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Clinical experience with minimally invasive reoperative coronary bypass surgery

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Abstract *Objective.* To minimize the risk of standard and reoperative coronary artery bypass, we developed a minimally invasive approach. In this study we have evaluated the effectiveness of this technique. *Method.* Between April 1994 and September 1995, 12 men and 6 women, aged 55–84 years (mean, 69 years) with chronic stable angina (4) and recent post-myocardial infarction unstable angina (14), with left ventricular ejection fractions ranging 17–60% (mean 37%), underwent reoperative coronary artery bypass grafting using 7-cm mini-left and right anterior thoracotomy and subxiphoid incisions. Coronary artery anastomoses were carried out on beating hearts with local coronary occlusion. Ischemic preconditioning, beta and calcium channel blockers and the maintenance of mean arterial pressure at 75–80 mmHg, were used as adjuncts for myocardial protection. The internal mammary artery was isolated under direct vision up to the second rib with excision of the fourth costal cartilage. Coronary artery target sites were the left anterior descending in 12, right coronary artery in 4, obtuse marginal in 3, posterior descending in 1 and diagonal branch in 1 patient. Arterial grafts (mammary, right gastroepiploic, radial), either as single or composite grafts, were used liberally. Preoperative risk factors in-

cluded congestive heart failure (7), chronic renal insufficiency (5), second reoperation (2), third reoperation (1), cerebrovascular disease (5), prior angioplasty (8) and preoperative intra-aortic balloon pumping in two patients.

Results. There was no perioperative mortality with minimal morbidity. Twelve patients underwent patency study of the grafts 48–72 h postoperatively. Ten of the twelve grafts were patent; one internal mammary artery graft to the left anterior descending coronary artery (<1.5 mm) early in our series was occluded and one additional left internal mammary graft had a kink several centimeters away from the anastomosis, which was successfully opened by angioplasty. At a mean follow-up interval of 8 months all 16 surviving patients are in functional class I or II and all of them remain free of angina.

Conclusion. In selected patients reoperative coronary artery bypass grafting can be performed with this minimally invasive approach with a low perioperative morbidity and mortality rate and satisfactory early graft patency rate with good symptomatic improvement.

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Key words Mini left · Thoracotomy · Beating hearts · Local coronary occlusion

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Introduction

Coronary artery reoperation is becoming common worldwide and now constitutes a substantial proportion of cardiac surgeons' practice. These procedures will increase in number in the future [3]. In 1995 it is estimated that 55 000 patients will undergo coronary reoperations annually in the United States. Reoperative procedures have several technical obstacles which differentiate them from primary procedures. These problems include: 1) difficulties with sternal re-entry with potential for cardiac and conduit injury during dissection when the surgical plane is obscured by dense adhesions and normal anatomical landmarks are obliterated, 2) availability of conduit, 3) management of patient vein grafts with severe atherosclerosis, 4) myocardial protection in situations where there are complex routes of myocardial perfusion, depending on the status of the native coronary circulation and the patency of the vein or internal mammary artery (IMA) grafts.

Alternative strategies currently used include different techniques for sternal re-entry, strict avoidance of graft manipulation to minimize the risk of graft atheroembolism and numerous modifications of myocardial protection, including performing coronary artery bypass grafting without cardiopulmonary bypass through the standard sternal re-entry approach. Since April 1994, we have developed a technique of utilizing an anterior mini-thoracotomy approach for routine coronary artery bypass grafting of the left anterior descending coronary artery (LAD) and right coronary artery with good clinical success. In this report we describe our experience in a selected group of 18 patients who underwent reoperative coronary bypass grafting utilizing this minimally invasive coronary artery bypass technique.

Materials and methods

Patient population

Between April 1994 and September 1995 82 patients underwent reoperative coronary artery bypass grafting at our Institution. Of these 82 patients, 18 patients underwent surgery utilizing a minimally invasive approach. The age range of the 12 male and 6 female patients was 55–84 years (mean, 69 years) including two patients over the age of 80 years. Eleven patients in this group were over the age of 70 years. Elective operations were performed in four patients with chronic stable angina refractory to medical therapy and previous angioplasty procedures. Fourteen patients in this group underwent urgent reoperative coronary bypass surgery because of unstable angina following recent myocardial infarction requiring intravenous nitroglycerin and heparin and, in two patients, intra-aortic balloon pumping. In these 14 urgent coronary bypass patients, one was operated with evolving anterior wall myocardial infarction and one patient was operated on for unsuccessful angioplasty within 48 h. Eighteen patients had suffered a prior myocardial infarction. Left ventricular ejection fraction in this group ranged 17–60% (mean, 37%), seven patients had congestive heart failure in addition to unstable angina, five were in chronic renal insufficiency, eight had prior

angioplasty, two were undergoing their second reoperations, and in one patient this was the third reoperation. Five patients had cerebrovascular disease as evidenced by prior stroke, prior transient ischemic attacks and prior carotid endarterectomy. Two patients, in addition to reoperative coronary bypass surgery, underwent an associated carotid endarterectomy. Six patients in this group had diabetes mellitus treated with insulin.

