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Conduits for Coronary Bypass: Vein Grafts

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The saphenous vein has been the principal conduit for coronary bypass grafting from the beginning, circa 1970. This report briefly traces this history and concomitantly presents one surgeons experience and personal views on use of the vein graft. As such it is not exhaustive but meant to be practical with a modest number of references. The focus is that of providing guidance and perspective which may be at variance with that of others and recognizing that there may be many ways to accomplish the task at hand. Hopefully the surgeon in training/early career may find this instructive on the journey to surgical maturity.

Key words: 1. Coronary artery disease
2. Coronary grafting
3. Saphenous vein

INTRODUCTION

This is the first of a series of reports on operative coronary bypass and will discuss use of vein grafts. Subsequent articles will encompass the internal thoracic artery, other arterial conduits and strategies for coronary grafting.

EARLY HISTORY

Experience with femoropopliteal bypass using saphenous vein validated this conduit for vascular reconstruction. The initial case reports of coronary grafting with vein were by Sabiston [1] in 1962 and Garrett et al. [2] in 1964. Favoloro [3] used interposition vein grafts to reconstruct the right coronary artery in 1968 and for aortocoronary bypass grafting in 1969. In the same year Johnson et al. [4] reported multivessel bypass grafting and later introduced sequential grafting which was amplified by Bartley et al. [5]. Subsequently there was rapid and widespread adaption of coronary bypass grafting with saphenous vein.

VEIN SOURCE

The greater saphenous vein is the primary source and although the lesser saphenous vein may be equally good there are limited data to support its use. Contrarily veins from the arm have poor patency at angiographic follow-up and were abandoned by most surgeons several decades ago [6]. Prior surgical excision (vein stripping), prior phlebitis with or without thrombosis, varicose changes, or deep vein thrombosis, which results in the saphenous vein becoming an important collateral, preclude its use as a conduit. Extensive varicosities may only involve branches of the saphenous vein and it can be a suitable conduit despite the appearance of the leg. Occasionally vein distal to the knee is small and rarely the vein above the knee is too small which poses a significant

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problem when vein use is planned because the lesser saphenous vein is likely to be small also as are the contralateral veins. These few patients with generalized small veins necessitate use of arterial grafts. If this is not an option the fall back position is that of cryopreserved, allogenic saphenous vein. Although initial patency with this conduit is moderate there is chronic rejection and loss of patency [7].

Preoperative ultrasonic assessment of the saphenous vein is routinely employed by some or selectively by others when physical examination suggests that there may be a problem with the vein or there is a history of venous disease or intervention on the vein or through the vein. Most often vein is harvested preferentially in the proximal thigh and moving distally to achieve the needed length. Some surgeons prefer vein from below the knee because it is smaller and therefore has greater flow velocity which may be associated with better patency. Vein grafts have a 10% to 20% loss of patency in the first month which can be related to slow, turbulent flow due to increased diameter and also limited flow capacity of smaller coronary vessels (1.5 mm) which in association with endothelial loss or injury, due to the trauma of harvesting, and layering of thrombus which progresses to thrombosis [8].

A concern with distal vein harvesting (below the knee) is that of impaired wound healing in individuals having associated peripheral arterial disease or in those with chronic venous insufficiency causing persistent edema, skin pigmentation, and subcutaneous fibrosis which may already be associated with "venous" ulceration. In addition to wound healing is the issue of vein preservation for future peripheral vascular reconstruction which is less important than previously because of the success of catheter based techniques for lower extremity arterial insufficiency. Similarly the vein may be an important collateral for venous drainage in chronic deep vein thrombosis in which saphenous preservation could be of critical importance.

VEIN HARVEST

Preparing and draping the legs circumferentially enables positioning to facilitate harvesting and will give access to the lesser saphenous vein if needed. Although initial prone positioning of the patient is optimal for lesser saphenous harvest this need is not always anticipated. When supine the hip and knee can be flexed and an assistant rotates the limb medially or the hip can be flexed to 90 degrees and the knee extended. The vein can be located between the Achilles tendon and the lateral malleolus.

Numerous studies of harvest related trauma have focused on endothelial and transmural injury so that it is apparent that any and all measures to reduce trauma to the vein are appropriate. Forceps should handle only the adventitia or adjacent tissue and not the vein wall. Visualization of the forceps tips will reveal the exact location and the surgeon can sense through the finger tips if there is more than adventitia being pinched by the forceps. Pinching the vein wall will damage or disrupt endothelium. Longitudinal tension should be minimized and fingers may be less traumatic than a vein retractor, umbilical tape, or an elastic vessel loop which are commonly used for retraction.

