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## Discussion

DR. WILLIAM A. BAUMGARTNER (Baltimore, Maryland): That was a very nice presentation on a novel approach to this problem. As you know, our group has been interested clinically in the beating heart approach as well as in the laboratory investigating peripheral bypass and cardiac arrest to do this operation similar to the conventional approach.

One of the things that I think is key to this, and probably the most important aspect, is what you pointed out in the very beginning of your presentation, and that is at 18 years, will the patency of the left internal mammary artery be 80% to 90%. Based on experience other than that of the Brazilian surgeon, there has been a lot of data gathered on doing coronary artery bypass grafting (CABG) without cardiopulmonary bypass through a median sternotomy. Those have not been associated with particularly good results. Dr. Gundry previously reported poor results in patency after a beating heart approach.

I wonder, in your series, although you only have one patient who had a problem with a right coronary artery anastomosis, have you done any studies, either Doppler or angiogram, to confirm patency? The proof of this procedure is whether or not one has long-term patency.

I would also question whether or not it should be used in combination with percutaneous transluminal coronary angioplasty (PTCA). I think we have learned over the years that complete myocardial revascularization is really what should be strived for, and a combination of this with PTCA seems to be something that is against what we have learned over the years. I do think, though, that this is a novel approach and that it will find an appropriate place.

DR. ALDEN H. HARKEN (Denver, Colorado): I am interested in the gold standards that were so nicely developed in which both the Cass and European trials indicated that a mammary artery to the left anterior descending (LAD) or vascular arterial conduit to the LAD can be expected to last 10, perhaps even 20 years, with a 90% patency, while a PTCA from the Emory Angioplasty Surgery Trial is probably in the 60% patency at 6 months range.

Therefore, we are being challenged, I think, not only to evaluate the physiologic, financial, and functional costs of therapy, but also the physiologic, financial, and functional costs of remaining well after therapy. In that regard, surgical therapy or arterial grafts really look very, very good. So what we are discussing now is the psychology of clinical pathway development. What we therefore need to know is, what are the costs of not only the therapy but also the costs of remaining well after the therapy?

We are comparing a sternotomy *versus* a thoracotomy and femoral incision *versus* a PTCA or catheterization, and we have looked at the upper abdominal thoracotomy group *versus* a sternotomy, and a sternotomy surprisingly does not seem to hurt the vital capacity or exercise tolerance very much. Dr. Landreneau, have you looked at an FEV<sub>1</sub> or vital capacity or exercise tolerance at 1 day, 3 days, 3 weeks, and 3 months after therapy, because my sense is the durability of the surgical arterial graft is going to look very good in that regard.

My final question is actually not to Dr. Landreneau but to Dr. Sabiston. Could you possibly have imagined that this is what would have happened to the revascularization procedure that you developed reasonably recently?

DR. BRUCE A. REITZ (Stanford, California): I would like to congratulate Dr. Landreneau and his colleagues on this outstanding work and also, on a personal note, for his advice and encouragement in our early efforts in thoracoscopic mammary take-down.

I do believe these minimally invasive approaches to cardiac surgery are here to stay, and we will only see more and more development in the years to come. However, to be accepted, and for us to apply them widely, it needs to be shown that they are as safe and effective as our current operations. Certainly, the results that you present today are beginning to give us some security in that regard.

Certainly, they need to be pursued. The patients desire these approaches. They can see the benefits of minimally invasive surgery in the fields of general surgery, orthopedics, and gynecology. We also have the managed-care imperative requiring us to do more with less.

I wanted to just mention some work that has gone on for the last few years at Stanford. My colleagues and I have been working with an endovascular system that provides the type of cardiac arrest that we have with open surgery, to best apply minimally invasive techniques. To do this, a catheter-based system with femoral artery bypass, a balloon catheter positioned in the ascending aorta, and with assisted venous drainage was developed. There also is a retrograde coronary sinus catheter that can give cardioplegia in this manner if desired.

Using this catheter-based system, we have now used similar

small thoracotomy incisions in 18 patients, 14 of whom have had single mammary artery grafts and 4 of whom have had mitral valve replacement. Based on our early experience, we confirmed that these small incisions do lead to quicker recoveries.

