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Minimally Invasive Subclavian/ Axillary Artery to Coronary Artery Bypass (SAXCAB): Review and Classification

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ABSTRACT

Background and Purpose: Subclavian/axillary artery to coronary artery bypass (SAXCAB) surgery is defined as a minimally (or less) invasive coronary revascularization procedure where one or more grafts are anastomosed to the second or third parts of the subclavian artery or any of the three parts of the axillary artery (inflow source) and attached to one or more coronary arteries, and where there are two separate minimally invasive incisions to expose the target coronary artery and the inflow sources, respectively. The indications and contraindications for SAXCAB surgery are discussed, and the relevant chest wall anatomy and that of the subclavian and axillary arteries are reviewed. The effect of respiration and anatomic variability as they impact the SAXCAB graft are discussed.

Three components of the anatomy that are important in SAXCAB surgery are discussed: The relation of the first rib to the clavicle insofar as it affects access to the third part of the subclavian artery, the anatomy of the subclavian and axillary arteries and their branches, and the anatomy of the chest wall and its movement. In addition, the different SAXCAB variations that have been applied clinically are reviewed and classified, and future aspects of SAXCAB research are discussed.

SAXCAB surgery is unique among the different types of minimally invasive direct coronary artery bypass (MIDCAB) surgery because of the enormous diversity of the techniques that have been described. Based on these descriptions, a new classification of SAXCAB grafting is proposed depending on whether the graft is inside or outside the rib cage and whether or not the coronary artery is exposed by rib resection or through an intercostal space. The third part of the classification takes into consideration the mode of entry into the chest, whether it is by rib resection or through an intercostal space.

Methods: Inquiries were made by telephone and by mail in the year 2000 to a number of surgeons who had published details of their SAXCAB techniques, and informal information was obtained by a series of personal communications as to the estimated number of operations they had performed and the outcomes. Published data was also used to formulate a rough guide as to the international status of the procedure at this time.

Results: The total estimated international experience is about 100 cases and the patency is between 70 and 100 percent in the time frame of about one to two years.

Conclusions: The MIDCAB technique in general has been successful in providing an alternative way to revascularize the coronary arteries, and the SAXCAB has proved to be one of the most interesting classes of MIDCAB surgery. SAXCAB grafts seem to be unique among coronary revascularization procedures and, indeed, probably almost all vascular procedures, in that there is enormous diversity in the route for the graft from the inflow source to the target coronary artery. Being knowledgeable about the different varieties of SAXCAB surgeries will help the surgeon during a rescue operation as the surgery can be tailored to suit a particular patient. The SAXCAB seems to be a very safe operation, and it is striking that so far no one has reported any major complications.

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INTRODUCTION

Minimally invasive direct coronary artery bypass (MIDCAB) surgery is a valuable adjunct to classical coronary bypass techniques [Benetti 1996, Calafiore 1996]. The advantages of MIDCAB surgery include avoidance of cardiopulmonary bypass with its attendant complica-

Table 1. Indications for SAXCAB Procedure

1. Internal mammary thrombosed from previous surgery.
2. Internal mammary has inadequate flow.
3. Internal mammary too short.
4. Internal mammary anastomosis difficulties.
5. Advanced emphysema. Patient would not tolerate chest wall retraction required to dissect length of LIMA.
6. Another inflow source needed for a diagonal vessel where the IMA has been used for the LAD.

tions, avoidance of aortic manipulation and the potential for dislodging emboli, and the avoidance of a sternotomy. In the last regard, MIDCAB surgery has proved particularly valuable in the setting of a first or second reoperation or where there is a hostile mediastinum. Usually the left internal mammary artery (LIMA) is used as the inflow source for the left anterior descending (LAD) and diagonal coronary arteries. However, in those situations where the LIMA is not a useful vessel, the subclavian or axillary artery may be used as the inflow source, and the radial artery or saphenous vein may be used as a graft to reach the LAD or diagonal coronary artery on the left side [Coulson 1997]. On the right side, a similar situation prevails; the right subclavian/axillary artery may be used as the inflow source for the right coronary artery or the posterior descending branch of the right coronary artery (PDA).

The aim of this review is to offer a definition of this new operative technique in coronary artery bypass grafting, to examine the indications and contraindications, and to summarize the history of the development of subclavian/axillary artery to coronary artery bypass (SAXCAB). Relevant chest wall anatomy and the anatomy of the subclavian and axillary arteries are reviewed. Three components of the anatomy are important in SAXCAB surgery: The relation of the first rib to the clavicle insofar as it affects access to the third part of the subclavian artery, the anatomy of the subclavian and axillary arteries and their branches, and the anatomy of the chest wall and its movement, as respiratory excursion may impact graft patency depending on the route of entry of the graft into the thorax. In addition, the different SAXCAB variations that have been applied clinically are reviewed and classified, and future aspects of SAXCAB research are discussed.

It should be stated at this point that the review deals only with the minimally invasive approach to the subclavian and axillary arteries and not with the thoracotomy approach, where the subclavian and coronary arteries are both exposed through the same large thoracotomy incision and the whole graft necessarily lies within the chest [Fanning 1993]. Similarly, this review does not deal with the use of the axillary or subclavian arteries as inflow sources in those situations where there has been a sternotomy approach to the heart; Bonatti et al. have discussed this type of surgery elsewhere [Bonatti 1999].

MATERIALS AND METHODS

Definition of SAXCAB Surgery

SAXCAB surgery may be defined as a minimally (or less) invasive coronary revascularization procedure where one or more grafts are anastomosed to the second or third parts of the subclavian artery or any of the three parts of the axillary artery (the inflow source) and attached to one or more coronary arteries, and where there are two separate minimally invasive incisions to expose the target coronary artery and the inflow source, respectively.

Indications for SAXCAB Operation

For the vast majority of MIDCAB procedures, the internal mammary artery (IMA) is the inflow vessel of choice (Table 1, ◎). However, the IMA may sometimes be traumatized during harvest and rendered useless. In addition, increasing numbers of patients are seen who have had a LIMA-to-LAD bypass in previous years and whose LIMA has subsequently thrombosed. Other patients are seen who have had previous valve operations, and their LIMAs have been inadvertently caught in the sternal wiring during closure and rendered useless. It is under these circumstances that the surgeon may resort to the SAXCAB procedure as a rescue operation [Bonatti 2000a].