Technique

All patients were operated on in a supine position. They were monitored with routine hemodynamic monitoring using radial arterial, central venous and pulmonary arterial catheters. In addition, continuous transesophageal echocardiography monitoring of the left ventricular wall motion and continuous ST-segment mapping were performed during the entire procedure. The left coronary arterial system (LAD, diagonal, marginal) was approached by a 7-cm incision over the anterior aspect of the fourth rib beginning just lateral to the sternum and ending just medial to the nipple. The mid and distal right coronary artery before the crux were approached by a similar incision on the right side and when the posterior descending coronary artery was grafted, a subxiphoid incision was made with excision of the xiphoid, the diaphragm was retracted down by a malleable retractor and the acute margin of the heart pulled up by traction sutures to expose the inferior surface of the heart. After the anterior incision over the fourth rib, the fourth costal cartilage was excised revealing the LIMA and the veins just beneath it. The arterial pedicle was mobilized, both proximally and distally. In some patients, the third costal cartilage was partially resected to allow more proximal dissection of the pedicle under direct vision up to the second rib. On the right side, a small portion of the fifth costal cartilage was partially resected instead of the third costal cartilage, especially if the bypass graft had to be performed in the right coronary artery beyond the acute marginal branch. The pericardium was incised just lateral to the IMA on both sides and this usually revealed the LAD and the diagonal on the left side underneath the pericardial incision and medial to the pericardial incision for the right coronary artery on the right side. For grafting of the circumflex and the high ramus intermedius branches, the pericardial incision was extended posteriorly and elevated with traction sutures to bring these branches to the anterior aspect of the incision.

In patients whose mammary artery had been used previously, gastroepiploic artery was harvested via a subxiphoid incision, to be used as an inflow conduit for the LAD. When composite grafts were used, radial artery and saphenous vein grafts were harvested prior to mobilization of the coronary arteries for grafting. Prior to the division of the arterial pedicle, heparin (5000–7500 units) was given intravenously as a bolus. Local occlusion of the coronary artery was carried out with large 5-0 Prolene sutures placed proximally and distally to the site of an anastomosis and encircling the entire coronary artery, the epicardial fat and accompanying vein. The sutures were double-looped sutures and these were used as traction sutures for immobilization of the heart during the anastomosis. Lateral epicardial traction sutures placed on the site of the coronary arteries achieved further stabilization of the coronary artery during anastomosis. Prior to the local coronary occlusion intravenous verapamil, 5–10 mg bolus, was given to prevent no-reflow phenomena during the reperfusion period and to decrease the heart rate during the coronary anastomosis. Intravenous Cardizem drip, at 4–5 mg/h, was routinely used during the entire operation. Increasing the depth of anesthesia and continuous Esmolol drip, in addition, helped to keep the heart rate at 50–60/min and to decrease the force of contraction of the heart during the anastomosis. All attempts were made to maintain the systemic mean arterial pressure in the range of 75–80 mmHg during the entire operation.

During the later part of our series, ischemic preconditioning was employed as an adjunct for myocardial protection. This was achieved with initial local coronary occlusion for a 5-min period, followed by

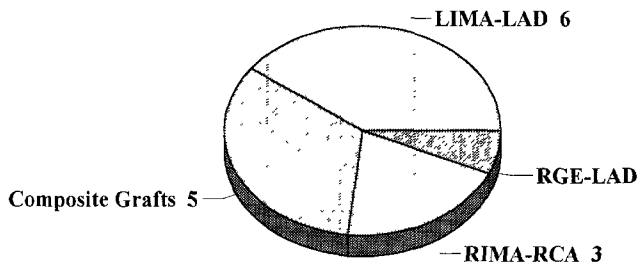


Fig. 1 Number of single grafts per patient (n=15)