My question for you concerns the use of cardiopulmonary bypass. How negative an effect is cardiopulmonary bypass? In your abstract, 7 of the initial 14 patients that you report did have femoral artery cannulation for bypass, and then ultimately only 9 of the 46 or so patients did. I wonder what changed in your thinking, or why you are now advocating more noncardiopulmonary bypass support? In your patients, can you see a difference between those who had cardiopulmonary bypass *versus* those who did not? We feel that we are still getting the benefits of a minimally invasive technique, and, in fact, bypass enhances the safety and provides the conditions which simplify the procedures in our opinion.

**DR. GORDON N. OLINGER (Milwaukee, Wisconsin):** This interesting presentation highlights the application of minimally invasive concepts by cardiothoracic surgeons somehow to stall the momentum of cardiology's "stentomania" that threatens to eliminate surgical revascularization for straightforward coronary reconstruction.

There are several variants on this theme, as most of us are aware, but each is conceived to eliminate the allegedly onerous median sternotomy and to minimize the use of cardiopulmonary bypass. It is hoped thereby that patients who are very astute will prefer it to catheter-based therapy, and purchasers of health care will regard it as a bargain.

These are admirable goals, but I share the concern of the other discussants that these efforts are creating a product that may seriously adulterate one of the most effective procedures coronary surgeons and their cardiologists can offer their patients.

Traditional bypass of the left anterior descending (LAD) coronary artery with the left internal thoracic artery (ITA), using state-of-the-art cardiopulmonary bypass with modern methods of myocardial protection, as has been noted, is remarkably safe, very expeditious, and long lasting. It depends on complete take-down of ITA, as has been emphasized by Dr. Landreneau but not by most advocates of the minimally invasive approach. Complete take-down eliminates collaterals, it optimizes available length of conduit to minimize tension on the pedicle, and, very importantly, it facilitates anastomosis to the most proximal segment of the ITA. This matches the largest diameter of graft least prone to spasm to that segment of the LAD most ideally entered. There is the potential that limited incisions may limit surgical options and that these options may be less than ideal. Dr. Landreneau, how do you deal with this issue?

A properly executed ITA graft to the LAD lasts virtually forever. As such, it will be vulnerable to compromise at the time of redo coronary revascularization for advanced native coronary disease. The properly mobilized ITA can be routed beneath the left thymic fat pad through a pericardial incision medial to the pleura that protects it from tension by the expanded lung and makes preservation straightforward during redo coronary bypass, particularly to the posterior and lateral left ventricle. I do

not believe minimally invasive approaches have taken this potential problem into consideration. Dropping the ITA straight down to the LAD through a short pericardiotomy could seriously compromise the long-term utility of this graft and of its proven effect on survival. Dr. Landreneau, could you comment on this?

All minimally invasive approaches, save the one just discussed by Bruce Reitz being investigated at Stanford, use regional myocardial ischemia with adjuvant beta blockade and perhaps ischemic preconditioning without cardiopulmonary bypass. They also employ some kind of loop control of the LAD proximally and distally to achieve a bloodless field for anastomosis. I encourage the minimalists to prove that myocardial damage is not a sequela in patients who have this particular procedure and that late coronary stenosis does not occur in these coronary arteries at the sites of loop control, as it did in the 1970s when this particular practice was very common.

Finally, I would echo concerns related to complete revascularization. Dr. Landreneau, do you and your colleagues advocate, as do others, that diseased posterior and lateral wall coronary arteries be approached by catheter after "keyhole" LAD bypass as the alternative to traditional surgical revascularization? If you do, what is the combined morbidity and cost of this approach? And if not, how do you respond to other advocates of the minimally invasive procedure who do?

Minimally invasive ITA bypass is rapidly evolving, highly variable, as yet unproven in terms of long-term results, driven by market forces, and being applied in bits and pieces by surgeons all over the country. I congratulate Dr. Landreneau and his colleagues for bringing their experience to this scientific forum and hope it will contribute to placing minimally invasive coronary bypass in its most clinically effective role in our therapeutic armamentarium.

**DR. ROBERT H. JONES (Durham, North Carolina):** This recent modification of an old effective procedure has been well introduced by these authors who are to be commended for a good short-term mortality. None of us believe that this modification of the surgical incision will affect the long- or short-term mortality of this operation in comparison with the standard coronary bypass.

