation.

Surgery

Cardiac surgeons experienced in OPCABG performed the operations. Premedication was 5 to 10 mg diazepam by mouth. Anesthesia was induced with 2 to 5 μg/kg fentanyl, thiopentone 2 to 5 mg/kg, and 0.15 mg/kg cisatracurium. Repeated doses of fentanyl and sevoflurane 1.0% to 2.5% maintained anesthesia. Heparin was given to maintain activated clotting time above 250 s.

Surgery was performed using sternotomy, and the heart positioned by pericardial sutures and a suction cup device

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(Starfish; Medtronic, Minneapolis, MN). Regional stabilization was obtained with an Octopus suction stabilizer (Medtronic). Patients in the shunt group had a shunt inserted through the arteriotomy after placing proximal and distal silicon snares around the LAD, 0.5 cm from the intended arteriotomy. Axius (Boston Scientific, Santa Clara, CA [n = 17]) or Chase (Chase Medical, Richardson, TX [n = 7]) coronary shunts were used. Size and type of shunt were determined by the surgeon. Oversizing was avoided. The proximal snare was tightened for at least 1 minute in the shunt group to ease shunt insertion. In the no-shunt group occlusion of LAD was maintained during construction of the anastomosis. The distal snare was loosely applied to minimize retrograde flow from LAD in no-shunt patients. To facilitate visualization, a Clear-View mist CO_2 blower (Medtronic) [12] and irrigation with saline were used. Anastomoses were sutured with 7-0 polypropylene suture. The time used to construct the LIMA anastomosis was about 10 minutes in both groups. Saphenous vein grafts were performed after completing the LIMA graft. Graft flows were controlled using transit time flow measurements [13].

Hemodynamic Management and Measurements

Arterial and central venous pressures were monitored. Cardiac output was obtained using pulse contour measurements [14–16]. Measurements were recorded and compared before occlusion of LAD, during grafting, and at reperfusion. Fluid boluses, and injection of vasopressors, vasodilators, or inotropic agents were avoided during LAD grafting if possible, and otherwise administered as necessary to maintain stable hemodynamics.

Table 1. Demographics and Perioperative Data

Randomization	No Shunt	Shunt	*p* Value
Number of patients	29	27	
Age, years (SD)	65.9 (9.3)	67.3 (9.8)	0.60
Female, n	3	5	0.46
Cerebrovascular disease, n	2	3	1.00
Diabetes mellitus, n	2	5	0.42
Previous myocardial infarction, n	8	5	0.54
Peripheral vascular disease, n	3	1	0.61
Acetyl salicylic acid adnistration, n	26	22	0.46
Beta-blocker administration, n	19	19	1.00
PCI in the past, n	2	3	0.66
Left main stenosis, n	9	5	0.36
Smoking, n	4	11	0.035
Angina pectoris, n	26	26	0.61
Atrial fibrillation, n	1	4	0.35
Ejection fraction, % (SD)	70.5 (10.6)	68.9 (14.1)	0.65
EuroSCORE (SD)	3.4 (2.7)	3.3 (2.2)	0.89
Received shunt, n	0	24	

EuroSCORE = European System for Cardiac Operative Risk Evaluation; PCI = percutanous coronary intervention.