Table 1 Types of grafts – distal anastomosis double grafts

LIMA → LAD	1
Right Gastroepiploic → PDA	
RIMA → RCA	1
LIMA → LAD	
LIMA + SVG → LAD	1
DI	

(LIMA left internal mammary artery, (LAD left anterior descending coronary artery, PDA posterior descending artery, RIMA right internal mammary artery, RCA right coronary artery, LIMA left internal mammary artery, SVG saphenous vein graft, DI diagonal branch)

Table 2 Types of grafts – distal anastomosis composite single grafts No. 5

Inflow	Conduit	Target coronary artery
RGE	→ SVG	→ OM
LIM	→ SVG	→ OM
Prior SVG	→ Radial artery	→ OM
LAD graft		
Primor RIMA	→ Radial artery	→ Distal LAD
LAD graft		
RGE	→ Radial artery	→ LAD

(RGE right gastroepiploic, SVG saphenous vein graft, OM obtuse marginal, LIMA left internal mammary artery, RIMA right internal mammary artery)

5 min of reperfusion, and then completed by occlusion for coronary artery anastomosis. The coronary artery anastomosis was performed in a standard fashion utilizing continuous 80 Prolene sutures.

Grafts and distal anastomosis

Fifteen patients underwent single coronary artery bypass graft and three had double bypass graft (Fig. 1, Table 1). All of these patients had three-vessel coronary artery disease. Additional grafts were not required, either because of the presence of other patent arterial and venous grafts or the presence of large akinetic segments in the distribution of the other diseased coronary arteries. In three patients the

remaining coronary artery target sites could not be bypassed because of diffuse disease. Six patients had LIMA to LAD, one patient had right gastroepiploic artery brought through a hole in the left leaf of the diaphragm to the apical part of the LAD, and three patients had RIMA to the mid-right coronary artery. Five patients had composite single grafts utilizing right gastroepiploic artery, LIMA and previously placed saphenous vein graft as the inflow part of the conduit (Table 2).

Routine postoperative care was carried out with emphasis on early extubation within a few hours and discontinuing all lines. The majority of patients were ambulated the next day, with discharge on the 4th or 5th day. Graft patency was tested either by angiogram or trans-thoracic Doppler echo of IMA 48–72 h postoperatively.

Results – intraoperative data

The exposure to the LAD, diagonal and high marginal branches was excellent through the left anterior mini-thoracotomy incision. The exposure to the mid-right coronary artery and the distal right coronary artery just beyond the acute marginal was also good through the right anterior thoracotomy approach. However, the exposure to the posterior descending coronary artery from the right anterior thoracotomy approach was inadequate. The exposure to the posterior descending coronary artery was excellent through the subxiphoid approach. Local coronary occlusion time for the coronary artery anastomosis ranged 8–27 min (mean, 17 min).

During the entire procedure patients were hemodynamically stable. Transesophageal echocardiography monitoring revealed mild hypokinesia in the anterior wall of the left ventricle in one patient. The same patient had an ST-segment elevation in the precordial leads less than 1 mm during the period of coronary occlusion for anastomosis. No serious ventricular arrhythmia occurred during the period of coronary occlusion. One patient had isolated unifocal and premature ventricular beat. There was a trend towards decreased heart rate in the later part of the series when we used ischemic preconditioning prior to coronary artery anastomosis. The posterior circumflex branches were hard to anastomose, predictably, through this approach on a beating heart without partial bypass support. In three patients, for grafting circumflex branches we used partial cardiopulmonary bypass by groin cannulation of the femoral artery and femoral vein with a long wire-reinforced (32F) cannula with a basket tip at the level of the right atrium. However, during the partial cardiopulmonary bypass the blood pressure was still high and the cardiac activity was still vigorous, indicating our ability to unload the heart through this peripheral approach with the current cannulation technique.

There was no perioperative mortality. Two patients had non-surgical deaths: one patient, a 77-year-old male Jehovah's Witness, who needed a reoperative coronary bypass with the LIMA to LAD, died 4 weeks after surgery due to massive gastrointestinal bleeding from Mallory-Weiss tear and refusing blood transfusion. The second 75-

