TRIPLE CORONARY ARTERY REVASCULARIZATION ON THE STABILIZED BEATING HEART: INITIAL EXPERIENCE

Raymond Cartier, MD,* Yves Hébert, MD,* Robert Blain, MD,* Normand Tremblay, MD;† Jacques Desjardins;† Yves Leclerc, MD*

OBJECTIVE: To decrease health costs and morbidity related to extracorporeal circulation, surgeons have modified the coronary artery bypass (CAB) technique so that it can be completed without the use of extracorporeal circulation. This study summarizes initial experience with direct coronary artery revascularization on the beating heart using a coronary stabilizer.

DESIGN: A case series.

SETTING: The Montreal Heart Institute, a university-affiliated centre, specializing in the treatment of cardiac illnesses.

PATIENTS: Ten patients underwent CAB by this technique. They presented with double or triple coronary artery disease with no intramural, heavily calcified, diffused atheromatous coronary vessels, or left main coronary disease.

INTERVENTION: CAB grafting in the beating heart. The anterior wall was grafted in all patients, the inferior wall in 7 and the posterior wall in 7.

MAIN OUTCOME MEASURES: Patient survival and graft patency.

RESULTS: One patient died of multiple organ failure not related to the grafting technique itself, and 1 patient suffered a non-Q myocardial infarction. Early coronary angiography performed on 8 patients showed 100% graft patency, most with excellent distal runoff (21/22 grafts).

CONCLUSION: In patients with adequate anatomy, performance of CAB without extracorporeal circulation can achieve excellent early results provided there is appropriate mechanical stabilization of the beating heart.

OBJECTIF : Pour réduire les coûts médicaux et la morbidité liée à la circulation extracorporelle, des chirurgiens ont modifié la technique du pontage aortocoronarien (PAC) de façon à pouvoir pratiquer l'intervention sans recourir à la circulation extracorporelle. Cette étude résume la première expérience de revascularisation coronarienne directe à cœur battant avec stabilisation coronarienne mécanique.

CONCEPTION : Série de cas

CONTEXTE : L’Institut de cardiologie de Montréal, centre affilié à une université spécialisée dans le traitement des maladies coronariennes.

PATIENTS : Dix patients ont subi un PAC réalisé par cette technique. Ils avaient une double ou triple coronaropathie sans vaisseau coronarien athéromateux diffus très calcifié à l’intérieur du myocarde ni atteinte de l’artère coronarienne gauche principale.

INTERVENTION : PAC pratiqué à cœur battant. Le territoire antérieur a été revascularisé chez tous les patients, le territoire inférieur, chez sept patients, et le territoire postérieur, chez sept patients.

PRINCIPALES MESURES DE RÉSULTATS : Survie des patients et perméabilité de la greffe.

RÉSULTATS : Un patient est mort des suites d’une défaillance multisystémique non reliée à la technique de revascularisation même et un patient a subi un infarctus du myocarde non Q. Une angiographie coronarienne précoce pratiquée chez huit patients a démontré un taux de perméabilité de la greffe de 100 % et un excellent écoulement distal (21 greffes sur 22).

CONCLUSION : Chez les patients dont l’anatomie le permet, la réalisation d’un PAC sans circulation extra-
Achieving complete coronary artery revascularization on a patient’s beating heart is the unspoken goal of every cardiac surgeon. With the advent of more efficient angioplastic devices, cardiac surgeons have to deal with multiple coronary artery disease more frequently. Also, the aging of the population and the search for a better lifestyle have increased the need for surgical management of coronary artery disease in a more demanding senior citizen community. Although direct coronary artery revascularization on beating hearts was carried out successfully (both experimentally and clinically) in the early 1950s and 1960s, most cardiothoracic surgeons abandoned the procedure when extracorporeal circulation (ECC) was introduced. However, even with the continuous technologic improvements achieved during the last 25 years, the technical advantages offered by ECC have been offset by its morbidity. The inflammatory response and systemic microemboli generated by ECC induce, to some extent, a dysfunctional state of the brain, lungs, kidneys and hematopoietic system that tends to increase with aging. However, some surgeons have persisted in performing coronary revascularization without bypass and have shown that the procedure is effective, safe, cost-effective and, in certain circumstances, superior to conventional surgery. Recently, we began performing double and triple coronary artery revascularizations on the beating heart using a specifically designed coronary stabilizer. This report summarizes our initial experience with this device.