The extreme form of atraumatic harvesting is dissection which preserves a layer of subcutaneous tissue surrounding the vein which is exposed only at the ends of the dissection. Having not utilized this methodology I cannot fairly comment but wound healing problems have not been reported and long term patency has equaled that of the internal thoracic artery [9]. I am not aware of reports by others of this ultimate technique to minimize vein injury but clearly this is needed before broader adaptation. Alternatively endoscopic harvest has become widely utilized since being introduced in 1996 and has become the preferred method of vein harvest in the US. It is associated with a reduced incidence of wound complications, less pain, better cosmesis, and greater patient satisfaction. However, The Project of Ex-vivo Vein Graft Engineering via Transfection IV trial utilized endoscopic vein harvesting and had a 45% vein graft failure rate 12 to 18 months after operation [10]. Many questioned the quality of this trial because of the worst patency ever reported. However, this report stimulated examination of training and competence in endoscopic technique and suggested guidelines to be followed. Further support for open harvest comes as a by-product of the Randomized On/Off Bypass trial which compared on-pump and off-pump bypass surgery in which one year angiography found an inferior patency rate, 74.5% vs. 85.2%, for endoscopically harvested veins which also had a significantly higher repeat revascularization rate (6.7% vs. 3.4%, $p < 0.05$) [11]. In reality there can be great variability in technical skills so that endoscopic harvest by skilled operators may yield conduits which perform as well as those harvested using open techniques by well trained and capable individuals. At this time there must be concern that endoscopic harvest is not a panacea and that additional well conducted, randomized studies with angiographic assessment are needed to define the role of this methodology and assure that it is not associated with an inferior conduit.

The best exposure for open harvest is provided by a single incision over the vein but I prefer multiple interrupted incisions which are cosmetically preferable. Skin bridges should not be so wide as to lead to more vein trauma. A longitudinal scar across the knee could become painful or restrictive. There are no reported differences in wound complications with either approach.

The length of vein required can be estimated from the following guidelines: distal right coronary, 12 to 15 cm; posterior descending artery, 15 to 18 cm; left anterior descending, 10 to 15 cm; first obtuse marginal artery, 10 to 15 cm; posterolateral artery, 20 cm. These distances approximate a normal sized heart and must be revised upward for an enlarged heart. Some prefer to harvest a single segment of vein while others divide it into segments based on guidelines or by measuring the distance from the aorta to the target vessel with suture or umbilical tape. Dissection may begin proximally in the thigh or at the medial malleolus where it is easier to identify the vein. Frequently the exposed vein can be dissected anteriorly with the index finger (2 to 4 cm) to the level of the next incision which can be made be made using the finger as a guide. Blunt and sharp dissection is utilized dependent on tissue quality. Obesity can make harvesting more difficult in the thigh and is associated with wound complications. Branches are controlled with small or medium clips placed 1 to 2 mm distally or with fine ties of nonabsorbable material.

The distal end of the vein is cannulated and the vein flushed with saline before placing a soft, disposable vascular bulldog clamp on it to distend the vein. Many studies have examined the optimal solution for intralumenal use and I believe heparinized blood may be best but may be impractical if there are leaks and a large volume is required while the vein is repaired. A balanced electrolyte solution or lactated Ringer's solution may be less injurious to the endothelium than physiologic saline which is widely used. Recent reports indicate saline is injurious to endothelium and blood with heparin is optimal [12,13]. The vein is stored in heparinized blood (50 mL) containing papaverine (0.5 to 1.0 μg/mL). It is to be noted that papaverine is highly acidic but is adequately buffered in blood but only by dilution with a large volume of saline. Papaverine in blood is also used to fill all arterial grafts to treat harvest related spasm while vein spasm is overcome by hydrostatic dilation. Several reports document that a high distending pressure ($>$150 mmHg) is injurious to the endothelium and produces wall edema both of which are thought to contribute to pathologic intimal hyperplasia [14]. Ideally the distending pressure can be monitored but is most often assessed by holding the vein between the thumb and forefinger when pressure is applied. Although this is not ideal it reminds the operator to minimize pressure and to maintain it briefly as the inimical effect is related to the duration of high pressure. Branches which have been cut short (a 3 mm or less stump length) or avulsed branches should be controlled by suture using 7-0 polypropylene suture with a transverse suture line, so as to not narrow it, unless the vein is large. Clips which were placed too near the body of the vein may gather adventitia or clips placed inadvertently on the wall of the vein and narrow the vein and are best removed and placed more distally or the stump or oversewn.

Some perform the proximal anastomosis prior to bypass which has the advantage of distending the vein with blood at arterial pressure which may not overcome harvest induced spasm. Venous endothelium inherently produces less nitric oxide than does arterial endothelium and harvested veins show further loss of endothelial function which persists early and late postoperatively and may contribute to graft failure [15,16]. Arterial grafts develop harvest related spasm which will resolve by the time the conduit is grafted if it is exposed to arterial pressure which is not true of the vein. It should be recognized that the vein media is not nourished transluminally but by the vasa vasorum which are divided by harvesting. Thus, the smooth muscle is in spasm but is ischemic and will become mostly nonviable and metabolically unable to relax.

Ultimately the media is largely replaced with fibrous tissue and the vein becomes a fibrous tube without vasomotion.