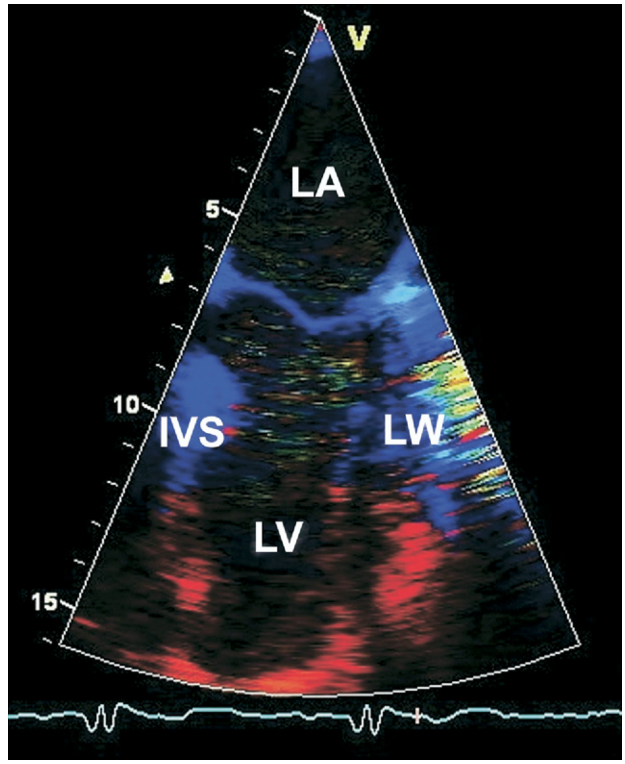

Fig 1. Transesophageal echocardiographic four-chamber view recording. Tissue velocities are color coded: red signifies motion toward the echocardiography probe, and blue represents motion away from the echocardiography probe. (IVS = interventricular septum; LA = left atrium; LV = left ventricle; LW = left ventricular lateral wall.)

Transesophageal Echocardiography

A transesophageal probe providing tissue imaging (6.7 MHz) and Doppler measurements (3.5 MHz) [17] was utilized to obtain two-dimensional recordings of color-coded tissue velocities in four-chamber view with a System FiVe echocardiograph (GE Vingmed Ultrasound, Horten, Norway). Pulse repetition frequency was set to 0.5 to 1.0 kHz, with a frame rate of $80 \pm 2\ s^{-1}$, which was considered acceptable for strain measurements [17–19]. All recordings were performed in the same position in each patient with the ultrasound beam aligned close to the direction of the interventricular septum. Elevation of the heart was minimized during LAD grafting to optimize echocardiographic recordings. Recordings were stored digitally as cine loops for offline analysis. A typical recording used for strain measurements is shown in Figure 1.

Echocardiographic Measurements

Strain (ε) represents regional myocardial contraction fraction. Strain of a myocardial segment is defined as a percent change from end-diastolic dimension (L_0) to instantaneous length (L), defined by the equation $\varepsilon = (L - L_0/L_0) \times 100\%$, and was derived from tissue velocity measurements. A strain curve for a given region was generated throughout the cardiac cycle, and peak systolic

Table 2. Septal Ischemia in Patients With Antegradely Perfused Left Anterior Descending Artery

	Shunt (No. of Patients)		No Shunt (No. of Patients)		
	Ischemia	No Ischemia	Ischemia	No Ischemia	*p* Value
Baseline	0	16	0	17	NS
Initial occlusion	12	4	14	3	0.69
Grafting	2	14	11	6	0.004
Reperfusion	0	16	0	17	NS

Baseline is before snaring of left anterior descending artery; initial occlusion is 1 minute after applying occlusive proximal snare; grafting is 5 minutes after snaring of left anterior descending artery; reperfusion is after completion of grafting.

NS = not significant.

strain obtained. Negative values described segmental shortening while positive values signified segmental lengthening. Strain values less than −10% were considered as normal and strain values greater than −10% represented ischemia. Measurements were performed at four time points: (1) baseline before LAD occlusion; (2) 1 minute after LAD occlusion (LAD was still occluded in both groups); (3) 5 minutes after LAD occlusion (shunt was in place in the shunt group while the LAD remained occluded in the nonshunt group); and (4) after removal of the shunt or release of the occlusion with open LIMA. Strain was measured in the mid and apical segments of the septum [17]. If strain was greater than -10% in any of these segments, ischemia was considered to have appeared.