Another problem that is sometimes seen in MIDCAB surgery is that the IMA may not be long enough to reach the target site, particularly if the target is the PDA; or on the left side the LAD or diagonal may be at an increased distance from the LIMA if the patient has cardiomegaly or extreme clockwise rotation of the heart. This problem may be addressed by using graft extensions of the IMA such as the inferior epigastric extension described by Calafiore et al. [Calafiore 1998] or using the TRUCAB technique [Coulson 1998a], or as an alternative the surgeon may elect to place a graft from the subclavian/axillary artery to the coronary artery. Sometimes there is nothing wrong with the harvest technique and the IMA is just intrinsically a small vessel with inadequate flow. Under these circumstances, especially if the target coronary is a large vessel, performing a SAXCAB using a large diameter saphenous vein might be a more prudent choice.

Sometimes there are technical problems with the anastomosis, such as when the IMA wall is brittle and cracks easily or crumbles. One option is to go higher up the IMA until a more manageable area is encountered and extend the shortened IMA with a graft or, alternatively, resort could be made to the SAXCAB procedure.

In all of these cases another alternative strategy would obviously be a sternotomy and the use of the ascending aorta as the inflow source. When the IMA is inadequate, surgical judgment is required in deciding between an extension graft, an off-pump coronary artery bypass procedure (OPCAB) with sternotomy, a SAXCAB, or possibly the use of the right gastroepiploic artery or other upper abdominal arteries as alternative inflow sources. The saphenous vein is more forgiving than the IMA and easier to work with. This makes a saphenous vein graft an attractive technique in a teaching environment [Coulson 1998c]. If both the LAD and diagonal coronary artery need grafts, one strategy would be to use the IMA to revascularize the LAD and use a SAXCAB approach for the diagonal. This approach is technically easier than attempting an IMA jump graft on the beating heart.

Another indication for the SAXCAB procedure is in patients with severe emphysema or advanced lung disease where the patient would not tolerate IMA harvest using conventional MIDCAB techniques because of the postoperative pain from the trauma to the rib cage required to expose the IMA for harvest. In these cases, the SAXCAB technique would reduce the trauma and pain that would otherwise impair these patients' breathing in the postoperative period.

Contraindications to the SAXCAB Technique

A patient with an obstructed subclavian or axillary artery would not be a candidate for the SAXCAB operation (Table 2, ◎). Similarly, patients with stents in the subclavian or axillary arteries would not be good candidates, nor would a patient with a subclavian aneurysm. Other contraindications to the use of a subclavian or axillary artery would be upper extremity ischemia or a hemodialysis patient with an arteriovenous fistula in the ipsilateral arm. Patients with infections or tumors in the infra-clavicular region or patients with a history of radiation therapy in this area would probably not be good candidates for the SAXCAB procedure. A relative contraindication would be the presence of a pacemaker or a permanent central venous access implanted in the subclavian vein with limited access to the nearby artery. Patients with a history of a fractured clavicle would need careful assessment preoperatively.

The First SAXCABs

The idea of using the subclavian/axillary artery as an inflow source to revascularize the heart while using a MIDCAB approach occurred to a number of different people at about the same time. Coulson and Bakhshay's first case [Coulson 1997] was performed at Dameron Hospital in February 1996. In Innsbruck, Bonatti's team received permission from the Department of Forensic Medicine to perform studies on cadavers in March 1996, Knight's first case took place in April of 1996 [Knight 1997], and Cooley's patient had his surgery in May of 1996 [Yaryura 1997].

The Dameron patient was transferred for emergency MIDCAB surgery from another hospital in Stockton. When the surgery started, the IMA was found to be caught in the sternal wiring placed earlier after an aortic valve replacement. The left subclavian/axillary artery was chosen as an alternative inflow source in preference to reopening the sternum of this high-risk patient. The vein graft was sutured to the LAD and then brought through the pleural space and out through a "window" made in the left second rib. It was then sutured to the subclavian/axillary artery in the area where the subclavian artery changes its name as it crosses the outer border of the first rib (Figure 1, ◎).

Table 2. Contraindications to the SAXCAB Procedure

1. Obstructed subclavian or axillary artery.
2. Previous stenting of subclavian or axillary artery.
3. Ipsilateral upper extremity ischemia.
4. Arteriovenous fistula for dialysis.
5. Aneurysm of subclavian or axillary artery.
6. Infection in the infraclavicular area.
7. Tumor in the infraclavicular area.
8. Pacemaker or permanent central venous access in the infraclavicular area.
9. Previous fractured clavicle.

ANATOMY

The Axillary Artery and Its Branches

The anatomy of the axillary artery (Figures 2 ◎ and 3, ◎) and its branches is subject to a number of possible variations [Huelke 1959]. Classically, the third part of the subclavian artery descends from the lateral border of the

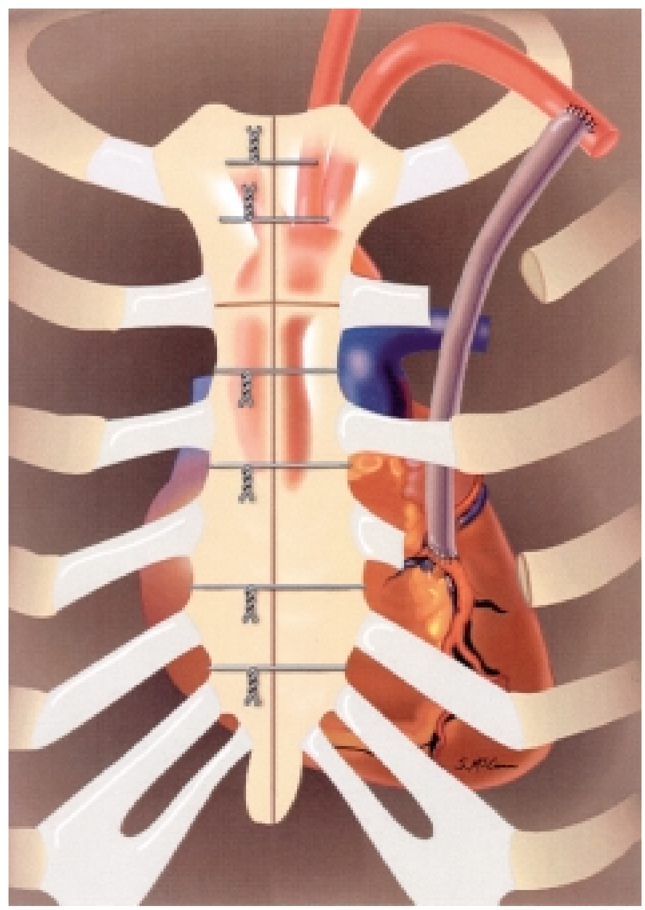

Figure 1. The left subclavian/axillary artery used as an alternative inflow source to revascularize the LAD in a MIDCAB patient where the LIMA was found to be caught in previous sternal wires. A "window" was made by resecting the left second costal cartilage and a nearby piece of rib (February 1996).