VEIN PHYSIOLOGY AND ENDOTHELIAL FUNCTION

The vein is surfaced by endothelial cells which are moderately adherent to the basement membrane overlying a poorly developed internal elastic lamina. Intimal thickening and medial hypertrophy may affect 90% of *in situ* saphenous veins by the sixth or seventh decades of life but their influence on patency as a graft is unknown [17,18]. The vein wall is highly compliant over the usual range of venous pressures but not so with arterial pressure [19]. In 1980 Furchgott and Zawadzki [20] made the signal observation that endothelium was necessary for the vasodilating effect of acetylcholine which is mediated by "endothelium-derived dilating factor" which later was proven to be nitric oxide. Not too many years earlier the value of the endothelium had only been viewed as a passive barrier to the escape of blood and its components from the lumen. Subsequently the endothelium has become recognized as an organ unto itself because of its many biologic functions including vasomotion, interaction with formed elements in blood, influencing clotting and clot lysis and mediation of vascular remodeling [21].

There have been many reports of the response of harvested veins to various pharmacologic vasodilators and constrictors which, while interesting physiologically, have little impact clinically because harvested veins are in spasm and once dilated hydrostatically it is rare to see spasm recur, either early or late. This may be because the media is ischemic from harvest, is not revascularized by grafting and is therefore nonviable. Early and late vein graft failure may be related to reduced nitric oxide production [22]. Although known for its vasodilating potency nitric oxide also inhibits platlet aggregation and adhesion, neutrophil adhesion, release and chemotaxis and inhibition of smooth muscle growth which may be important in preventing or limiting intimal hyperplasia in arterialized veins [23]. Prostacyclin, another endothelial product, also strongly inhibits platlet aggregation on damaged or denuded endothelium [22]. Endothelium also produces a plasminogen activator that mediates local thormbolysis and secretes heparin-like compounds and antithrombin, the heparin cofactor [24,25].

Thus preservation of functional endothelial cells is important because of the biologic substances produced but also by physically covering the basement membrane and preventing platlet and leukocyte adherence and fibrin formation. Harvesting is associated with endothelial preservation in proportion to its gentleness and also to the irrigating solution, duration of storage, temperature, and distending pressure and duration. Ringer's solution or a balanced electrolyte solution are less injurious than physiologic saline but as noted above heparinized blood is least injurious [12,13,26,27]. Storage of the vein is best at room temperature or 37^{o}C [26,27] while 4^{o}C is harmful and causes the flattened cells to assume a spherical shape and detach from the basement membrane as well derange the internal architecture [26,27]. Storage for 60 to 125 minutes is well tolerated. Veins have been distended at 50 to 600 mmHg but 150 mmHg causes little endothelial damage while the duration of exposure to high pressure is of critical importance [14,15,26-29].

DISTAL ANASTOMOSIS

The sequence of distal anastomosis may be based on a strategy of delivering cardioplegia through each conduit and selecting the most ischemic region first although the availability of retrograde cardioplegia renders this approach somewhat obsolete. For sequential grafts I prefer doing the distal anastomosis before the side-to-side, although the reverse works well, but with the distal completed the vein can be filled and the optimal position of the second anastomosis and lie of the vein determined. If there is an associated *in situ* arterial graft the need to manipulate the heart to provide exposure for a vein anastomosis and the potential for undue tension on the *in situ* anastomosis dictates doing vein anastomoses prior to *in situ* arterial anastomoses.

The ideal anastomotic site is a disease free, 2.0 mm or larger artery but this is frequently not available so that many target vessels are 1.5 mm as it may be necessary to go that far distal to have a healthy target which is most important for long term patency. A 1.0 mm coronary is technically difficult to sew to and the low flow is associated with a high rate of early thrombosis. Arteries this small are not grafted except when: inadvertently opened; all the arteries are of this size (rare); or an arterial graft can be substituted for the vein. The presence of distal coronary disease involving the anastomotic site necessitates a less than optimal anastomosis but is frequently necessary. Some vessels have posterior distribution of atherosclerosis and a normal or healthier anterior wall to utilize for anastomosis. Calcification when posterior does not preclude anastomosis but does not allow suturing when more extensive. An advantage of bypass over stenting is its ability to bridge two-thirds or more of a vessel while stenting treats a lesion, although multiple stents can treat a long segment.

Arteriotomy length in general is equal to the diameter of the vein unless it is small (less than 3.0 mm). A small vein should be "fish mouthed" to follow the principal that the anastomotic diameter should be one and one-half times that of the smaller vessel. Thus, a 2.0 mm coronary would require a 3.0 mm incision to comply but a 6.0 mm vein would need a 6.0 mm arteriotomy for a good match. The vein should be transected straight across as any other division would unnecessarily increase the length of the anastomosis (Fig. 1) [30] and therefore anastomotic time. Another advantage of right angle transaction is the feasibility of placing the vein in any direction (universal anastomosis) such that a posterior graft could be directed to the right or left based on other considerations including the unplanned decision to use sequential anastomosis or the need for a short Y-graft because of inadequate vein length. Most surgeons use 7-0 and some 8-0 polypropylene suture with a running anastomosis which begins a few bites from the toe or heel and continues around the circle to the starting point or can continue two-thirds of the distance and the final segment completed with the other suture limb.