On-Table Angiography

On-table angiography was performed under anesthesia by femoral route after chest closure [20], enabling on-table graft revision. The LIMA to LAD anastomosis was

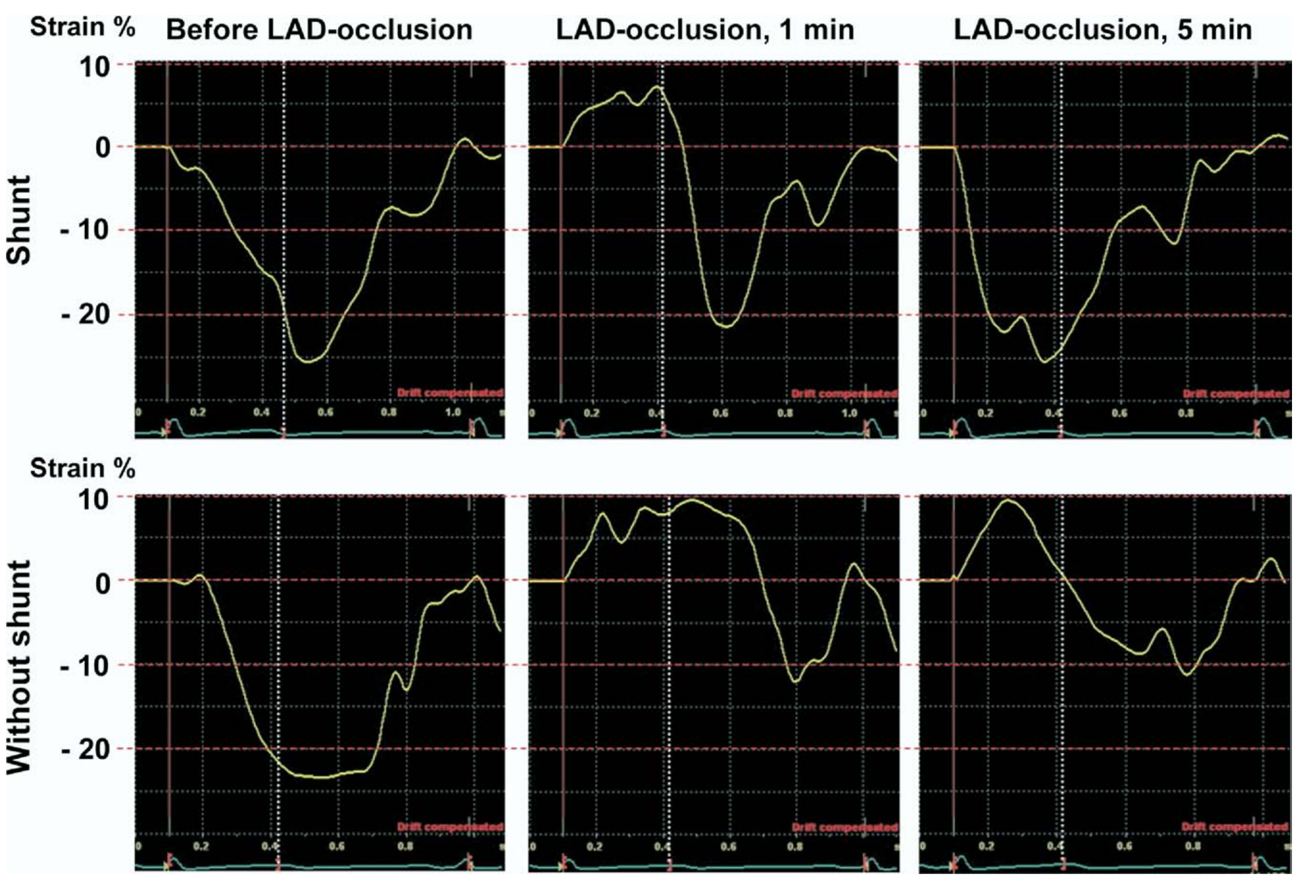

Fig 2. Strain curves from the apical septum in 2 different patients. Recordings shown demonstrate strain curves before left anterior descending artery (LAD) occlusion, at 1 minute of occlusion and at 5 minutes of occlusion. In the upper panel, it is demonstrated that ischemia appeared, reflected by positive strain values, as the LAD was occluded during shunt implantation. However, the ischemia disappeared as the shunt reestablished the LAD flow. In the patient without shunt (lower panel), ischemia continued till the time of reperfusion. Strain after reperfusion is not shown.

imaged in two planes. Findings were graded as described by FitzGibbon and coworkers [21], where grade A is used for a graft with excellent flow without obstruction, grade B means a graft with significant obstruction, and grade O means an occluded graft.