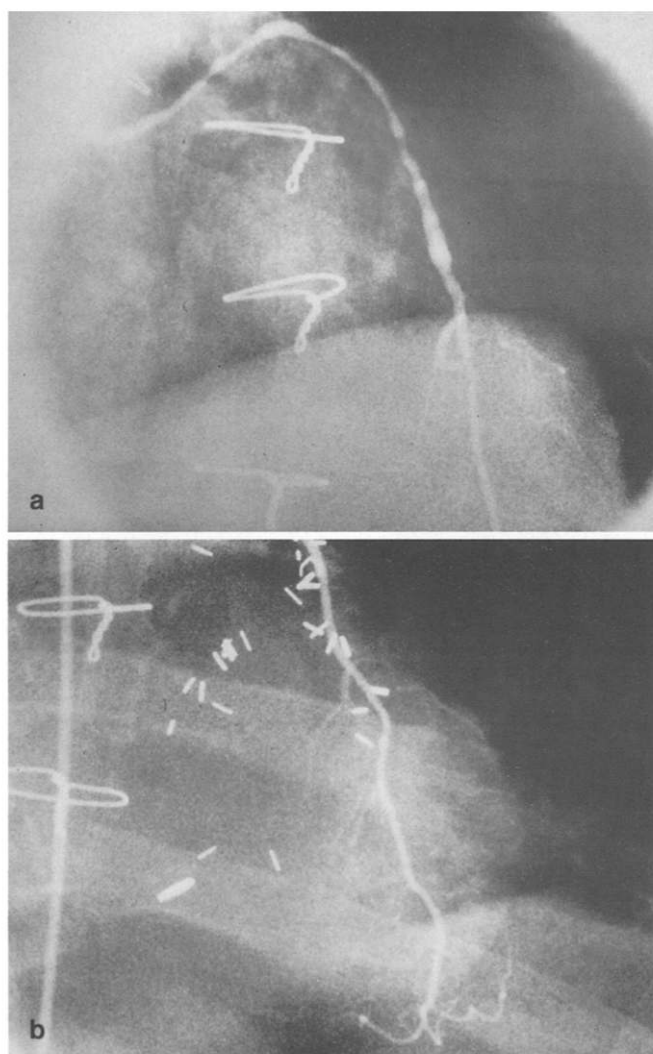


Fig. 2a Preoperative angiographic appearance of atherosclerotic saphenous vein graft to left anterior descending coronary artery in a 74-year-old female with post-myocardial infarction unstable angina on intra-aortic balloon pump. **b** Angiographic appearance of left internal mammary artery graft to left anterior descending coronary artery after reoperation through mini-thoracotomy approach

year-old patient, who was in chronic hemodialysis, died of hyperkalemia and massive electrolyte shift during chronic hemodialysis at 5 weeks after surgery.

One obese 77-year-old female, who had a bilateral mammary artery graft through the mini-thoracotomy approach, had a superficial wound infection of the left anterior thoracotomy incision limited to the subcutaneous tissue. She was successfully treated by conservative measures and is now doing well clinically. There was no perioperative myocardial infarction new onset of renal failure or cerebrovascular complications. Thirteen patients were

extubated in under 6 h, one patient was extubated within 12 h from surgery and four patients were extubated after 48 h. No patients were reoperated for postoperative hemorrhage; no patients were transfused in the first 48 h.

Of the 12 patients who underwent graft patency study, 8 had angiography (Fig. 2A, 2B) and 4 underwent trans-thoracic Doppler echo analysis of the IMA flow. One 77-year-old male had shown an occlusion in the postoperative study at 48 h and another 56-year-old diabetic female, who had a reoperative coronary bypass with LIMA to LAD showed a kink at the proximal extent of the mobilized IMA; this kink was successfully angioplastied and the patient now remains clinically well with a follow-up of 9 months. Fifteen patients were followed for a range of 2–17 months (mean 8 ± 4.5 months). All of these patients remained in the New York Heart Association class I or II and they are all free of angina.

Discussion

A recent report provided an alternative strategy for reoperative coronary artery bypass grafting without cardiopulmonary bypass with favorable clinical results [1]. However, eliminating cardiopulmonary bypass alone has not diminished the potential risks of the re-entry of the mediastinum. Manipulation of the graft without interrupting previously placed vein grafts increases the potential for embolization of atherosclerotic debris from the old vein grafts. In approaching the left coronary arterial system from the mid-line sternotomy incision to undertake the coronary bypass on a beating heart, there are certain technical limitations. The left coronary arterial system is to the left of the mid-line; hence, the left ventricle has to be rotated and brought back to the center which, in some instances, causes hemodynamic compromise. Furthermore, the contraction of the heart makes it somewhat difficult, technically, to perform a perfect anastomosis with the IMA to the LAD.