Side-to-side anastomosis allows more than one anastomosis to a conduit and is therefore conservative of conduit and saves time by reducing the number of proximal anastomoses. Patency is increased by 10% to 15% with sequential anastomosis [31]. Ideally the vein should end on the larger coronary with smaller vessels as side anastomoses to achieve a higher flow rate to the end of the vein which is associated with better patency but coronary anatomy does not always allow such a configuration. Early in coronary surgery a few surgeons grafted the entire heart with a single vein ("snake graft") which usually coursed to the right coronary, then around the back of the heart to pick up posterior arteries and ending on an obtuse marginal artery unless internal thoracic artery was not employed in which case the vein ended on the anterior descending artery. It was soon appreciated that a lesion in the proximal graft could create extensive myocardial malperfusion and this approach was abandoned. Thus, most would limit a sequential vein graft to a single coronary territory or allow it to include one secondary branch of another territory when coronary anatomy is favorable.

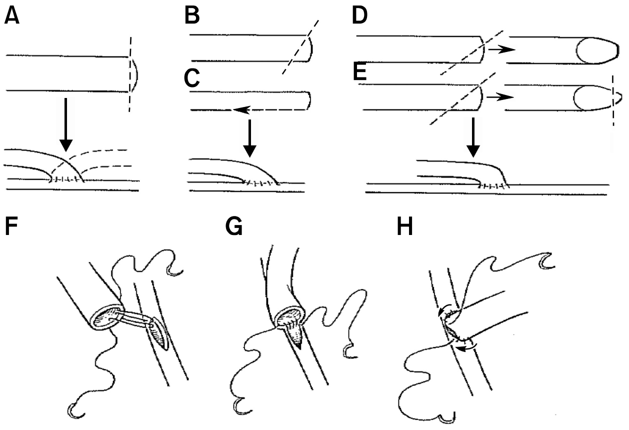

Fig. 1. Various techniques for preparing the vein for distal anastomosis are illustrated. Straight transaction (A) is appropriate for a 4 mm diameter or larger vein because other transections increase the length of the anastomosis and therefore sewing time. (B—E) Suturing is begun at the heel and can be clockwise or counterclockwise but the former allows completion on the side facing the surgeon as shown. (F—H) The entire anastomosis can be done with one needle, saving time, but if exposure is not optimal the other suture limb is used to finish (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

A side-to-side anastomosis can be crossing (diamond) or in parallel with the latter being technically easier. With experience there can be all degrees of angulation at the anastomosis which is occasionally helpful to facilitate optimal positioning of the graft. Parallel side-to-side requires two parallel incisions of equal length remembering that the vein will stretch and the artery will not. With crossing anastomosis the vein incision may be longitudinal or transverse with the latter limited to larger veins as a smaller vein may be flattened by the

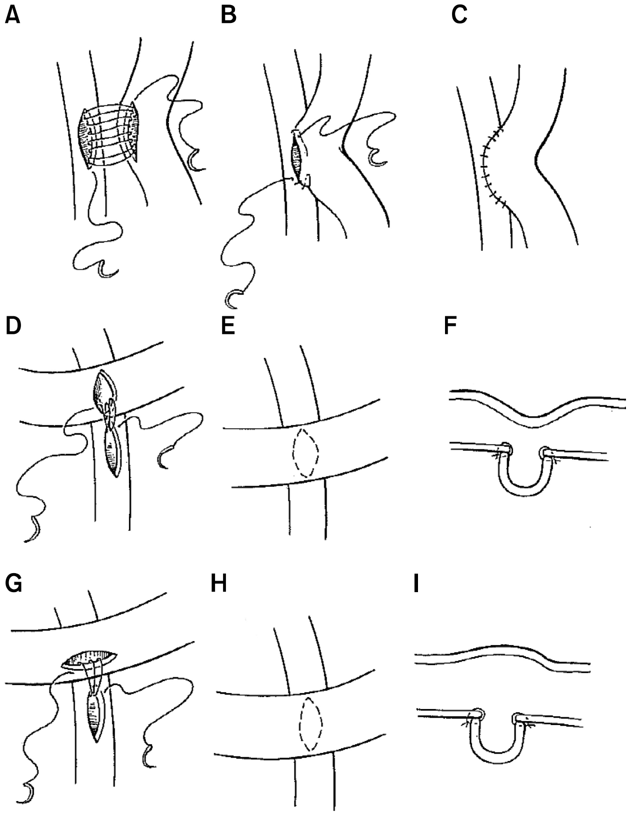

Fig. 2. A parallel side-to-side anastomosis is illustrated (A—C). "The suture line is started at the heel and the far side of the anastomosis through the toe is completed in a parachute fashion before completing the near side. A crossing side-to-side anastomosis with a transverse incision in the vein (D—F) may result in a "seagull" deformity if the vein is not large or the incisions too long (F). Alternatively a longitudinal vein incision always works (G—I) (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