The discussion slide compares the results of standard coronary bypass in 9263 consecutive patients at Duke treated with medicine, bypass surgery, or angioplasty and followed for a period of at least five years.<sup>1</sup> The patients are separated by anatomic severity of disease, going from the most simple single-vessel to the most complex three-vessel disease. Results are presented as survival difference per 100 patients that received bypass compared with medical treatment or angioplasty compared to medical treatment.

Groups 1 and 2 are simple single-vessel disease, and they show no survival benefit over the entire period with bypass compared with medical treatment, in contrast to angioplasty, which shows no survival benefit for 2 years, but then survival benefit that seems to persist beyond 5 years. The single group characterized by a 95% stenosed proximal left anterior descending (LAD) is the only group with single-vessel disease that demonstrates survival benefit from coronary bypass.

Of the more than 600,000 patients in this country who receive coronary revascularization procedures annually, only 3% have single-vessel bypass as that procedure. It would appear difficult for any large trial to show greater safety and efficacy for minimally invasive coronary bypass compared with angioplasty as an alternative procedure in this group. This conclusion is further supported by results of randomized trials, such as Bypass Angioplasty Revascularization Investigation (BARI), in patients with double- and triple-vessel disease who showed no survival difference at 5 years between these two procedures for multivessel disease.

I would suggest that there may be a role for minimally invasive bypass in patients with coronary bypass for three-vessel disease who only require one or two vessels revascularized. A previous bypass raises operative mortality by requiring repeat sternotomy. Minimally invasive coronary bypass might have greater short-term safety and, therefore, provide greater long-term benefit than standard bypass in these patients.

Dr. Landreneau, would you share your thoughts about future directions that might provide meaningful outcome comparisons of this with more standard therapies? Which patient population will be used to show what role, if any, this procedure modification has in the treatment of this common disease.

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DR. THOMAS C. MOORE (Torrance, California): I had a feeling of *deja vu* both listening to this very fascinating paper and seeing the illustrations. Some 40 years ago, I reported in *Surgery* (1958; 43:245-253) an experience doing in dogs a mobilized mammary artery anastomosis into a distal coronary artery (just distal to an acutely ligated coronary artery) in a beating heart. I used an internal shunt (a siliconized polyethylene tube) from the mammary artery into the distal coronary to maintain circulation and to facilitate operation on the beating heart. This was a very perplexing and difficult problem and took a good deal of time trying to get it placed properly.

The current report is a most interesting and important approach.

DR. RODNEY J. LANDRENAU (Closing Discussion): I shared Dr. Baumgartner's concerns regarding the risk of iatrogenic local coronary injury and subsequent stenosis. When off bypass coronary artery, revascularization with proximal and distal coronary artery isolation is used. I have discussed this potential problem with Steve Gundry and others who have studied this problem more extensively than I. Our present impression is that such injury can be avoided by obtaining local control by using a wide purchase of myocardium about the coronary vessel rather than controlling the coronary vessel directly. We use either a 4-0 prolene suture or a blunt needled silastic tourniquet

to accomplish this local control placed about the coronary artery at a distance of 5 mm to avoid these problems.

Dr. Baumgartner also inquired into our follow-up on the patients. Five patients have undergone coronary angiography, one of whom had demonstrated an anastomotic stenosis. The other four patients had vague chest pain, but no surgical problem was identified. All the other patients have been evaluated with postoperative echocardiography. They are showing good ventricular wall motion function without evidence of perioperative infarction. The single patient mentioned who had an anastomotic narrowing of the right internal mammary anastomosis to proximal right coronary artery graft was successfully managed with percutaneous transluminal coronary angioplasty (PTCA).

We have been doing this "keyhole" coronary artery bypass grafting (CABG) at approximately 7 months with a mean follow-up of approximately 4 months. At this time, I think our results must be viewed as preliminary. Although we are encouraged by these early results, we will have to reassess the therapeutic efficacy of keyhole CABG at a longer follow-up interval.