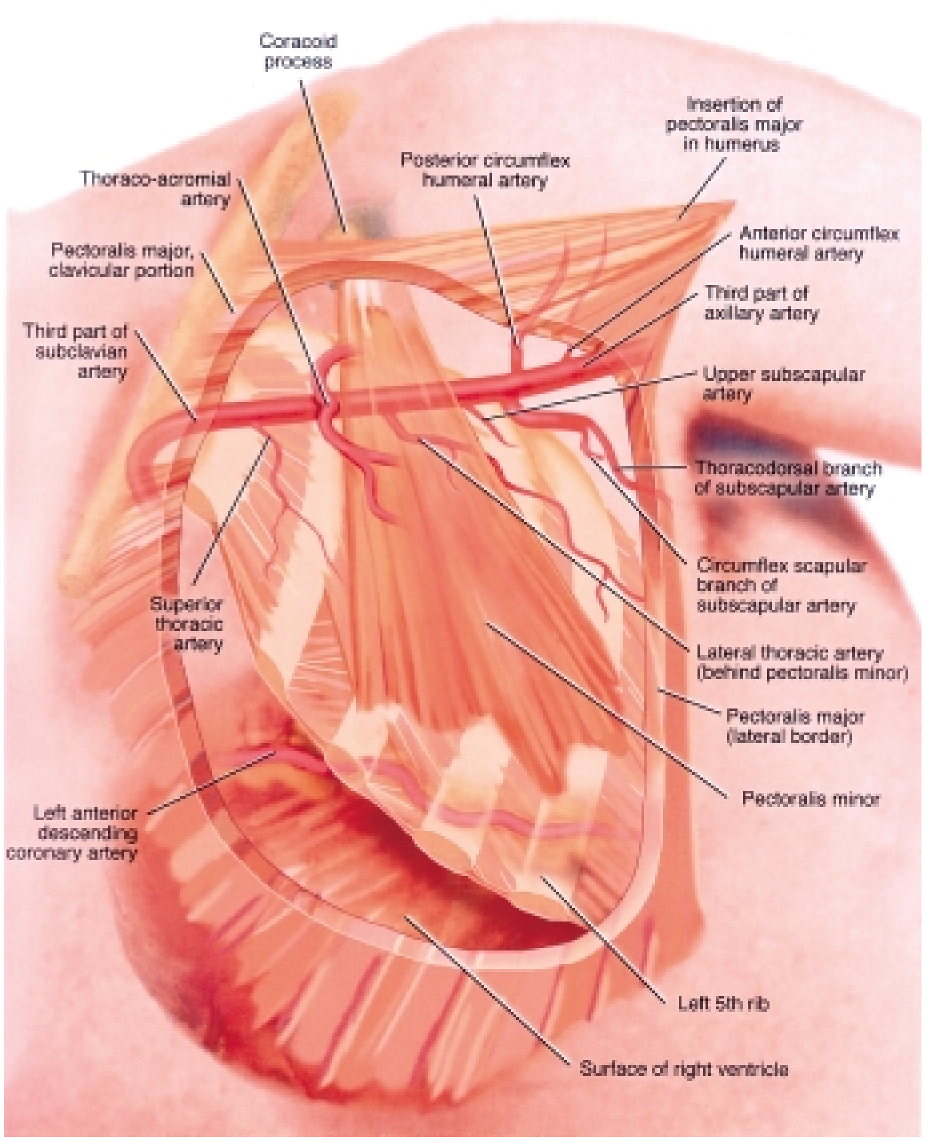

Figure 2. The anatomy of the third part of the left subclavian artery and the three parts of the left axillary artery. The axillary artery is divided in three parts by the pectoralis minor muscle. The relationship of the axillary artery to the left anterior descending coronary artery is depicted.

scalenus anterior to the outer border of the first rib, where it becomes the axillary artery. The subclavian artery is related anteriorly to the deep cervical fascia and the external jugular vein. The subclavian vein is located antero-inferiorly, and the lower trunk of the brachial plexus is postero-inferior between the artery and the scalenus medius. The upper and middle trunks of the brachial plexus are located superolaterally. The dorsal scapular artery usually arises from the third part of the subclavian artery.

The axillary artery begins at the outer border of the first rib and ends at the inferior border of the teres major, where it becomes the brachial artery. The junctional, or border, area where the subclavian artery changes to the axillary artery may be a source of confusion during the conduct of surgery; it is possible, for example, to have half the proximal anastomosis in what is nominally the subclavian artery and half in what is nominally the axillary artery.

The pectoralis minor crosses the axillary artery and divides it into three parts. These parts are in turn proximal, posterior, and distal to the muscle. Anterior to the first part of the axillary artery are the clavicular fibers of the pectoralis major and the clavipectoral fascia, and the cephalic vein. Posteriorly are located the first intercostal space covered by the first digitation of the serratus anterior, the long thoracic nerve, and the medial cord of the brachial plexus. The posterior cord of the plexus is situated laterally, and the axillary vein is related anteromedially.

The second part of the axillary artery is deep to the pectoralis major and pectoralis minor muscles, and anterior to the posterior cord of the brachial plexus resting on the subscapularis muscle. Medially lies the axillary vein and