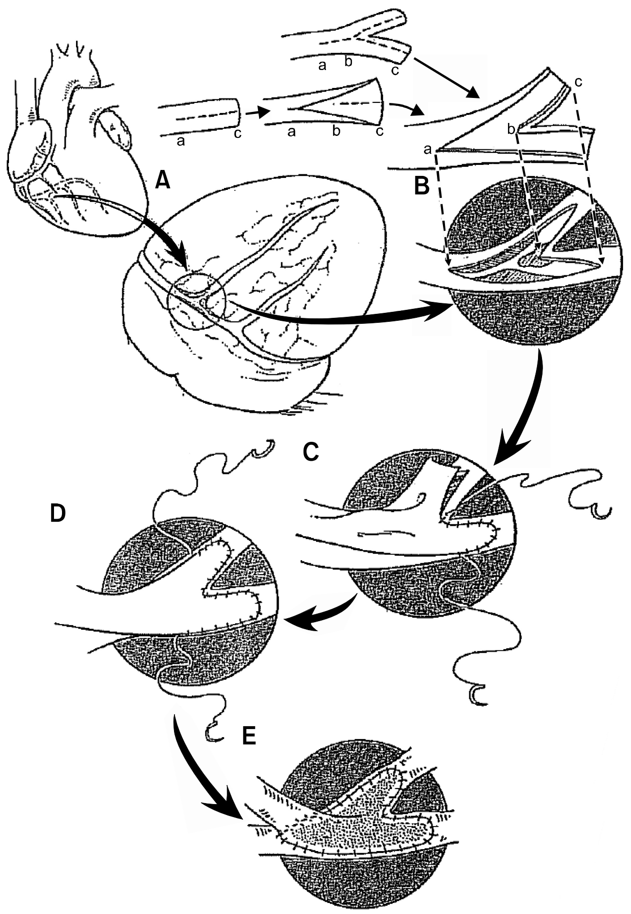

Fig. 3. The Y-anastomosis across a bifurcation lesion can occasionally be accomplished with a "natural" Y graft or more often by appropriate incisions in the vein. (A, B) Obviously the two arteries are usually bypassed separately but occasionally the branches are small or more distal exposure compromised (C—E) (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

anastomosis, "seagull deformity," which is avoided by a longitudinal incision (Fig. 2) [30].

The Y-anastomosis is useful in treating a bifurcation lesion and can occasionally be achieved with a natural branching of the vein or by appropriate incisions in an unbranched vein (Fig. 3) [30]. A vein "patch" angioplasty is use of a long anastomosis usually in one of two settings: with open coronary endarterectomy (Fig. 4) it is appropriate to close the artery with a patch the length of the incision; extensive coronary disease which does not warrant endarterectomy (nonocclusive or with a graftable distal artery) can be managed by long arteriotomy ending in a reasonably healthy vessel which is then closed with a patch (Fig. 5) [30]. Usually the "vein patch" is not a free patch but a longitudinally opened vein with tubular vein proximal; a bipedicled patch places the tubular vein centrally (Fig. 5) or a free vein patch may be combined with an arterial graft (Fig. 6) [30].

PROXIMAL ANASTOMOSIS

Historically it was common to release the aortic cross

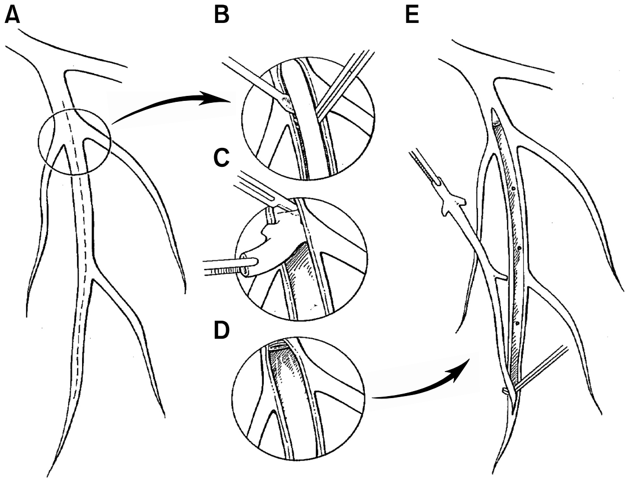

Fig. 4. This classic "open" endarterccectomy (A, B, E) with proximal transaction of the core (C, D) is usually closed with a vein patch which is in continuity with the associated vein graft (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw- Hill; 1997, with permission from the McGraw-Hill Companies) [30].