Postoperative Course

Patients underwent standard postoperative management including daily recordings of ECG, creatine kinase with isoenzymes (creatine kinase–myocardial band), C-reactive protein, aspartate aminotransferase, and alanine aminotransferase. Troponin was not measured routinely.

Clinical and Angiographic Follow-Up

Patients were examined by a clinician after 3 months and asked to report on the presence of angina or other cardiac symptoms. Follow-up angiograms were performed by radial approach. Two independent angiographers described the LIMA to LAD anastomosis without knowledge of treatment group. If stenosis was demonstrated on 3-month follow-up, the previous angiograms were examined. If a lesion was not seen on earlier angiography, the lesion was assumed to be new and possibly related to operative manipulations.

Statistical Analyses

The number of patients included was based on power analysis. Variables were described using mean and standard deviations for continuous variables and by counts for categorical variables. Continuous variables were compared using *t* tests. Pearson correlation coefficient was calculated for normally distributed continuous variables. Crude associations between categorical variables were assessed with χ^2 tests. Adjusted associations were modeled using logistic regression. As 3 patients in the shunt group did not receive a shunt owing to technical difficulties, two sets of analyses were performed: one for the "intention to treat" group and one with the group for which shunt was actually used. Numbers presented in the text refers to grouping according to actual use if not otherwise indicated. A *p* value less than 0.05 was considered statistically significant. Analyses were performed using SPSS version 13 (SPSS, Chicago, IL).

Results

Twenty-seven patients were randomly assigned to shunt and 29 to no shunt. There were no differences between groups with regard to demographics or risk factors, except for more smokers in the shunt group (Table 1). In 3 patients, shunt insertion was unsuccessful, and the graft was performed as in the no-shunt group. Two shunts had a diameter of 1.25 mm, 14 had a diameter of 1.50 mm, 7 had a diameter of 1.75 mm, and 1 had a diameter of 2.00 mm. All no-shunt patients were treated without shunt.

Clinical and Biochemical Outcomes

No patient had a perioperative myocardial infarction. One patient in the shunt group had Q waves in anterior ECG leads without a rise in enzymes and a patent LIMA graft. One no-shunt patient had creatine kinase–myocardial band level above 75 IU without ECG changes and patent grafts at 3 months. Two patients in the no-shunt group continued to have angina postoperatively. One required percutanous coronary intervention of a stenotic LAD and another of the right coronary artery. There were no significant differences in creatine kinase, creatine kinase-myocardial band, C-reactive protein, aspartate aminotransferase, alanine aminotransferase, or troponin between study groups.

Septal Ischemia by Transesophageal Echocardiography

No patient was ischemic before LAD snaring. No ischemia developed in 10 patients with retrograde filling of an occluded LAD, independent of whether shunt was utilized. Twenty-six of 33 patients with antegrade flow in the LAD had septal ischemia during snaring. Patients randomly allocated to the shunt group had less ischemia than patients in the no-shunt group ($p = 0.03$). When patients were grouped according to actual use of shunt (Table 2), the difference was more significant ($p = 0.004$).