PATIENTS AND METHODS

Patients were selected according to certain anatomic criteria guided by surgeon preference. Essentially, these patients presented with double or triple coronary artery disease with no intramyocardial, heavily calcified, diffused atheromatous coronary vessels, or left main coronary disease. Patients who needed more than 1 bypass on the circumflex artery territory were rejected. All surgical procedures were performed by the same surgeon (R.C.) under general anesthesia maintained by continuous infusion of narcotics and benzodiazepines and intermittent administration of pancuronium bromide to provide muscle relaxation. During the study period, a total of 23 patients were revascularized, 10 (43%) of whom underwent the procedure without ECC. Coronary stabilization was achieved with a mechanical coronary stabilizer that we designed to function as a “pushing device” (Fig. 1) as well as a “pulling device” (Fig. 2) (patent pending), according to the location of the target artery. To do this, we used a silicone rubber band hooked to a blunted needle (Retract-o-Tape; Quest Medical, Inc., Allen, Tex.) to occlude the vessel proximally and distally to the arteriotomy (Fig. 3). The heart beat was slowed down to 50 to 60 beats/min with an intravenous bolus injection of esmolol hydrochloride to allow us to carry out the procedure more easily and to decrease myocardial oxygen consumption. With our “pulling-pushing device” it was possible to decrease the coronary artery “travelling” to less than 1 to 2 mm. In this manner we were able to perform coronary artery bypass (CAB) grafting with the same technique used under cardioplegic arrest and ECC, including the use of an 8-0 polypropylene running suture with a single parachute technique for an intrathoracic artery (ITA) to CAB and a 7-0 polypropylene suture for vein graft anastomosis. All surgical procedures
were performed through a median sternotomy. The left anterior descending artery (LAD), the right coronary artery (RCA) and the posterior descending coronary artery (PDCA) were approached with minimal myocardial mobilization; however, the circumflex artery (CXA) was reached by placing the patient in a 30° side position and by using pericardial traction. The heart was then slowly torqued by the assistant to allow adjustment of the stabilizer. This technique allowed us to gain access to the second, third and fourth obtuse marginal (OM) branches and obtain good stabilization. ST-segment trends and invasive monitoring were used to detect myocardial ischemia and cardiovascular instability, which were treated using intravenous perfusion of nitroglycerin and phenylephrine as required.

RESULTS

Ten patients (7 men, 3 women) underwent coronary artery revascularization with this technique. All were in a state of unstable angina and were receiving optimal medical treatment. One patient had an intraoperative balloon pump installed 24 hours before the operation for persistent chest pain despite optimal intravenous treatment. The mean (and standard deviation) age of the patients was 66 (10) years (range from 48 to 79 years). The mean (and SD) left ventricular ejection fraction was 51% (5%) (range from 25% to 71%). A mean of 2.7 grafts per patient were placed, including 10 ITA and 17 saphenous vein grafts. The LAD was grafted in all 10 patients, the first diagonal (DX) artery in 3 patients, the CXA in 7 patients (the second OM branch in 5, the third OM branch in 1 and the fourth OM branch in 1), the RCA in 2, and the PDCA in 5. Four patients underwent 2 CABs, 5 patients underwent 3 CABs and 1 patient underwent 4 CABs. Most of the ITAs were grafted to the LAD (9/10). In 1 patient the LAD and first DX artery were sequentially bypassed with a left ITA. All but 2 patients were recatheterized early on after surgery. One 78-year-old patient who died of multiorgan failure 7 days after the operation was not recatheterized. The decision to proceed without bypass was based on his very poor lung condition (vital capacity of 1.63 L, 40% of predicted value and forced expiratory volume/1 s of 0.75 L, 23% of predicted value) to avoid ECC-related lung damage. The surgery was complicated by mediastinal hemorrhage related to the sternal closure. Although the patient was quickly explored and the bleeding corrected, he suffered from shock-related complications. The postoperative electrocardiogram remained normal, as did the creatine kinase (CK) MB count (16 mmol/L, maximal count) and all bypasses were found to be patent (LAD, first diagonal, third OM branch) at the autopsy. Another patient who had already undergone 2 prior revascularizations and many angioplastic proce-