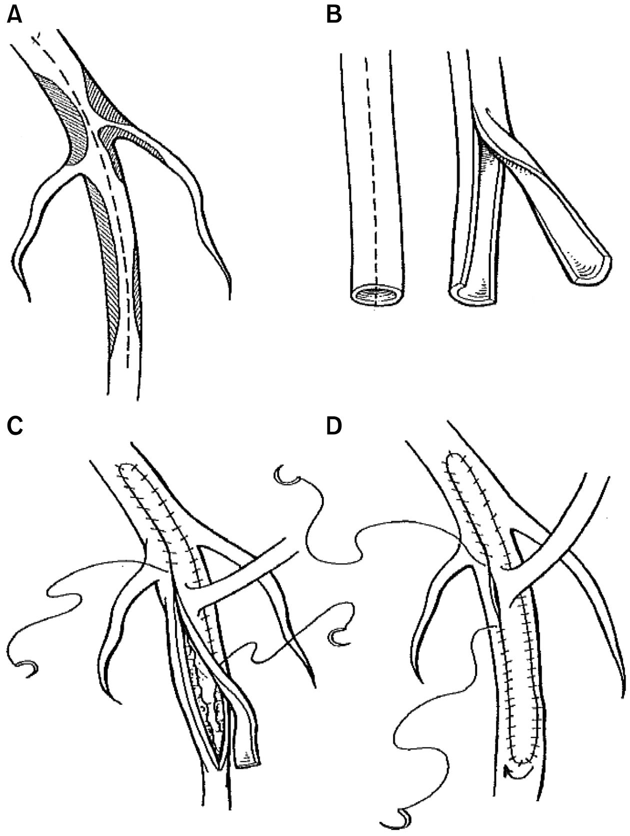

Fig. 5. Certain situations with extensive, diffuse disease (smaller artery, lesions with calcium extending through the media to the adventitia or by choice because endarterectomized vessels have no endothelium and thrombosis is a complication) are managed by arteriotomy and patch closure. (A) The patch can be vein or artery and incorporates a bypass graft which is usually incised to create the patch. (B−D) The T-tube technique was described by Galvin (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

clamp, to reduce clamp time, and apply a partial occlusion clamp. It became recognized that this practice was associated with greater potential for traumatic release of atherosclerotic material from the aortic wall with cerebral embolization which led to its discontinuation. If there is any suggestion of aortic atherosclerosis it is increasingly common to scan the aorta with epiaortic ultrasound to select a healthy site for the cross clamp as well as proximal anastomosis. Extensive aortic disease or a "porcelain" aorta necessitates a strategy change and use of an aortic arch branch, the descending thoracic aorta or *in situ* internal thoracic artery for proximal anastomosis. A commercial punch will create an aortic opening of 3 to 6 mm or more. The vein is filled with saline or blood to determine its length and axial orientation, if it has not been marked with a pen after harvest, and a tension free length noted. This is relatively straightforward for left sided grafts but can be challenging for right sided grafts because the right ventricle and right atrium collapse during bypass which must be considered when estimating ultimate graft length. Occasionally it is necessary to fill the heart to estimate graft length which may also apply to left sided grafts when the right ventricular outflow tract/pulmonary artery are large or occasionally when the left ventricle is dilated. After incising the transversely divided vein to match the aortic opening the anastomosis is constructed with 6-0 continuous polypropylene. If the aortic wall is judged to be too thick or diseased for a satisfactory anastomosis it may be possible to resect a larger area of the wall and replace it with a pericardial patch, using a 6-0 or larger running suture. The vein is attached to the patch after using a punch or incision. Rarely if the latter is not feasible there is the option of replacing the ascending aorta with a Dacron tube graft and attaching the graft(s) to it. Perhaps a better option is to attach the vein to an *in situ* arterial graft and avoid a complicated anastomosis.

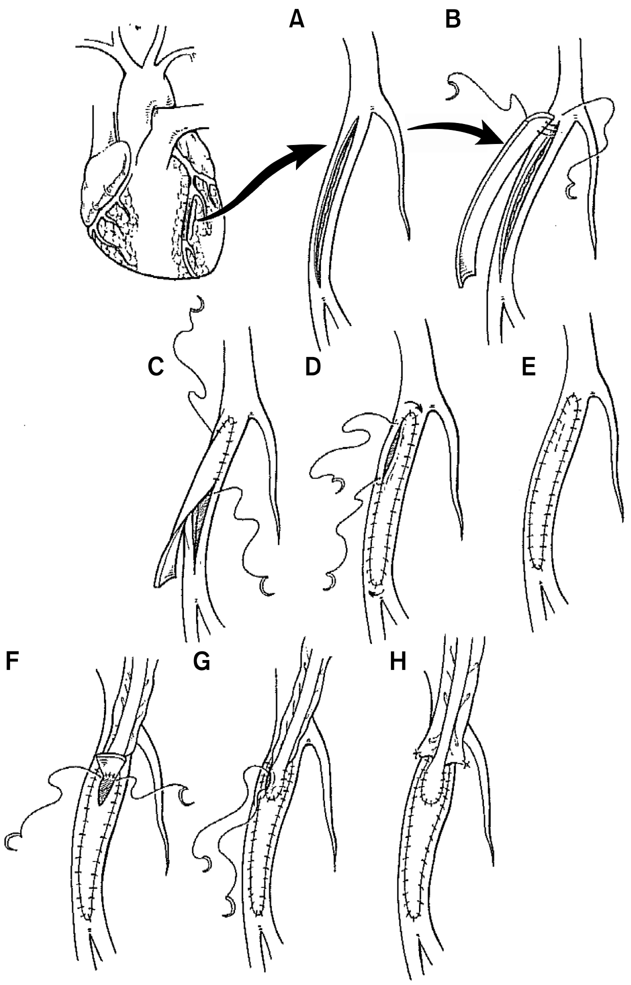

Fig. 6. A vein patch closure is used if the internal thoracic artery does not have sufficient length to be opened as a patch (A—H) (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

If there is only one adequate site for vein anastomosis to the aorta an additional graft may be attached to the aortic “hood” of the vein, and a third vein may be placed on the second, or to any distal site on the vein as a Y-graft (Fig. 7) [30]. The Y-graft option is also appropriate when a vein will not reach the aorta and is useful when vein length is quite inadequate and the Y-anastomosis positioned posterior to the heart.