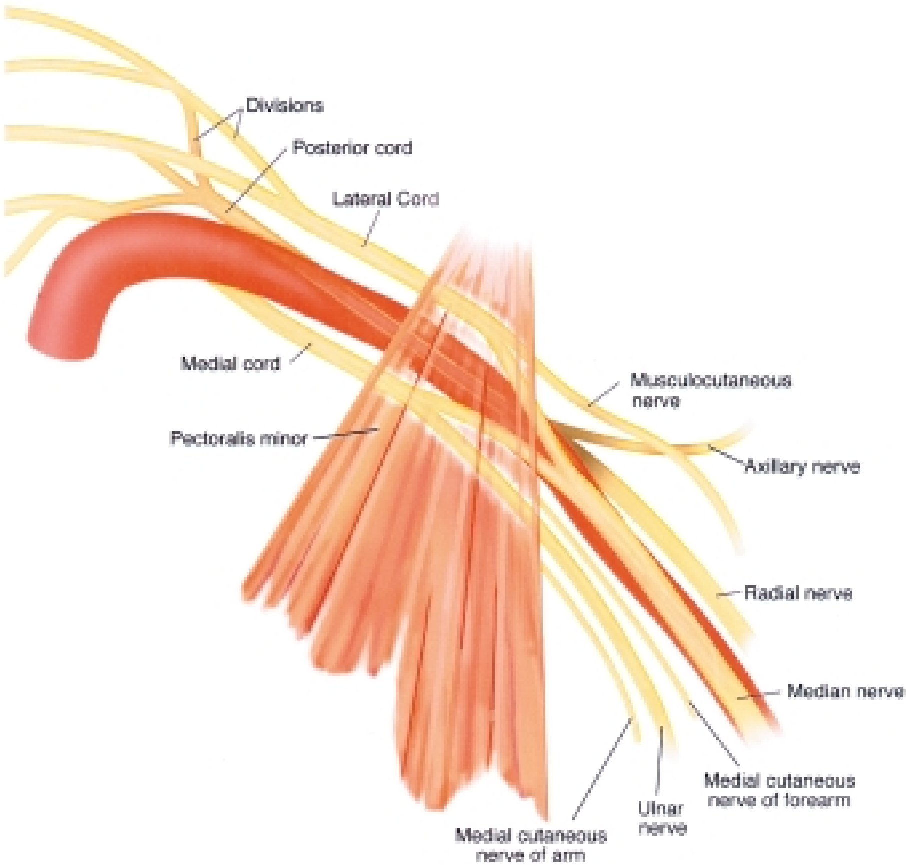

Figure 3. The relationship of components of the left brachial plexus to the left axillary artery.

the medial cord of the plexus between the vein and the artery. The lateral cord of the plexus is related laterally. The cords of the brachial plexus, thus, surround the second part of the artery on three sides (Figure 3, ◎).

The third part of the axillary artery is the longest, and it is related anteriorly to the pectoralis major and posteriorly to the tendons of the latissimus dorsi and the teres major. The vein is on the medial aspect. Components of the brachial plexus continue their intimate relationship with the artery. On the lateral aspect is located the musculocutaneous nerve and the lateral root and trunk of the median nerve. Medially between the artery and the vein are the medial cutaneous nerve of the forearm and the ulnar nerve, and anteriorly is the medial root of the median nerve. The medial cutaneous nerve of the arm is medial to the axillary vein.

Important branches of the axillary artery are the superior (supreme) thoracic artery arising from the first part of the axillary artery. From the second part arises the thoraco-acromial (acromiothoracic) artery, which traverses the medial border of the pectoralis minor before piercing the clavipectoral fascia. The lateral thoracic artery (also a branch of the second part of the axillary artery) follows the lateral border of the pectoralis minor and is larger in females.

The largest branch of the axillary artery is the subscapular artery, which arises from the third part of the axillary artery at the inferior border of the subscapularis. The subscapular artery follows the border of the subscapularis muscle to the inferior scapular angle. The anterior circumflex humeral artery arises from the lateral side of the third part of the axillary artery and runs horizontally anterior to the surgical neck of the humerus. The posterior circumflex humeral artery arises from the third part of the axillary artery and runs back with the axillary nerve through a quadrangular space. Both the thoraco-acromial and thoracodorsal branches of the axillary artery have been used as inflow sources for coronary bypasses.

Ribs and Respiratory Movement

Variations in the thickness of the ribs and the width of the intercostal spaces are both relevant to SAXCAB surgery, as is the respiratory excursion of the ribs, because deep inspiration and expiration, as well as coughing, may theoretically jeopardize flow in a SAXCAB graft. In this regard, Tovar [Tovar 1998a] thought that a graft traversing the first interspace might be pinched by the ribs. In fact, on further analysis, it has been shown that there is hardly any possibility of a pinching effect resulting from movement of the medial parts of the second and third ribs, as they are only a short distance from the area where they are fixed to the sternum. Magovern [Magovern 2000] advocates a wide incision in the medial aspect of the first interspace to permit graft access – one wide enough to admit two fingers.

Rib motion can be thought of as a hinge movement about an axis that passes through the neck of the rib and the articulation of the head and the tubercle. The direction of this axis is oriented backwards and laterally. The rib is inclined downwards and forwards and terminates in a cartilage that inclines upwards and forwards. Rotation about the posterior hinge axis causes the second through seventh ribs (the vertebrosternal ribs) to move upward, laterally and forward. The inferior margin of the rib is displaced more laterally than the upper margin. This rotation of the rib also results in an increase in the transverse diameter of the chest cavity. At the same time, the intercostals cause the sternal ends of the costal arches to rise. In consequence, the body of the sternum is pushed forward, and the anteroposterior diameter of the chest increases. With deepening inspirations, intercostal muscles become active in progressively higher spaces to move the upper ribs and sternum.

There are differences in the movement of the upper and lower parts of the chest wall. In the lower ribs the lateral movement is more emphasized. As a result of these differences, the enlargement of the upper part of the chest is to a greater extent in the sagittal plane, while that of the lower part is in the transverse plane. This might indicate that the higher up the graft enters the chest cavity the better, as the graft would be subjected potentially to less trauma at the point of entry secondary to rib movement.

The forward movement of the ribs in inspiration results in the lower end of the sternum undergoing a greater forward displacement than the upper end. This movement is greater in the manubrium than in the body of the sternum. The body, thus, becomes bent more on the manubrium at the sternal angle.

The thoracic movement that takes place in breathing produces stresses within the costal cartilages that tend to restore the thorax to its neutral respiratory position. The range of movement differs in different individuals; however, in general, it may be stated that from the neutral position the upward movement of the sternum in deep inspiration varies from one to two inches. In deep expiration, the downward movement is less than half an inch [Boyd 1956a]. Using the vertebral column as a reference point, absolute movement at the level of the first, second, and third ribs where they join their respective cartilages is about a quarter to half an inch.

Based on the above considerations, there has been a substantial discussion in the literature on the interaction between the surgical technique employed and the mechanics of respiration as they affect the outcome of the SAXCAB graft. For example, rib resection to make a window to reduce the risk of graft compression would seem to be a simple and obvious thing to do. However, such rib and cartilage resection might not be entirely without problems. Tovar [Tovar 1998b] thought that resection of the second rib might cause chest wall instability when combined with fourth rib resection to expose the LAD, and for this reason he thought that removal of the anterior portion of the first rib was preferable rather to a second rib resection. In addition, Tovar thought that resection of the first rib allowed easier exposure of the axillary artery, and he made the point that the saphenous vein graft does not have to go over the first rib as it enters the pleural cavity. Knight, however, commented [Knight 1998], "In at least one way I favor Coulson and Bakhshay's technique, passing the vein through the bed of the resected second costal cartilage. This allows a deep, protected course for the graft." Magovern et al. [Magovern 2000] have not found rib resection to be necessary if the intercostal incision is wide enough to admit two fingers.