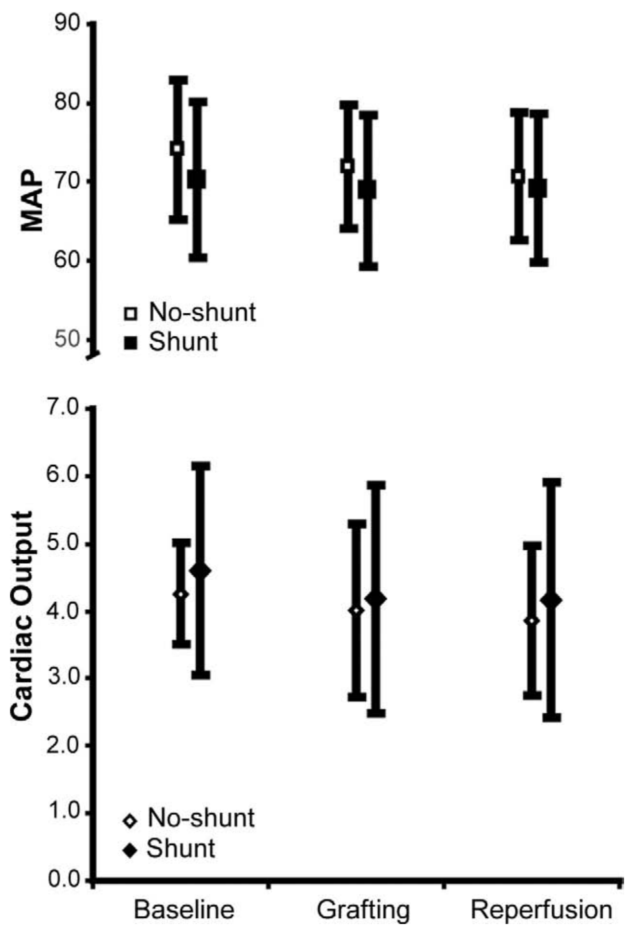

Fig 3. Mean arterial pressure (MAP [open squares = no shunt; solid squares = shunt]) and cardiac output (open diamonds = no shunt; solid diamonds = shunt) at baseline, during grafting, and after reperfusion.

Typical recordings of strain patterns in shunted and not shunted patients are shown in Figure 2. Logistic regression demonstrated that presence of retrograde flow was a significant factor in avoiding ischemia, before and during grafting. Use of shunt was a highly significant independent factor contributing to avoidance of ischemia during grafting ($p = 0.001$). Prevention of ischemia was independent of shunt size.

Intraoperative Hemodynamics

Mean arterial blood pressure or cardiac output did not change from baseline during grafting or reperfusion (Fig 3), nor did other hemodynamic variables. One patient in the no-shunt group required conversion to CPB during grafting of the circumflex coronary artery. Two shunt and 6 no-shunt patients required rapid infusion of volume or administration of vasopressors during LAD grafting ($p = 0.45$). The requirement for volume push or administration of drugs was not correlated to the development of ischemia ($r = -0.179$, $p = 0.269$).

On-Table Angiography

Forty-eight patients, 24 randomized to no-shunt and 24 to shunt, had on-table angiograms. Three of the latter were grafted without shunt. One patient in each group had dissection of the distal LIMA; both were repaired by revising the anastomosis and had normal repeat angiograms. All grafts in the shunt group were Fitzgibbon grade A, whereas there were 4 grade B grafts in the no-shunt group ($p = 0.06$). Of the 4 no-shunt anastomoses with Fitzgibbon grade B, 3 became normal on postoperative angiograms, but 1 lesion in the distal LIMA was present on postoperative angiogram and required intervention.

Postoperative Angiography

Fifty-three patients underwent postoperative angiography. Twenty-three lesions were demonstrated in the area of the LIMA to LAD anastomosis or in the native vessel close to the anastomosis. Fifteen of the lesions were not present on preoperative angiography (Table 3). The lesions were more common proximal to the anastomosis than distal: proximal 9 of 53; distal 2 of 53 ($p = 0.03$). There was no difference between the two groups. Average severity of the new lesions was 44% (SD 17%). Both distal lesions were retrospectively seen to be present on the on-table angiogram, as were 4 of 11 proximally located new lesions. Five new proximal lesions were not seen on on-table angiogram; in 2 cases, comparison between on-table and postoperative angiogram was not possible.