The risk of reoperative coronary bypass surgery, in spite of currently available multiple alternative techniques, still remains high. Since a patent LIMA graft to LAD is the main determinant of long-term survival [2], it seemed attractive to us to perform the LIMA-LAD operation via mini left anterior thoracotomy in a reoperative situation, avoiding entirely the potential complication of sternal re-entry and the cardiac dissection. While performing pericardial drainage and biopsy via left mini-anterior thoracotomy, it became clear to us that the LAD and the diagonal branches are easily approached by this incision.

With our current technique of mini-thoracotomy, the heart is closer to the surface; the mediastinal structures and the pericardium are still attached to the undersurface of the sternum thus ensuring that the heart does not move too much while we are performing an anastomosis off cardio-

pulmonary bypass. The traction sutures used for local coronary occlusion and the lateral epicardial sutures immobilize the coronary artery extremely well so that the anastomosis with IMA to LAD can be performed safely. In a reoperative situation, as in this series, the dissection does not have to be extended except in the area of the target coronary artery. The local coronary occlusion is well tolerated in the mid-LAD.

Our series of 18 patients who underwent the operation by this approach fall into a high risk category for coronary artery bypass surgery. In the majority of patients the indication for reoperation is for unstable angina following recent myocardial infarction with high risk co-morbid preoperative factors, i.e. chronic renal insufficiency, cerebrovascular disease and poor ejection fraction. In addition, over half of the patients had congestive heart failure as well as unstable angina. Several patients in our series had undergone prior angioplasty. In spite of the high risk profile of these patients in our group, we were able to perform successfully coronary artery bypass with arterial conduits in 15 patients including complex composite grafts in five patients.

There were no serious intraoperative or postoperative complications and no postoperative hemorrhage in spite of the high risk situation of these patients. In addition, the old vein grafts were never manipulated during the reoperation

via the mini-thoracotomy approach, which eliminated thromboembolism from the graft atherosclerosis.

In the current study we have shown that we can safely and successfully perform anastomosis to the coronary arteries in the anterior surface of the heart such as LAD, diagonal and the high ramus branch. However, the circumflex coronary artery is too far back to do it without cardiopulmonary bypass; hence, partial bypass was used to support the circulation. In our series, the right coronary artery was easily approached through the right anterior thoracotomy in its entire extent except the posterior descending coronary artery, which was approached in one patient with subxiphoid incision. Further experience is necessary before advocating this approach for the posterior descending coronary artery bypass. Modifications of this minimally invasive approach for coronary reoperation, such as temporary perfusion catheter, local cardioplegia, support with closed chest cardiopulmonary bypass and the use of a hemopump, will continue to evolve.

In conclusion, we believe that in selected patients reoperative coronary artery bypass grafting can be performed by mini-thoracotomy approaches on both the left and right arterial system with low perioperative morbidity and mortality rates, satisfactory early graft patency rate and good early symptomatic improvement.

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Discussion

Dr. T. Aberg (Umeå, Sweden): Thank you very much for this very interesting and far-reaching paper. I would like to know a little bit about the selection of the patients. In how many patients did you plan to do it this way and have to revert to a conventional mid-sternotomy approach?

Dr. Subramanian: In the reoperative group we have not converted to a midline sternotomy in any patient. In the elective group we had five patients converted to the standard midline approach. Early in our experience the reasons were IMA injury in two patients, intramyocardial LAD in one, too laterally placed LAD in one, and calcified mid-RCA in one patient planned for

bilateral mammary artery grafting to the LAD and RCA. The reoperative group of 18 patients we have presented here represent roughly 15–20% of the reoperative coronary bypass surgery at our institution.

Dr. H. Borst (Hannover Germany): You talk about partial bypass. How partial is it?

Dr. Subramanian: Well, we could do all we can with a femoral vein and femoral artery cannula. We are running about at three liters at least. We found it was not helpful because we did not find that it would unload enough of the heart, so we early resorted not to use bypass as much as possible

Dr. E. Kolesov (Ukraine): I wish to remind Dr. Subramanian and the audience that we used the thoracotomy approach for pioneering coronary surgery about 30 years ago and have already operated on about 400 patients. We do it routinely now. And I think that this presentation adds significantly to a way of thinking about coronary surgery. That is very important and thank you very much, Dr. Subramanian, for that.

I have only one question for you, but before. I would mention that we usually use tiny staplers to connect the internal mammary with coronary arteries. So in general it gives a completely different approach, more simplified and less costly than the usual approach.