FIG. 4. Left panel: Angiogram shows the patency of a quadruple bypass, left internal mammary artery (LIMA) (sequential bypass) to left anterior descending artery and first diagonal branch (A), saphenous vein graft bypass to posterior descending artery (B), and second obtuse marginal branch (C). Right panel: Postoperative angiogram showing excellent patency of LIMA to left anterior descending artery bypass (A) and a saphenous vein graft to right coronary artery bypass (B).
dures for recurrent vein graft and native coronary artery stenosis was not restudied. However, the postoperative thallium Persantine test for ischemia gave negative results. In patients who were studied early on, graft patency was assessed according to the Fitzgibbon classification. All grafts were patent and 95% (21/22) were considered class A (no stenosis greater than 50% involving proximal, distal or main trunk anastomosis) (Fig. 4, Table 1). One grafted third OM branch was found occluded distal to the anastomosis, but the graft was patent, perfusing in a retrograde fashion through a second OM branch. The median amounts of blood loss were 300 mL perioperatively and 625 mL postoperatively. Five patients required blood transfusions. In those patients, the median number of blood units used was 2 per patient, as was the total number of units of blood products used per patient. Arterial lactate level remained normal during the procedure (1.96 [0.15] mmol/L), although it rose, on average, to 3.48 (42) mmol/L during the first 12 hours postoperatively. The mean (and SD) length of hospital stay was 6.7 (1.03) days, and only 1 patient suffered postoperative atrial fibrillation. All survivors had an uncomplicated postoperative course. The average (and SD) postoperative CK MB count was 19 (13) mol/L on the day of surgery, 22 (26) mmol/L (postoperative day 1) and 18 (17) mol/L (day 2). Only 1 patient (with the occluded third marginal) had a CK MB count above 50 mmol/L (at 89 mmol/L) and probably sustained a non-Q perioperative infarction. No patients were converted to a standard procedure. The average (and SD) operating room time was 146 (11) minutes.

**DISCUSSION**

The purpose of this study was to evaluate the morbidity and mortality, as well as the early graft patency, associated with the CAB technique performed on beating hearts with the use of a mechanical stabilizer. Although direct myocardial revascularization can be done successfully without stabilization, as proposed by Benetti and associates and others, it requires a significant learning curve and is not necessarily convenient for all cardiac surgeons. Thus, the introduction of a mechanical coronary stabilizer in MIDCAB (minimally invasive direct CAB) surgery as proposed by Greenspun, Adourian and Fonger 14 and Subramanian (Dr. V.A. Subramanian, Lenox Hill Hospital, New York, NY: personal communication, 1996) has contributed considerably to the practicality of the procedure. The stabilizer we designed can be adapted to a standard sternotomy retractor and can then be used at all angles through a regular sternotomy approach. Furthermore, by interchanging the different blades, it can be used in a “pulling” as well as a “pushing” mode, which makes it very functional. We placed an average of 2.7 grafts/patient, a number comparable to that in a previous series of patients operated on by standard techniques as reported by our institution. Complete revascularization was achieved whenever the vessel diameter was suitable, without limitation due to the surgical technique itself. Of the 22 grafts studied, all were patent and most (21/22, 95%) displayed excellent runoff. These results are excellent and, despite the limitations of this series, they are comparable to those in the recent series reported by Fitzgibbon and associates, in which the early graft occlusion rate was 12% and the grade B graft runoff was 7%. The only death was unrelated to the revascularization technique, and no Q wave infarction was noted in this series. Operating time did not appear to be shorter than usual, but we expect that it could be improved with experience.