Table 3. Number of Patients With New Lesions in Left Internal Mammary Artery (LIMA) or Left Anterior Descending Artery (LAD) Not Present on Preoperative Angiography

	Randomized (No. of Patients)			Actual Use (No. of Patients)		
Group	Shunt	No Shunt	p Value	Shunt	No Shunt	p Value
Angiography	26	27		23	30	
New lesion	7	8	1.00	7	8	0.78
LAD proximal	6	3	0.12	6	3	0.12
LAD distal	1	1	1.00	1	1	1.00
LIMA distal	0	4	0.08	0	4	0.08

LAD proximal is a new lesion in LAD located within 10 mm proximal of the anastomosis; LAD distal is a new lesion in LAD within 10 mm distal of the anastomosis; LIMA distal is a lesion in distal LIMA at insertion to LAD.

Comment

Technical improvements have made OPCABG a more attractive option for coronary revascularization than when described by Kolesov [22] in the 1960s. The OPCABG surgeon still occasionally faces myocardial ischemia and hemodynamic collapse during surgery. An intracoronary shunt may prevent such events and the need for emergency initiation of CPB [2, 23] and help the surgeon to perform a better anastomosis. It is possible, however, that a shunt may denude the endothelium and cause vessel damage, thrombosis or subsequent stenosis [10].

Ischemia in the LAD distribution may be demonstrated by measuring strain in the interventricular septum [17]. This study included patients with significant stenosis or total occlusion of the LAD. None of the hearts with totally occluded LAD developed ischemia during snaring, probably because of well-established collaterals [24] and the absence of stress, which may challenge the adequacy of collateral blood supply [25].

Most patients with antegrade flow in the LAD had ischemia when the LAD was occluded. Insertion of a shunt reversed ischemia except in 2 patients, whereas most snared patients remained ischemic. Distal flow in a shunted artery is dependent on proximal perfusion pressure and the size of the shunt [26]. The 2 patients in whom shunt did not reverse ischemia may have had inadequate flow in the shunt due to technical factors or inadequate proximal perfusion pressure.

Hemodynamic collapse [23] requiring conversion to CPB did not occur during grafting of the LAD. Such events are infrequent, and this study was not powered to answer whether shunting could prevent conversion [2]. Other investigators have demonstrated that shunting during LAD grafting can prevent temporary wall motion abnormalities [27–29], and case reports have documented reversal of hemodynamic instability by shunting. It has also been demonstrated that shunt may reduce troponin release [30], although we did not demonstrate any difference in troponin or other markers of myocardial damage. In our study, shunt was only used routinely during LAD grafting, and any benefit on biochemical markers may have been diluted by temporary occlusion of other vessels.

Opinions have been divided on whether the use of shunt is helpful in the creation of the anastomosis. The presence of a shunt may prevent the surgeon from taking too large arterial bites during suturing [8] and may prevent bleeding and improve visibility [7]. This study demonstrated a trend toward improved on-table angiographic results in the shunt group. All shunt patients had Fitzgibbon grade A anastomosis, whereas there were 4 grade B anastomosis in the no-shunt group. Except in 1 of these 4 cases, angiograms were normal at 3 months, indicating that the on-table angiographic changes may frequently be due to spasm [20]. The use of shunt may, potentially, denude the endothelium and cause intimal hyperplasia and stenosis [11, 31]. Angiograms performed on 53 patients 3 months after surgery showed 15 new lesions in the anastomotic area, not seen on the preoperative angiogram. Most lesions were located proximal to the anastomosis corresponding to the proximal snare. Snaring of an arteriosclerotic artery may cause endothelial damage, plaque rupture, and microthrombosis [31]. In this study, the proximal LAD was exposed to snaring in both groups, although in the shunt group, potential endothelial denudation from the shunt could occur as well [11]. The area distal to the anastomosis was snared only in no-shunt patients, but the snare was applied with less force than the proximal. There was only 1 new distal lesion in each group, both present at on-table angiography. This finding indicates that light snaring and use of intracoronary shunt is relatively safe, with a low rate of permanent damage [11]. The increased incidence of new, proximal lesions, several of them absent on both preoperative and on-table angiography, could indicate that occlusive snaring of the LAD may damage the vessel and cause late obstructive lesions.