So my question Dr. Subramanian, is how you check the condition of the patient. Is it necessary sometimes to go to heart-lung bypass before starting surgery or, starting routinely, maybe you have some complications?

Dr. Subramanian: First of all, I want to thank Professor Kolesov. I was going to show a slide of your publication back in the *Journal of Thoracic and Cardiovascular Surgery*, and he was indeed the first author who proposed the left anterior thoracotomy. It wasn't clear in that report whether it was an anterior thoracotomy or a standard posterolateral thoracotomy.

To answer your question, currently we do not have a pump standby. We do most of them with a heart pump, and, as I said, except if we feel that as a second module, perhaps, when doing a triple bypass graft, we will use it.

Selection on whether to proceed with it or not is really dependent on the time of your LAD occlusion, but we have not seen any problem with local occlusion of the LAD perhaps because of very, very aggressive use of ischemic preconditioning. I do believe that there is a tremendous message in ischemic preconditioning, especially from the basic investigation as far as the inferences we draw from a clinical correlate of operating on patients with a stunning myocardial infarction or in the cath lab, PTCA reference to cath in a coronary bypass. I think we do have preconditioning effect in our coronary bypass routinely, anyhow, in a lot of these patients. So I think that may be an important factor here why we did not have to resort to cardiopulmonary bypass in most of the instances.

Dr. A. Moritz (Vienna, Austria): Having performed some similar operations, but through a median sternotomy without cardiopulmonary bypass, we found it extremely helpful to reduce the heart rate. We were not that happy with the verapamil; we

could not achieve as how a heart rate as we planned to. So we went to the animal lab and did a series comparing short-acting beta blockers versus calcium blockers, and we found that beta blockers superior both in the goal of achieving a slower heart rate and of achieving better myocardial preservation. Although in the animal experiment there is a different situation of the coronary arteries because they don't have primarily a stenosis to deal with. Do you think that your current drug regimen is satisfactory or are you developing other regimens?

Dr. Subramanian: The midline sternotomy coronary bypass operation without a pump is ergonomically a different operation because in an anterior thoracotomy approach, the pericardial attachment is still left intact to the sternum and the heart is not dislocated in contrast to the midline sternotomy approach, making the LAD closer to the surface of the incision. Hence, ergonomically, it is quite simple and easy to do the LIMA – LAD anastomosis with the anterior thoracotomy operation.

In our clinical experience with ischemic preconditioning we have noticed a trend towards a slower heart rate during the period of local coronary occlusion. We believe that this may be related to adenosine entrapment in the interstitial compartment of the myocardium. Further basic investigational work needs to be done to prove this hypothesis. Further evolution of techniques of immobilization of the coronary artery and the local myocardium nearby will continue. The octopus stabilization platform for the LAD developed by the Utrecht group, which was presented in a recent workshop held on minimally invasive coronary bypass surgery prior to this meeting, is very interesting. Our own group soon will be evaluating techniques for controlled reversible localized myocardial stunning either by local cardioplegia with pharmacologic agents and/or with local myocardial cryotherapy. I believe controlled localized

myocardial stunning for this operation will probably be the future to allow this operation to be applied to a larger number of patients by a greater number of surgeons and to be of practical use in the area of coronary bypass surgery as well. We believe the controlled localized reversible myocardial stunning could mimic the natural history of mid LAD coronary artery infarct where the heart usually becomes hypokinetic without major pump failure or ventricle arrhythmia with the advantage of resuscitation of the heart in the early periods of ischemia by the varieties of techniques we will be evaluating.

Dr. P. Nataf (Paris, France): I would like to congratulate Dr. Subramanian for his important contribution in this new field of minimally invasive coronary bypass grafting. Using conventional surgical techniques, he marks the first step of a tendency towards a minimal access approach. Our experimental, and now our clinical, work uses a thoracoscopic approach for LIMA harvesting and a 4 cm left anterior thoracotomy for LAD-LIMA anastomosis on a beating heart without CPB.

(Film) So as you can see on this experimental model, it is easy to harvest the internal mammary artery through thoracoscopy with only two incisions of 1 cm, and you see the cauterization, or we can put some vascular clips on branches. With this method it is possible to harvest the LIMA completely. Thank you.

Dr. Subramanian: I think that thoracoscopic immobilization is one part of the technique which is going to be coming more into use. I think we have to prove that if you take 100 thoracoscopic IMA immobilizations, how many of them are you going to injure or throw it out. So I think that remains to be seen. I am very intrigued by that technique as an added armamentarium of this approach.