Tovar expressed the concern that tunneling the graft into the thoracic cavity might limit its patency. Bonatti's response [Bonatti 1998] was that graft occlusion by intercostal compression was avoided by taking special care to create "a large hole" to allow a "loose and compression-free course for the graft." Intraoperative flow measurements and postoperative duplex scans both performed during forced respiration on outpatients have shown no changes in bypass flow [Bonatti 1999]. Bonatti's concern about the course of the graft was directed more towards the possibility of development of neointimal hyperplasia at the rib crossing site, and he thought that partial rib resection was debatable in some cases. So far, studies on SAXCAB grafts indicate that there is no predilection for neointimal hyperplasia to develop in the area of the thoracic window; neointimal hyperplasia seems rather to develop diffusely along the whole length of the graft. However, Bonatti stresses that his data is based on relatively short-term observations and this necessitates some caution at this time.

Relation of Clavicle to First Rib and Variation of Habitus

The clavicle provides bony protection for the subclavian and axillary vessels and the brachial plexus. The normal anterior curvature in its medial two-thirds provides an arch through which the neurovascular bundle can pass behind and beneath it to enter the axilla. In some individuals this curvature is minimal, thus narrowing the costoclavicular space [Lord 1971].

Access to the third part of the subclavian artery as it lies on top of the first rib is governed by the curvature of the clavicle and the distance between the clavicle and the first rib. Some idea of the anatomical variation can be gauged from the studies of Lechner et al. [Lechner 1989], where they showed that when three bony landmarks are measured, the medial end of the clavicle, the acromion, and the sternal angle, the distance between the acromion and the sternoclavicular joint varied from 160 to 210 mm depending on the patient's constitution. Studies by Land [Land 1971] showed that there was a considerable variation in the relationship between the subclavian artery and vein and the clavicle. The relative positions of these structures also change with abduction of the arm and with elevation of the shoulder.

Another important consideration is the habitus of the patient, as no two chests seem to be exactly alike [Boyd 1956b]. A patient with an increased anteroposterior diameter will have an increased distance from the subclavian/axillary artery to the heart. A tall, thin patient with a pyknic or asthenic morphology would similarly

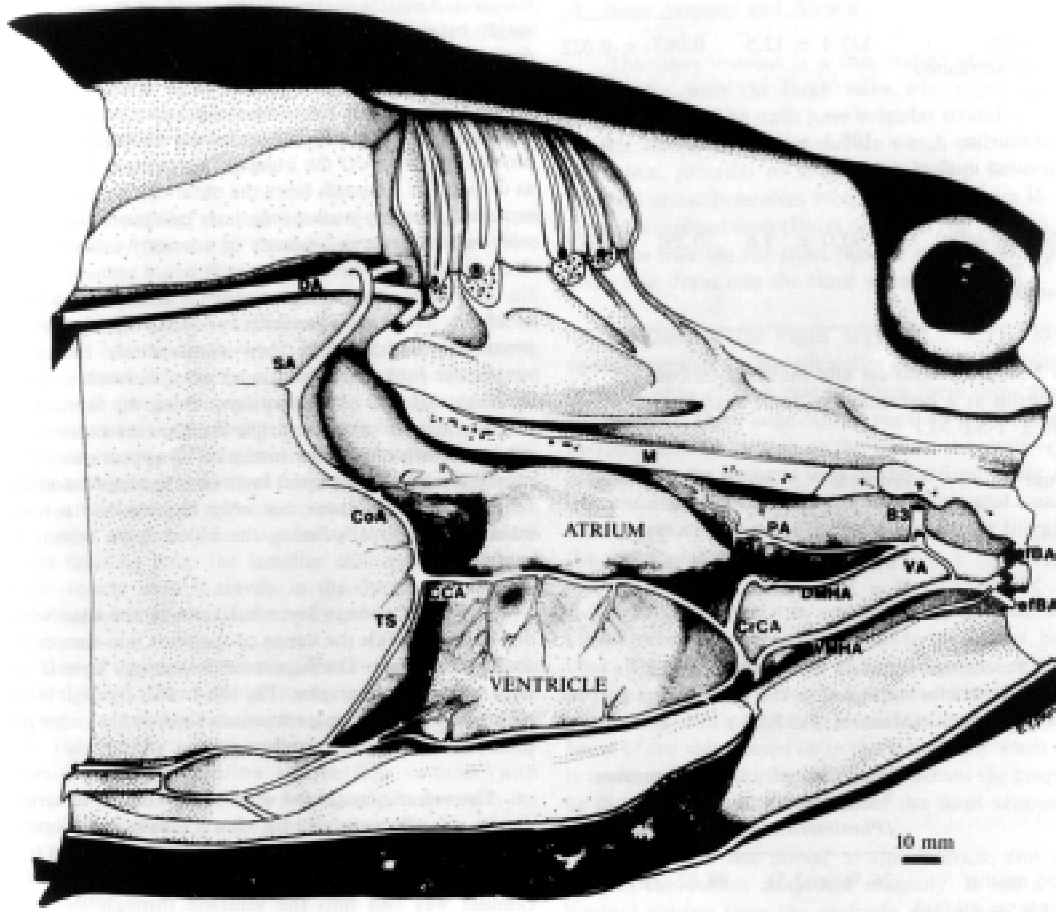

Figure 4. The heart of a striped marlin in situ. The caudal coronary supply is derived from the dorsal aorta (DA) via the subclavian artery (SA), and coracoid artery (CoA). The caudal coronary arteries (CCA) arise from this vessel and cross the pericardial cavity to the ventricle. Reproduced by permission of Dr. Peter S. Davie from his book Pacific Marlins, Anatomy and Physiology published by Massey University, Palmerston North, New Zealand.

have an increased distance to traverse because the heart is elongated. Habitus also impacts access to the distal subclavian artery. A thin patient will permit easier access to the first rib and the subclavian/axillary junctional area, whereas in an emphysematous or bull-chested individual this approach would pose more of a problem. Anatomists generally have been impressed by the striking individual variations in the nature of thoracic movement; it seems to be affected by the "form of the thoracic skeleton, the patient's habitus, and other factors...." [Williams 1989].

Pectoralis Major and Minor

The pectoralis major assists humeral adduction and medial rotation. With the shoulder braced back and the pectoralis major contracted hard, there is considerable pressure deep to the muscle.

The pectoralis minor assists the serratus anterior in drawing the scapula forward around the chest wall. With the levator scapulae and the rhomboids, it rotates the scapula, depressing the shoulder. If division of the pectoralis minor is necessary during SAXCAB surgery, it should not greatly impact shoulder or arm movement.

Sakakibara [Sakakibara 1998] expressed concern about Knight's position for his saphenous vein graft. It was his impression that the saphenous vein graft was "crammed" between the pectoralis major muscle and the ribs. He suggested that direct extrinsic pressure on the saphenous vein graft resulting from muscle contraction and respiration in daily life might cause graft occlusion in the acute phase, and might also result in the production of long-term vein graft disease. He indicated that he preferred Yaryura's technique [Yaryura 1997] with tunneling over the first rib and under the second rib to avoid a long course for the saphenous vein graft.

