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Arterial Wall Damage Caused by Snaring of the Coronary Arteries During Off-Pump Revascularization

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Luis Roberto Gerola, MD, L. A. R. Moura, MD, Luiz Eduardo Villaca Leão, MD, H. C. Soares, MD, João Nelson R. Branco, MD, and Enio Buffolo, MD

Divisions of Cardiovascular and Thoracic Surgery, Department of Surgery at Escola Paulista de Medicina, São Paulo, Brazil

ABSTRACT

Background: Anastomosis of a saphenous or mammary artery conduit to the coronary artery requires precise and reproducible microsurgical technique. Over the past three decades, the elective induction of cardiac arrest and circulatory support have provided the conditions suitable for microsurgical anastomosis to all coronary vessels. Beating heart coronary grafting was rejuvenated at our center in 1985 as an alternative to cardiopulmonary bypass and cardioplegic arrest. One of the requirements for off-pump grafting is local vascular control of the target vessel and prevention of bleeding into the field from the open coronary artery. The most common hemostasis technique in use today is the application of circumferential traction sutures and snares around the coronary artery. We performed a human cadaver study to evaluate the potential for local trauma to the native coronary artery caused by this method of hemostasis.

Methods: Our research team applied both 5-0 polypropylene and 2-0 polyester snares to the proximal and distal right coronary artery (RCA) and left anterior descending (LAD) in 25 isolated fresh human cadaver hearts. A total of 100 points of snare application to the native coronary vessels were induced and then investigated histologically, with hematoxylin-eosin, Weigert, and phosphotungstic hematoxylin staining.

Results: The results suggested a direct relationship between the severity of the arterial lesion induced by the snares and the degree of local atherosclerotic disease in the native coronary artery. Compression and buckling of the elastic lamellae with medial fractures (similar in nature to angioplasty but directed inward) were seen when snares were applied to a region with marked atherosclerotic disease.

Conclusions: The application of snares to the coronary artery proximal and distal to the anastomotic site must be done with caution. In cases of marked atherosclerotic disease in the underlying coronary artery, a new intimal-medial lesion can occur with indiscriminate application of a tourniquet. This phenomenon may account for some of the reported cases of late peri-anastomotic or distal stenoses seen with off-pump coronary artery bypass grafting and significantly detract from the advantages offered by beating heart surgery. If one or both snares can be avoided entirely, or applied carefully to disease-free segments of the vessel, this problem may be avoided entirely.

INTRODUCTION

In 1985, our group reported a series of patients in which coronary artery bypass grafting (CABG) was electively performed without the use of the heart-lung machine and diastolic cardiac arrest [Buffolo 1985]. In subsequent reports from other centers, the safety of off-pump revascularization has been proven [Buffolo 1990, Benetti 1991, Pfister 1992, Fanning 1993, Buffolo 1996]. Survival rates and perioperative infarction rates have been shown to be equal to, or better than, survival rates with CPB and cardiac asystole [Bergsland 1998, Calafiore 1998b, Hart 1999]. This experience has been expanded in the last few years with an additional emphasis on less invasive surgical incisions. Minimally invasive direct coronary artery bypass (MIDCAB) or the left anterior small thoracotomy (LAST) procedures are essentially off-pump revascularization through limited incisions [Calafiore 1996, Diegler 1997]. There is now ample evidence that these procedures can be performed with acceptable graft patency rates with the addition of lowered complications, length of stay, and total hospital costs [Zenati 1997]. The favorable experience

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Address correspondence and reprint requests to: Luis Roberto Gerola, MD, Escola Paulista de Medicina, SPDM-Hospital São Paulo, Rua Napoleão de Barros, CEP 04024 002, São Paulo, Brasil

Table 1. Native vessel atherosclerosis versus trauma-induced arterial lesions (both LAD and RCA results combined)

	Snare-Induced Arterial Lesion			
Atherosclerosis	Mild (Type 1)	Moderate (Type 2)	Severe (Type 3)	Total N (%)
Grade 1: Mild	71	6	0	77 (77)
Grade 2: Moderate	7	4	0	11 (11)
Grade 3: Severe	2	6	4	12 (12)
TOTAL	80 (80%)	16 (16%)	4 (4%)	100 (100)

of MIDCAB for single vessel disease has now spurned an international growth in transsternal, multivessel off-pump grafting (OPCAB).