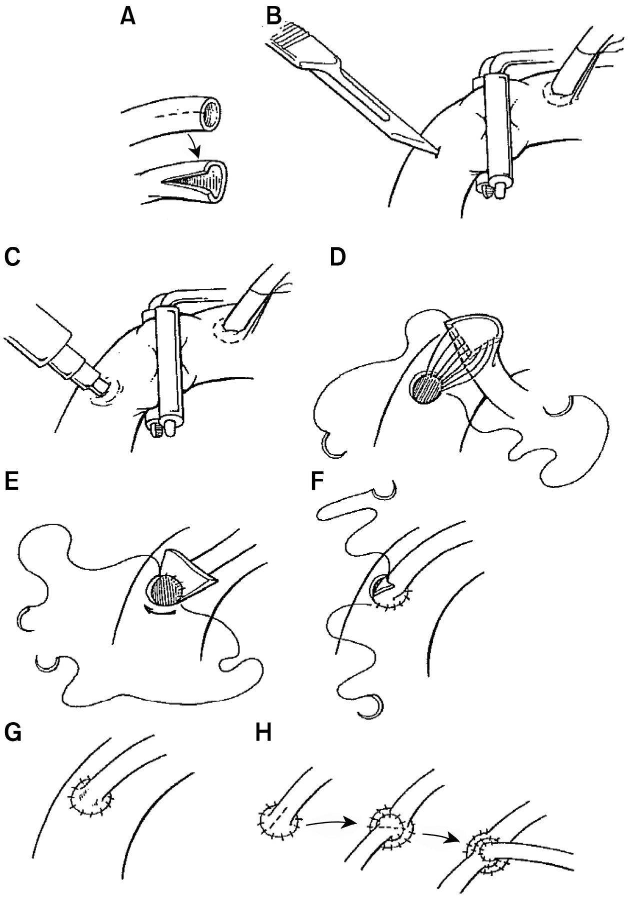

Fig. 7. Technique for the proximal anastomosis (D—G) includes use of a 4- or 5-mm aortic punch. (B, C) The vein is spatulated (A) to provide adequate tissue. In cases where the wall of the aorta is diseased with space for only one graft additional grafts can be stacked on the vein “hood” (H). Alternatively veins can be attached downstream as Y-grafts (Reproduced from Edmunds LH. Cardiac surgery in the adult. New York: McGraw-Hill; 1997, with permission from the McGraw-Hill Companies) [30].

MEASUREMENT OF GRAFT FLOW

Early in the history of coronary surgery graft flow was measured with the electromagnetic flow meter. It was learned that veins grafted to 1.5 mm coronaries have lower flow (less than 40 mL/min), because of a smaller subserved myocardial mass than for larger vessels, and a higher early closure rate at one week and one year angiography [31]. Flow of less than 20 mL/min is seen with 1.0 mm coronaries and more than 50% close by one year. Thus coronary diameter and graft flow correlate with one another and with postoperative graft patency.

The absence of flow in a graft or flow significantly lower than anticipated from coronary diameter alerts the surgeon to a technical error such as failing to reverse the graft, axial torsion causing a twist or kink in the graft or a technical anastomotic error resulting in stenosis or occlusion. It is important to recognize that a pulse in the graft is not synonymous with patency or flow. With experience procedural errors become infrequent and despite the comfort of documenting good graft flow the vast majority or surgeons do not obtain such measurements.

The advent of the transit time flow meter in the mid 1980's was simpler to employ, more reliable and provided wave form analysis which increased the prevalence of flow measurement to determine if certain grafts might require revision because of low flow or unfavorable waveform characteristics [32]. Low mean flow (<15 mL/min), a pulsatility index of <3.0, a systolic dominant or balanced systolic/diastolic flow curve in the left coronary territory or a systolic dominant pattern flow curve in the right coronary territory were associated with technical/hemodynamic problems and a high probability of graft closure [33]. This newer technology has increased the use of graft flow measurement, which I routinely utilize as practice facilitates ease of use and enhances the understanding of coronary-graft hemodynamics, particularly for arterial grafts [33]. Successful correction of technical problems recognized by transit time flow measurements has been achieved in 3% to 7% of grafts studied [32-34].

GRAFT PATENCY

A graft is only beneficial if it remains patent. For this reason an open graft ranks right behind freedom from death and infarction as a yardstick of a successful operation and brings to focus the importance of graft durability Patency has gradually improved over time related to reduced vein trauma during harvest and preparation and greater appreciation of the importance of endothelial function and therefore its preservation. Surgical technique is also important and there is a learning curve during which patency improves as technical mistakes are reduced. Flow is a function of pressure (blood pressure) and resistance which is determined by the resistance vessels (arterioles) unless there is an obstruction in the arterial system. Because the vein diameter is several fold larger than the coronary it has unlimited capacity to deliver flow unless the surgeon has created a problem. Thus flow in this particular system is limited by arteriolar resistance, then coronary resistance and lastly by the vein or anastomosis.