Shabb and Khalil [Shabb 1999] also had concerns about the subpectoral tunneling affecting long-term patency. They recommended close follow-up of such grafts. In their patients who had subpectoral tunneling, all grafts were patent at six months, indicating that mechanical compression may not be a significant factor in long-term patency in their population.

Comparative Anatomy

In amphibians, reptiles, and mammals, the coronary circulation arises from the aorta close to the heart (Figure

Table 3. Classification of SAXCAB Surgeries

SAXCAB Type	Location of Graft	Exposure of Coronary Target	Entry into Chest	Reference
A	Inside the chest.	Rib/cartilage resection.	Supraclavicular.	Tovar [1998a]
B	Inside the chest.	Rib/cartilage resection.	Rib/cartilage resection.	Coulson [1997] Tovar [1998a]
C	Inside the chest.	Rib/cartilage resection.	Through intercostal space.	Yaryura [1997]
D	Inside the chest.	Through intercostal space.	Supraclavicular.	Dottori [2000]
E	Inside the chest.	Through intercostal space.	Rib/cartilage resection.	
F	Inside the chest.	Through intercostal space.	Through intercostal space.	Bonatti [2000c] Wolf [1999] Morishita [1998] Watanabe [1998] Magovern [2000]
G	Outside ribs under pectoralis major.	Rib/cartilage resection.	N/A.	Knight [1997] Bhimji [1998]
H	Outside ribs under pectoralis major.	Through intercostal space.	N/A.	Shabb [1999]
I	Subcutaneous outside pectoralis major.	Rib/cartilage resection.	N/A.	
J	Subcutaneous outside pectoralis major.	Through intercostal space.	N/A.	Machiraju [1998]

4, ◎). In eels, marlins, rays, and skates there is an additional posterior origin for coronary arteries that usually goes to the apex of the ventricle. This posterior coronary circulation is usually associated with the coracoid branch of the subclavian artery and reaches the heart by way of the ligaments between the pericardium and the ventricle.

In the rays, there are one or two "posterior" coronary arteries arising from the subclavian artery or its coracoid branch. They extend along the sinus venosus to be distributed to the dorsal aspect of the ventricle. In the case of the fish Raia clavata, an elasmobranch fish, the ventricle is attached to the pericardium. In addition to the normal coronary arteries with a cephalic origin, there are also two caudal arteries on each side corresponding to the lateral apical arteries of the eel. Both arise from the coracoid branch of the subclavian artery [Grant 1926].

THE PROPOSED CLASSIFICATION OF SAXCAB SURGERIES

Most MIDCAB techniques are fairly standardized regardless of whether the inflow vessel is the IMA, the descending thoracic aorta, or the right gastroepiploic artery. There are few controversies concerning the actual conduct of the operation. However, in the course of placing an extra-anatomic graft from the second or third parts of the subclavian artery and its axillary artery continuation, and entering the chest to reach the target coronary artery, many different options are theoretically possible. (See Table 3 ◎ and Figures 5–13, ◎.) Tovar noted that several routes have been reported to tunnel axillocoronary grafts into the chest cavity: a subcutaneous course, a subfascial plane, a tunnel through the bed of the second costal cartilage, or a tunnel through the intercostal muscles [Tovar 1998a].

The following new classification of possible SAXCAB surgery techniques is proposed (Table 3, ◎). Altogether 10 different possibilities are considered (A through J). The first consideration is the location of the graft, and in the first six types (A through F) the graft is inside the chest. Types A, B, and C have exposure of the coronary artery by way of a rib or cartilage resection. Types D, E, and F have exposure of the coronary artery through an intercostal space without rib or cartilage resection. In type A, entry into the chest is via a supraclavicular route; in type B it involves a rib or cartilage resection, and in type C the entry is through an intercostal space. In the case of Type D, entry is into the chest through a supraclavicular route. Type E involves rib or cartilage resection, and type F is though an intercostal space.

Types G, H, I, and J have the graft located outside the ribs, either under the pectoralis major (G and H) or in a subcutaneous location (I and J). In the case of type G, the coronary artery is exposed by rib or cartilage resection. In type H, the coronary artery is exposed through an intercostal space, and in type I, the coronary artery is exposed by rib or cartilage resection. In type J, the coronary artery is exposed through an intercostal space.

So far, no one has described types E or I, but all the other types have been described in detail by one or more surgeons. The techniques are tabulated in Table 3 (◎) and depicted in Figures 5 through 13 (◎).

RESULTS

Inquiries were made by telephone and by mail in the year 2000 to a number of surgeons who had published details of their SAXCAB techniques, and informal information was obtained by a series of personal communications as to the estimated number of operations they had performed and the outcomes. Published data was also used to formulate a rough guide as to the international status of the procedure at this time. It should be noted that Dr. Bonatti is assembling a much more detailed international registry for this procedure and welcomes any contributions.

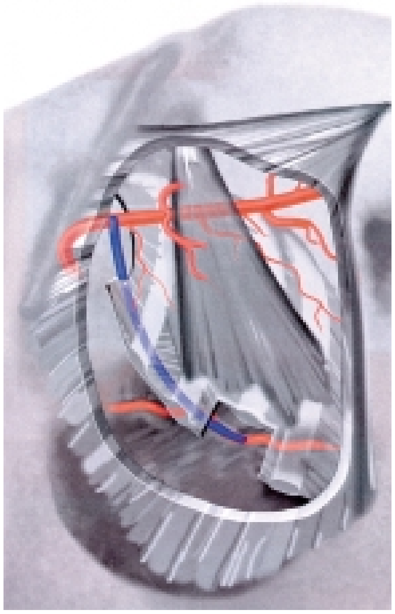

Figure 5. Type B SAXCAB graft. The graft is inside the chest, the coronary artery is exposed by rib/cartilage resection, and entry into the chest is by resection of the first rib (Tovar 1998a).

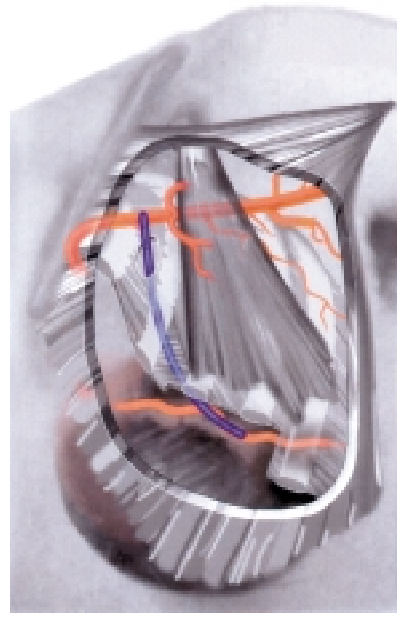

Figure 7. Type C SAXCAB graft. The graft is inside the chest, the coronary artery is exposed by rib/cartilage resection, and entry into the chest is through the first intercostal space (Yaryura 1997).