One of the essential surgical maneuvers needed to perform beating heart grafting is control of bleeding from the open coronary artery. When the heart is arrested on CPB, this is not an issue. However, when the heart is beating, flow in the native coronary must be temporarily stopped to allow visualization of the arteriotomy and precise suturing. The most common technique used for local hemostasis is the application of encircling sutures and tourniquets (i.e., "snares"). Although effective in achieving hemostasis, the potential for local trauma to the coronary does exist. Gundry et al. reported a concerning incidence of peri-anastomotic lesions in the native coronary artery after OPCAB that he attributed to the effect of snares [Gundry 1998]. To evaluate the potential for trauma to the coronary artery by encircling snares, we performed an original investigation in cadaver hearts [Gerola 1987]. We are now reporting our results and the relationship of regional atherosclerotic disease to the potential for snare-induced vascular trauma.

MATERIALS AND METHODS

Our study was performed using 25 fresh human cadaveric hearts of both genders ranging from 20 to 80 years of age and obtained from recent autopsy material. For the purposes of this study, the left anterior descending (LAD) and right coronary artery (RCA) were chosen as target vessels. In the LAD, snaring was performed in its middle third which is the most common site of graft anastomosis in the clinical setting. For the right coronary artery, the snares were placed around the distal RCA in the atrioventricular groove just distal to the origin of the acute marginal branch.

Snares were constructed from silicon tubing segments threaded over one of two types of suture material: 5-0 polypropylene or 2-0 polyester (see Figure 1, ◎). Using the attached needle, the RCA or LAD was surrounded, penetrating into the atrioventricular sulcus or into the anterior interventricular septum, respectively. Tension on the snare is maintained by drawing the thread through the silicon tubing and clamping with a Kelly type clamp.

Four snares were applied to each cadaver heart, one each in the proximal and distal aspect of both the LAD and RCA. To control and assess hemostasis, a system was devised whereby saline was injected into the main coronary ostia under physiologic pressure. After snaring the vessel for twenty minutes, the arterial segments were excised from the heart, longitudinally opened with Dietrich scissors, fixed in Bouin's solution for a period of 4 to 6 hours, and then stored in absolute alcohol for 24 hours. After that period, the material was sent to the pathologic anatomy laboratory where they were stained with hematoxylin-eosin, Mallory's phosphotungstic hematoxylin and Weigert's methods for elastic fibers. All samples were interpreted by the same anatomic pathologist.

RESULTS

A total of 100 points of snare-induced coronary occlusion were analyzed (25 hearts with two each from the RCA and LAD, respectively). We also correlated the histologic appearance of vessel trauma with the grade of underlying atherosclerosis in the nearby vessel wall. The following scale of atherosclerotic lesion severity was applied:

Grade 1: mild atherosclerosis (see Figure 2, ◎): discrete thickening of the intima, with thickness not going over the equivalent to the median layer

Grade 2: moderate atherosclerosis (see Figure 3, ◎): the thickening of the intima was equivalent to about half the median layer, in addition to the presence of few plaques with dystrophic calcification

Grade 3: severe atherosclerosis (see Figure 4, ◎): presence of a large number of atheromatous plaques, frequent calcifications and ulcerations

Lesions, which were induced at the site of the snares, were also classified in three degrees of severity:

Type 1: mild lesion (see Figure 5, ◎): splitting of the elastic membrane and discrete crushing of the medial layer.

Type 2: moderate lesion (see Figure 6, ◎): crushing of the medial layer with loss of the architecture and, eventually, of any of the elastic membranes.

Type 3: severe lesion (see Figure 7, ◎): total rupture of the media and of the elastic membranes.

Our results are summarized in Table 1 (◎). Our data indicate that local trauma to the coronary arteries can occur when snares are applied. The degree of injury varies from minor splitting of the elastic lamellae (Type 1) to severe rupture of the elastic fibers and media (Type 3). Nearly 80% of the snare locations show evidence of mild trauma (Type 1). Severe disruption of the local vessel architecture (Type 3) was documented in 4% of the snare application sites. The severity of injury appears to be related to the amount of underlying atherosclerotic disease at the site of the snare application. Severe trauma was seen mostly in vessels that also had severe atherosclerotic disease (Grade 3, see Table 1).