We have not combined the keyhole CABG procedure with PTCA to manage multivessel disease, which would have been conventionally approached by open CABG. Dr. Harken and Dr. Baumgartner were interested, as others, in this issue. At the present time, I think keyhole CABG should be limited to elective revascularization of patients having symptomatic single-vessel coronary disease involving the left anterior descending (LAD) circulation or proximal right coronary artery as a potential alternative to repeated endovascular interventions.

Dr. Harken also asked about the possibility of injury to the coronary vessel while conducting the anastomosis on the beating heart. I think that is a legitimate concern. This is a technically demanding anastomosis. In our hands, it takes twice the time it takes to perform the same anastomosis under cardioplegic arrest. You have approximately 15 to 20 minutes of relative local myocardial ischemia to accomplish the anastomosis before potential ventricular dysfunction occurs. Beyond this point, risk of serious ischemia is in question. We have not particularly found "ischemic preconditioning" to be an important assisting maneuver overall. If there is any question at all about the local quality of coronary artery, if the vessel is calcified, if there is any issue of marginal length of the mammary graft, or if local vascular control cannot be achieved, we recommend conversion to a standard sternotomy approach with transfemoral or intrathoracic access for circulatory support. We must remember that mammary artery bypass to the LAD performed under standard conditions can result in control of the patient's anginal symptoms with tremendous long-term results. Our overall goal should be to accomplish uncompromised long-term coronary artery revascularization with the least risk to our patients. For properly selected patients, I do not think this keyhole coronary bypass approach violates these principles.

We have not done a formal assessment of postoperative exercise capacity or postoperative pain differences between open and keyhole CABG patients. Our subjective feeling is that in these keyhole CABG patients, the pain level on the first post-

operative day is equivalent to "open" CABG. However, by the second day, the keyhole CABG people really are a lot more functional than our patients who have undergone standard sternotomy approaches to single-vessel bypass grafting.

Dr. Reitz asked if there was a negative aspect to the use of cardiopulmonary bypass support for this keyhole CABG operation. Were there any adverse effects among the nine patients who underwent femoral cardiopulmonary bypass support? We have not seen any significant problem with the use of such support, other than issues related to the femoral incision and the time required for the establishment of circulatory bypass and separation from cardiopulmonary bypass. We are eager to collaborate with him and his group in their efforts exploring cardiopulmonary bypass supported, minimally invasive coronary artery bypass, and valvular heart surgery. I think that there certainly will be a role for this system in the future as we expand our approaches to multivessel CABG and valvular heart surgery.

Dr. Olinger asked about complete take-down of the IMA and the safety of the present keyhole CABG technique. I truly believe that complete take-down for mammary graft dissection of the mammary artery is important. The most appropriate approach to accomplish this is yet to be determined. Other investigators using a "direct" minithoracotomy approach alone have shown postoperative angiograms demonstrating anastomosis problems characterized by acute angulation of the mammary artery from the chest wall when only partial dissection of the mammary vessel is performed. He also asked if there was

any increased risk of internal mammary artery pedicle injury with subsequent sternotomy. I think that the internal mammary artery is well protected with complete take-down of this pedicle within the groove near the cardiopulmonary hilum. This may be in the long run a better way of controlling, or avoiding, internal mammary artery injury in the redo circumstance because the resulting adhesions related to sternotomy are avoided with this keyhole coronary approach.

At Allegheny General Hospital, we perform approximately 1400 isolated coronary arterial surgical revascularizations a year. The year before beginning the keyhole project, only 50 of those patients had undergone single-vessel coronary bypass. We believe a very small subset of patients are earmarked for the keyhole CABG. Whether or not the number of single-vessel CABGs will increase as the keyhole CABG procedure is chosen as an alternative to PTCA or intraluminal stenting of such lesions is yet to be determined.

Finally, Dr. Moore's comment regarding internal coronary artery shunting during the procedure is an important one. Industry is moving straight ahead in trying to facilitate the development of such shunting tools combined with coronary occlusion devices and apparatuses aimed at immobilizing the epicardial surface of the heart to make the mammary to coronary artery bypass easier. I think it is an exciting time to be involved with surgical coronary artery revascularization. This early experience with minimally invasive operative approaches must be judged as little more than a launching site for other innovative surgeons who will contribute to the refinement of such techniques.