As seen in Table 4 (◎), the total estimated international experience is about 100 cases and the patency is between 70 and 100 percent in the time frame of about one to two years.

It is interesting that SAXCAB surgery has been relatively free of reported major complications, particularly when one considers the intimate relationship between the brachial plexus and the axillary artery. In this regard, Bonatti has made the point that axillary artery cannulation has been carried out on a routine basis for many years without reports of any major trauma to the brachial plexus [Sabik 1995].

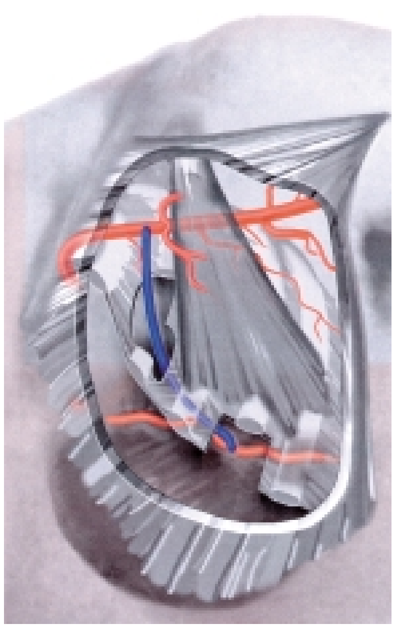

Figure 6. Another example of Type B SAXCAB graft. The graft is inside the chest, the coronary artery is exposed by rib/cartilage resection, and entry to the chest is by resection of the second costal cartilage and nearby rib (Coulson 1997).

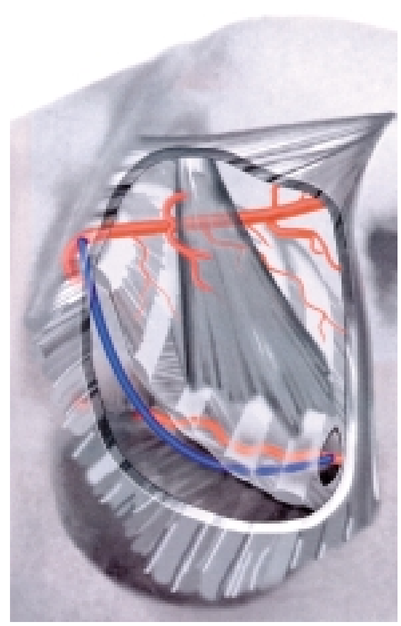

Figure 8. Type D SAXCAB graft. The graft is inside the chest, the coronary artery is exposed through an intercostal space, and entry into the chest is by a supraclavicular route (Dottori 2000).

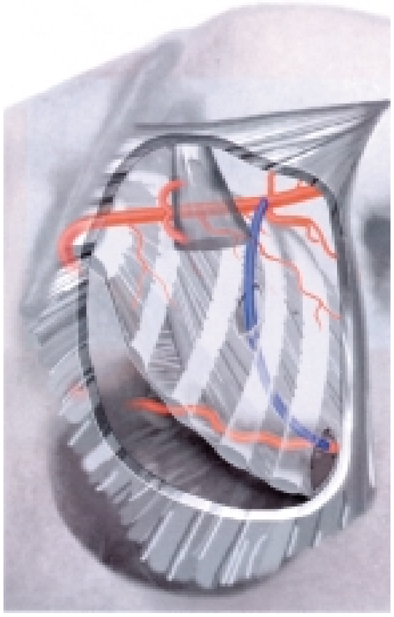

Figure 9. Type F SAXCAB graft. The graft is inside the chest, the coronary artery is exposed through an intercostal space, and entry into the chest is through an intercostal space, in this case the third one (Bonatti 2000c).

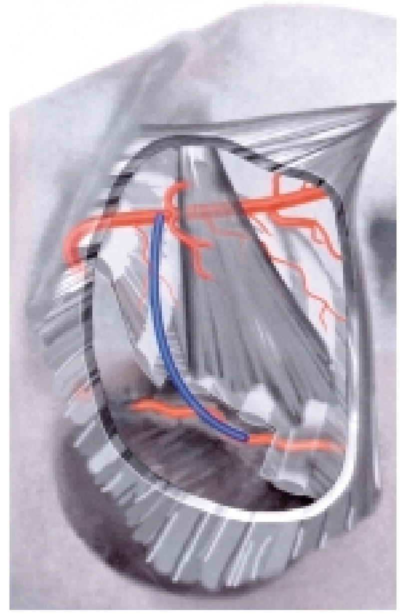

Figure 11. Type G SAXCAB graft. The graft is outside the ribs under the pectoralis major, and exposure of the coronary artery is by rib/cartilage resection (Knight 1997).

DISCUSSION

One of the striking features of the SAXCAB technique is that it was initiated in patients before many studies had been done in the laboratory. In an attempt to correct this problem, Bonatti has undertaken studies in human cadavers and recently in a pig model [Bonatti 1997, Bonatti 2000b] so that some of the basic questions about this technique can be answered. For example, there has been much discussion about whether the graft should be placed inside or outside the chest. Tovar [Tovar 1998b]

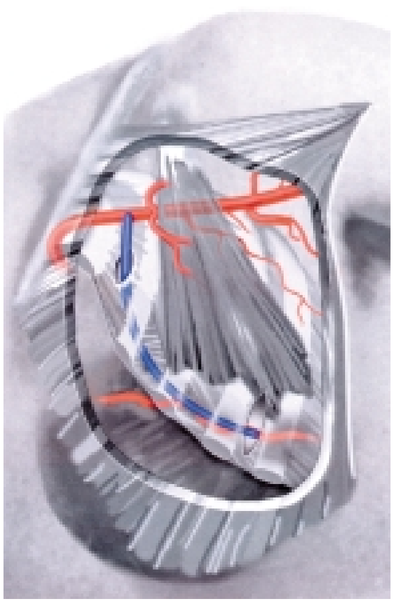

Figure 10. Another example of Type F SAXCAB graft. The graft is inside the chest, the coronary artery is exposed through an intercostal space, and entry into the chest is through an intercostal space, in this case the first one (Wolf 1999).