DISCUSSION

Local vessel trauma from the application of occlusive vascular clamps has been a well-described phenomenon for many years. Egdahl reported the macroscopic alterations provoked by grasping of the aorta with clamps in a canine experiment [Egdahl 1956]. Henson et al. reported local vessel injury in an in vivo study during abdominal surgery by testing several vascular clamps on the right gastroepiploic artery with subsequent microscopic analysis [Henson 1956].

Hickman et al. proposed three important characteristics for evaluating new vascular clamps: 1) occlusion, 2) prehensile and, 3) lesion degree [Hickman 1962]. These authors were mainly interested in the properties of the vascular clamps and the inflicted lesions, making little reference to the condition of the underlying vessels where the clamps were applied. Wylie, in 1954, had already stated: "The appliance of vascular hemostatic clamps on the aorta that has atherosclerotic disease provokes results that are not observed in a normal aorta" [Wylie 1954]. Masuoka et. al. evaluated several vascular clamps in an experimental atherogenic rabbit model [Masuoka 1980].

These pioneering studies provided a basis for our interest in the effect of snares on the coronary artery during beating heart grafting. The surgical patient with coronary artery disease usually has proximal focal obstructive plaques, but the presence of non-obstructive intimal thickening and atherosclerotic matrix in the vessel wall can often be seen around or near the site of proposed anastomosis. With traditional CPB and cardioplegic arrest, it is not difficult to completely avoid any interaction with local plaque disease in the coronary artery. In some cases, the graft is placed where the vessel is thickened, but the lumen is asanguinous and hemostatic devices are not needed.

With off-pump techniques, the potential for "clamp trauma" is reintroduced into the CABG procedure. Current results indicate satisfactory early angiographic patency rates (over 96%) [Subramanian 1997, Bergsland 1998, Calafiore 1998a & b]. However, there have been concerns raised by Gundry et al. in his report of seven-year follow-up after OPCAB [Gundry 1998]. In his retrospective review, 30% of the OPCAB group required recatheterization for recurrent anginal symptoms versus 18% for conventional cases performed during the same era. Angioplasty or repeat CABG was needed in 20% of the OPCAB group versus 7% of the conventional group. The authors indicated that many of these repeat interventions were needed because of fewer grafts constructed in the OPCAB group (less complete revascularization). However, in the manuscript they also reported new angiographically documented lesions at the site of the vessel loops in three patients with beating heart left internal mammary artery (LIMA)–LAD grafts. In the subsequent discussion, Gundry commented that he found "a fairly even distribution between anastomotic narrowing and narrowing at the site of our vessel occluders" [Gundry 1998].

Gundry and colleagues used silastic tapes to encircle the coronary arteries rather than polypropylene or polyester sutures. However, the technique reported from his center included traction on these tapes to assist in regional stabilization of the coronary artery. This practice is no longer recommended and is certainly unnecessary in the era of mechanical stabilizers. However, the presence of new lesions in the native vessel was a concern that needed to be addressed. It is more common for surgeons (including our center) to use a non-elastic suture such as polypropylene or polyester that is tightened over the vessel using a tourniquet. We chose to investigate this particular hemostatic technique in a cadaver model.

In our study, the importance of local atherosclerotic change in the vessel was clarified. In the absence of severe local atherosclerosis, encircling sutures and snares (tourniquets) induced minimal vessel damage. However, as the severity of local disease progressed, so did the potential for injury by the snares.

Our study was limited by several factors. The coronaries were perfused with saline rather than blood during the period of occlusion. The perfusion was non-pulsatile and the vessels were not reopened to flow under normal, physiologic pressure for a period of time before histologic study. Finally, our testing took place at room temperature rather than body temperature. These factors may have individually, or in combination, influenced the histologic findings. However, the main derivative of our study was to show that snare-induced trauma is real and can lead to significant morphologic changes in the peri-anastomotic coronary vessel. It is very conceivable that a physical stenosis would have evolved at a future date if this were to happen in vivo, causing recurrent symptoms or occlusion of the graft.