There was a trend toward more anastomotic lesions in no-shunt patients, both at on-table angiography and postoperatively in the distal LIMA, indicating that shunt may be helpful in avoiding technical mistakes. Other investigators have also demonstrated equal or improved angiographic results in shunted patients [32]. The avoidance of endothelial damage is important in any type of vascular surgery. A modified shunt design may decrease the potential for damage [33]. It seems logical that the shunt should not be oversized even though undersizing may cause increased bleeding and less shunt flow [34]. We avoid oversizing and if necessary allow some bleeding, which usually decreases rapidly, possibly because of mild coronary spasm. We saw no correlation between the presence of ischemia during grafting and the size of the shunt. The amount of blood flow necessary to prevent ischemia may be low in the anesthetized patient and dependent not only on the presence of a shunt, but also on the proximal intracoronary pressure as well as the collateral circulation [34].

To conclude, we have found that intracoronary shunts prevent ischemia in the antegradely perfused LAD during LIMA grafting. The quality of the anastomosis is at least as good as when a shunt is not utilized. The relatively frequent occurrence of new coronary lesions proximal to the anastomosis may indicate damage from occlusive snaring. We recommend the use of intracoronary shunt during OPCABG surgery. The use of snaring of the native vessel should preferably be avoided.

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INVITED COMMENTARY

Good visualization of the anastomotic site is critical to the performance of a technically precise anastomosis on a beating heart. Off-pump coronary artery bypass (OPCAB) surgeons have several options to achieve this:

1. *Proximal and distal snares* – Unless the arteriotomy is directly over a perforating branch, this will usually provide good visualization. The disadvantages are acute ischemia and risk of coronary artery trauma.
2. *Proximal snare only* – Collateral flow from the distal coronary bed can interfere with visualization and require increased flows on the CO_2 mister-blower, which may cause endothelial trauma. A coronary steal effect may lead to increased distal ischemia. The potential for trauma to the proximal coronary artery remains.
3. *Intracoronary shunts* – Shunts provide nutritive distal flow and excellent hemostasis. They can enhance anastomotic precision by serving as a mandrel and protecting the back wall. They can, however, at times be difficult to insert. Many surgeons still use snares to facilitate insertion so the risk of coronary trauma persists. Some animal studies suggest the potential for endothelial trauma and dysfunction, but others suggest this does not occur in diseased coronary arteries.

Surgeons who perform OPCAB can be divided into those who (1) rarely, if ever, shunt, (2) routinely shunt, and (3) selectively shunt based on anatomy (eg, right coronary artery or proximal left anterior descending coronary [LAD] grafts) or signs of active ischemia. It is our impression that those of us who routinely shunt remain in the minority.

Bergsland and colleagues [1] present a well-designed and executed randomized trial, which should encourage increased use of shunts and avoidance of snares during OPCAB. They clearly demonstrate that shunts prevent ischemia. Proximal snaring caused acute ischemia in approximately 80% of patients with anterograde flow in the LAD. Shunting was 80% successful in eliminating the ischemia. Two-thirds of patients without shunts had persistent ischemia during the grafting. Importantly, electrocardiographic and hemodynamic changes were not sensitive enough to detect ischemia. These findings support the concept that snaring often causes a low-grade but cumulative ischemic burden, which may not manifest itself until final grafts are being performed on the lateral wall. Interestingly, the only conversion to CPB in this study was in the no-shunt group. This is very important since emergency conversion to CPB has been shown to dramatically increase mortality.

The early and late angiographic data also support the use of shunts over snares. Shunted patients had a strong trend toward superior anastomotic quality both early (95% vs 80% Fitzgibbon A) and late (0% vs 15% distal left internal mammary artery [LIMA] lesions). Nearly 30% of all patients had new LAD lesions (mostly proximal)

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