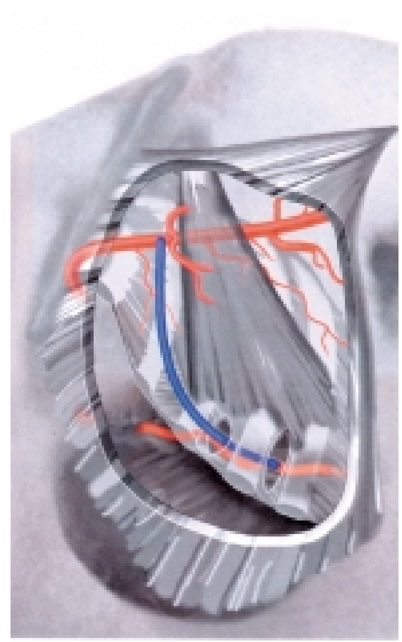

Figure 12. Type H SAXCAB graft. The graft is outside the ribs and under the pectoralis major, and the coronary artery is exposed through an intercostal space (Shabb 1999).

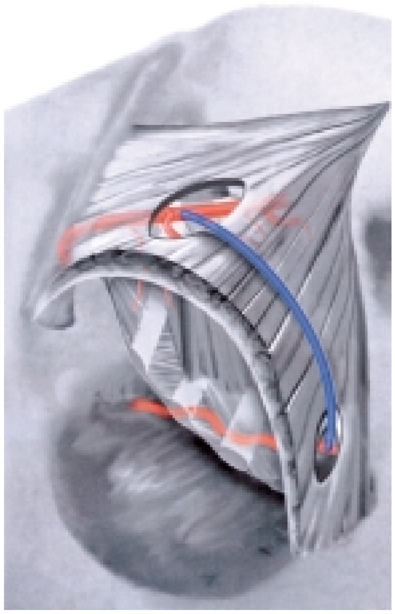

Figure 13. Type J SAXCAB graft. The graft is outside the pectoralis major, and the coronary artery is exposed through an intercostal space (Machiraju 1998).

commented that an intrathoracic tunnel was "preferable" and that the location inside the chest "allowed a sound and protected course for the axillo-coronary graft." Morishita et al. [Morishita 1998] expressed concern about Knight's routing of the graft behind the pectoralis major and superficial to the ribs as they thought it might result in pressure on the vein graft from the surrounding muscle and ribs, and this was their motivation to modify the technique. They brought their graft through an intercostal site caudal to the left axillary artery and penetrated the thoracic space with a tunneling device. Although they thought that it was difficult to make a definite conclusion about which route was better, their opinion was that the intrathoracic route had two advantages over the supracostal route. First, a shorter length of vein was required and, secondly, pulmonary expansion created less pressure on the graft than muscle contraction.

Another research issue relates to whether or not rib resection is required in the course of entering the chest or if the use of an intercostal space is satisfactory. The question of the pressure exerted by the pectoralis major on grafts is clinically important and needs to be researched in the future to see whether it poses a long-term problem. For the present, SAXCAB surgeons need to be aware of the functional anatomy of the chest wall.

There is an obvious need for regular follow-up by duplex scanning to assess long-term patency of these grafts, and patients should also be instructed about the limitation of arm movement and particularly the need to avoid abrupt arm elevation, as it may impact the proximal anastomosis. Another clinical area that needs stressing is the routine checking for subclavian stenosis in coronary bypass patients preoperatively: checking the pressures in both arms, and checking for bruits prior to

Table 4. International Outcomes of Different SAXCAB Techniques as of 2000

SAXCAB Type	Surgeons	Number of Patients	Target Vessels	Estimated Patency Rate
A	Tovar [personal communication]	2	LAD	100%
B	Coulson [1998b]	13	RCA, PDA, LAD, DX	83%
	Bonatti [2000c]			
	Tovar [personal communication]	10	LAD	90%
	Tovar [1998b]			
C	Cooley [personal communication]	6	LAD	100%
	Morishita [personal communication]	3	LAD	67%
	Knight [personal communication]	5	LAD, DX	100%
D	Dottori [2000]	5	CX, LAD	100%
E				
F	Bonatti [2000c]	1	LAD	100%
	Wolf [1999]	10	LAD	100%
	Flege [2000]			
	Morishita [personal communication]	3	LAD	80%
	Watanabe [1998]	1	CX	100%
	Magovern [2000]	22	LAD	90%
	Dullum [personal communication]	8	LAD	100%
G	Knight [personal communication]	4	LAD	75%
	Zumbro [personal communication]	3	LAD	66%
	Bhimji [1998]			
H	Shabb [1999]	3	LAD	100%
I				
J	Machiraju [personal communication]	2	LAD	100%
	Morishita [personal communication]	1	LAD	100%

surgery to rule out stenosis. It should also be possible in the future to determine the range of normal flow in the axillary artery using ultrasonic probes so that if the axillary artery is required for a rescue procedure, the flow in the artery could be assessed intraoperatively to make sure it was adequate to use as an inflow source. Postoperatively, patients need to be educated about the importance of avoiding subclavian venous punctures on the side of their graft.

So far, informal inquiries as to the outcomes of the graft patency really have not shown any trends with regard to which route is the best one for the graft from the axillary artery to the coronary artery, although there is a trend toward lower patency with Type G SAXCABs. Overall, the results look surprisingly good at this time, although it must be stressed that continued caution should be observed when working with the third part of the axillary artery due to the close relationship with the branches of the brachial plexus which are arranged around that part of the artery.

CONCLUSIONS

The MIDCAB technique in general has been successful in providing an alternative way to revascularize the coronary arteries, and the SAXCAB has proved to be one of the most interesting classes of MIDCAB surgery. The possibility that the SAXCAB graft might mimic the behavior of a native mammary artery is one that Bonatti has stressed with the concept he termed "neomammary." It is possible that grafts placed in a position parallel to the IMA might exhibit some of the protective hemodynamic features of the IMA, particularly with regard to neointimal hyperplasia and atherosclerosis.

SAXCAB grafts seem to be unique among coronary revascularization procedures and, indeed, probably almost all vascular procedures in that there is enormous diversity in the route for the graft from the inflow source to the target coronary artery. So far, the second and third parts of the subclavian artery and the first, second, and third parts of the axillary artery have all been used successfully as inflow sources. Being knowledgeable about the different varieties of SAXCAB surgeries will help the surgeon during a rescue operation, as the surgery can be tailored to suit a particular patient.

In the years ahead, we anticipate that more of these procedures will be done. It is a logical, direct, and efficient procedure, and it is therefore not surprising that so many different groups thought of this procedure at about the same time, between February and May of 1996. The SAXCAB technique, "a new approach, not previously described" [Yaryura, 1997] is a particularly valuable option when the patient requires a redo bypass to the LAD, diagonal coronary artery, or the right coronary artery and the risk of reopening the sternum is high because of the patient's comorbidities. The SAXCAB seems to be a very safe operation, and it is striking that so far no one has reported any major complications.

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