Although our experimental conditions did not exactly reproduce the surgical conditions typical of off-pump grafting, we conclude that snaring of the coronary artery in a region of mild or absent atherosclerosis is a safe technique and will not typically disrupt the vessel architecture. However, if the same technique is applied where there is moderate-to-severe plaque disease, the potential for a new lesion exists. This type of physical trauma can be viewed as a "reverse angioplasty" as the disruptive force is directed inward rather than outward. The occluding force is also applied over a very small and focal point along the arterial wall, which means a high force per unit area and increased likelihood of damage.

We believe that it is imperative to place snares in a region that is either disease free or the least affected by plaque as possible. This means the anastomosis must be placed somewhat distal on the target vessel in order to avoid the usual proximal plaques. Moving the arteriotomy distally implies that the vessel is bypassed where the diameter is somewhat smaller, but also the chance of late development of new disease is lessened. If the snare distal to the graft site can be avoided, this would eliminate the possibility of a late obstructive lesion impairing graft outflow. The development of misted blower devices has reduced the need for a snare to control backbleeding from the distal vessel [Teoh 1991].

Snares should be applied with the least force possible to occlude flow. In some cases, the use of a snare may be

avoided by insertion of an intraluminal shunt [Rivetti 1998] or intraluminal occluder. Shunts can also restore flow to the distal coronary and reduce ischemia during graft construction. When silicone tapes are used for coronary hemostasis, care must be taken to limit the traction force and these tapes must not be used to assist in mechanical stabilization of the target vessel.

In conclusion, caution is advised regarding the indiscriminate use of snares in OPCAB grafting. In order to achieve results that are equal or better than those of arrested heart techniques, the potential for coronary arterial damage by encircling snares must be minimized. Application of the snare to a disease-free portion of the coronary artery, avoidance of distal snares whenever possible, the avoidance of mechanical stabilization by traction on the snare, and/or the use of an intraluminal shunt should effectively eliminate the possibility of a new postoperative coronary artery stenosis from snare-induced plaque damage.

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REVIEW AND COMMENTARY

1. Editorial Board Member XF139 writes:

The concept and mechanism of vascular injury caused by temporary coronary occlusion is obviously of great interest to those surgeons performing OPCAB. Although the study has significant flaws, it will stimulate further work and may influence surgical technique.

a) The figure shows an unbuttressed snare closely encircling the coronary artery. I hope that nobody actually does this in real life. How far were the snares from the vessel wall? Given the needle size on 5-0 prolene, I presume they were very close.

b) The experiments were done on (presumably) refrigerated cadavers. What is the significance of histologic changes resulting from post-mortem injury?

Authors' Response by Luiz Roberto Gerola, MD:

a) The cadavers in this experimental study were autopsied within a short time of death, most of them within less than 8 hours. During this period, the cadavers were maintained in a refrigerator and were removed to performed the autopsies. The hearts were removed during autopsies and the experiments were immediately performed. Although post-mortem changes influence histologic changes, it's important to remember that we compared different segments with severe and not severe atherosclerosis and when we found an important traumatic lesion from a snare, it was associated with severe atherosclerosis.

b) If the post-mortem histologic changes had significant influence on these lesions, perhaps there would not have been an observable association between intensity of atherosclerosis and severity of snare-induced lesions. With regard to the distance of needle from the vessel, the procedures were similar to those used in clinical operations—very close without removing fat around the coronary artery. We tried to simulate the same technique used in surgical practice.

2. Editorial Board Member TK289 writes:

Limitations of the methodology as stated by the authors are accepted. We need some quantification of the tension applied to each snare. All of these can be pulled up to just occlude flow or very tightly. Ideally, this is the preliminary data for an in vivo study, which really should accompany and add enormously to this study. Thus, we would need a model of atherosclerosis and this would need to be a perfused model. The authors need to assess the role of local ischemia as a contributor to the endothelial damage due to snares.

Authors' Response by Luiz Roberto Gerola, MD:

The association between local ischemia and the endothelial damage is an important question, but ischemia in cadavers is too difficult to assess because the time of death, which influences and possibly adds lesions to the endothelium. On the other hand, this study was performed during the initial phase of our off-pump CABG program. During that time we were worried about possible traumatic lesions from the snares and tried to assess different occlusion techniques. In this respect, we believe that this pilot study answered our initial questions and, as a result, we changed our standard to use of silicone tubes with prolene 5-0 for coronary occlusion. Today, we have more than 2,500 patients operated on using this method with a mortality rate of 1.8%.