Although Longmire may have been the first surgeon to perform direct coronary revascularization using the ITA as a vascular conduit in a human, it was Kolesov who mastered the technique at the First Lenigrad Medical Institute during the 1960s. Between 1964 and 1976, Kolesov and his associates performed direct coronary revascularization on beating hearts on over 130 patients, achieving a long-term angiographic patency of 90%.

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**Table 1**

**Evaluation of Patency in 22 Grafts**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>A</th>
<th>B</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left anterior descending coronary artery</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>First diagonal artery</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Circumflex coronary artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second obtuse marginal branch</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Third obtuse marginal branch</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fourth obtuse marginal branch</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Right coronary artery</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Posterior descending coronary artery</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

A = no significant stenosis, B = stenosis > 50%, O = occluded
In many of these patients, revascularization was obtained with a stabilizer device designed under Kolesov’s direction. In the 1970s, Benetti, from Argentina, began performing off-pump bypasses for economic reasons and, through the years, developed extensive experience with the procedure. Others achieved similar results during the same period. Although Benetti initially reported an average of 1.4 grafts/patient, he was able to achieve an average of 3.1 grafts/patient later on, and used the procedure in more than 80% of all coronary revascularizations.

The advantages of performing CABG without ECC are numerous. Aside from decreased perioperative blood loss and reduced hospital stay, there is evidence that the avoidance of ECC better preserves left ventricular function. Akins and colleagues observed a trend toward a superior left ventricular function in patients operated on without ECC and attributed it to improved preservation of septal wall motion compared with those operated on with the traditional method. When comparing 2 surgical groups operated on with and without ECC, Phister and colleagues found a decreased incidence of low-output state among those operated on off-pump. Similarly, Benetti and associates have shown, from left ventricular biopsies, that mitochondria are not affected during the off-pump procedure. Furthermore, among a series of 32 patients operated on while in acute myocardial infarction, Benetti, Mariani and Ballester reported a marked reduction of mitochondrial and myofibrillar damage following revascularization, and no clinical episode of low cardiac output in this otherwise high-risk subset of patients, confirming the protective aspect of the procedure. Although direct revascularization on the beating heart can be performed with good left ventricular preservation, the procedure also has to achieve comparable technical results. Mechanical stabilization allows the surgeon to perform the surgery with a technique similar to the standard procedure under bypass, which basically eliminates the learning curve. In our limited initial experience we have been able to perform coronary anastomosis with excellent angiographic results. We found that the main limitation of the procedure relates to the anatomy and quality of the vessel. Patients with diffuse atheromatous disease necessitating a long arteriography or even endarterectomy are not suitable candidates for this technique. The circumflex territory remains the more challenging part of the procedure. Although the second and third OM branches were relatively easy to stabilize and revascularize in a nonhypertrophic heart, we found the first OM branch and ramus intermedius quite difficult to reach, and the accessibility to the CXA less predictable on the dilated heart. Fifty percent of our patients required blood transfusion, a lower rate than expected, since only 32% of our patients operated on with traditional technique do not need any transfusion. This is probably due to the nonreversal of the heparin at the end of the procedure and the partial occlusive technique used for blood-flow interruption during the anastomosis. Since then, we have shortened the distance between the proximal and distal occlusions, which has decreased the presence of potential hidden side branches. Currently, 70% of our off-pump procedures do not require transfusion. There is no doubt that this technique is cost-effective. By avoiding the hardware related to the ECC (oxygenator and pump are present in the operating room but not primed) and the vascular cannulas, we save Can$603.70 and Can$70.00 respectively. However, extra costs are associated with the use of intravenous fluid rewarming devices due to nonreusable tubing (Can$62.48). In total, an average operating cost reduction of Can$610.00 per case is expected.

CONCLUSIONS

Direct coronary revascularization on the beating heart is an appropriate alternative to standard cardioplegic technique provided that appropriate mechanical stabilization is used and that the coronary anatomy is suitable. Long-term angiographic studies are mandatory to confirm the benefit of this procedure.

References

8. Kirklin JK, Westaby S, Blackstone EH,