In the early years of coronary bypass grafting there was obviously no information regarding patency after the operation although there were patency data for femoropopliteal saphenous vein bypass grafts. This void was filled by angiography obtained prior to discharge at one week, one year and then five and ten years after operation [35-37]. These studies provided information on graft patency which declined significantly in the first weeks and months to 70% to 75% at one year and then stabilized with 1% to 2% of grafts closing each year between one and five years subsequent to which 2% to 4% of grafts failed each year as they became atherosclerotic. By 10 years graft patency was 50% and 50% of patent grafts were atherosclerotic by their angiographic appearance and likely to fail in the next few years. However the other grafts evidenced no signs of atherosclerosis which was puzzling but also encouraging in that if we knew why some grafts tolerated this arterial mileur so well why could we not achieve this with all vein grafts. Indeed this has happened because more recent reports document improving patency at five and 10 years and beyond [38,39].

In the first month 10% to 15% of vein grafts fail secondary to a large diameter vein with sluggish flow or smaller diameter vein with slow flow due to a small or diseased coronary so that thrombus forms in grafts, promoted by endothelial loss and/or dysfunction and perhaps assisted by postoperative hypercoagulability, resulting in a small thrombus or layer of fibrin which progressively grows. These events can also lead to graft failure between one and twelve months postoperatively. Other grafts may fail for technical reasons, vein imperfections such as prior phlebitis, large vein valve sinuses where thrombus may form related to the valve or from pathologic intimal hyperplasia. We learned from femoropopliteal vein grafts that all grafts developed fibrointimal hyperplasia, which in a few becomes pathologic in that it progresses rapidly and profoundly resulting in stenosis, or even occlusion within a month or two. Fortunately this extreme form of fibrointimal hyperplasia became rare as harvesting, preparation and storage techniques improved and the associated harvesting trauma was lessened. However, what has remained is the "obligatory" fibrointimal hyperplasia which is generally complete by one year but, as believed by many, forms the basis for subsequent atherosclerotic change. Microscopic evidence of early atherosclerosis is commonly noted in veins studied at two years postoperatively. Graft atherosclerosis has been reduced by antiatherosclerosis therapy which was not utilized for more than a decade after coronary surgery began [40,41].

Whether grafts are venous or arterial patency is influenced by the target vessel such that those to the left anterior descending artery have the best patency which decreases progressively in lateral wall grafts to the ramus intermedius or circumflex artery branches followed by posterior targets, whether arising from the right coronary artery or the circumflex system. Competitive coronary flow may reduce arterial graft patency but not vein graft because the diameter of the latter surpasses that of the coronary and flow is preferentially through the graft because of less resistance. It may be said unfair that the "gold standard" for graft patency has become the *in situ* left internal thoracic artery to the left anterior descending artery because the nearly ubiquitous use of this configuration precludes the use of this "best target" for other conduits. Sequential vein grafts enjoy better patency than do grafts to a single target by 10% to 15% [39,42]. Some believe that this is secondary to flow velocity which is usually greater with multiple anastomses but others have not observed this patency advantage [43].

Recently, and for the first time, the natural history of saphenous vein grafts age 13.5±3.6 years has been assessed by serial intravascular ultrasound at baseline and 16.2±7.4 months later in 44 patients [44]. During these intervals graft area and lumen area decreased while plaque area and plaque burden increased, all significantly. The remodeling index also decreased from baseline to follow-up but plaque morphology did not change. When patients were divided into two groups based on follow-up intervals of <12 months or >12 months there were no significant differences in the progression of plaque area or plaque burden. There were linear relationships between follow-up low density lipoprotein (LDL) cholesterol and change in plaque area and lumen area. With regression analysis, the cutoff value of follow-up LDL cholesterol that best predicted no plaque area increase was 100 mg/dL. Comparing high-dose statin therapy (n=18, 60 to 80 mg/day) with usual dose (n=32, <40 mg/day) revealed plaque area decreased in the former and increased in the usual-dose group ($p<0.001$). Plaque regression was observed more frequently in the high-dose group compared with usual-dose group (55.6% vs. 9.4%, $p<0.001$) [45]. Importantly, these studies indicate that vein grafts undergo remodeling just like native arteries and that high dose statin therapy will achieve this which has also been observed by others [40,41,45,46]. Twelve month graft patency improved from 83.3% to 96.5% (p=0.03) in patients whose LDL was greater than or less than 100 mg/dL respectively [45].

For more than a decade after the advent of coronary bypass surgery we neglected to focus on the treatment of the disease, namely atherosclerosis. We failed to insist that tobacco be stopped, blood pressure controlled, weight and fat intake be reduced, aspirin continued and we did not have statins. Subsequently there was gradual recognition of the need to treat all bypass patients for the disease that brought them to surgery to prevent further progression of their coronary disease and to prevent vein graft disease.

Looking ahead the saphenous vein will continue to be used as a bypass conduit despite the ubiquity of bypassing the left anterior descending artery with left internal thoracic artery and gradually increasing use of all arterial grafting because the vein is available in most patients, readily harvested except in the obese, versatile in its application and easy to work with. It is beyond doubt that vein patency has improved since the first decade, 1970 to 1980. During that early time very few patients discontinued cigarette use because we did not tell them to do so or if we did this message was not reinforced by societal pressure and education which has since developed. It was mistakenly assumed by many patients, and some physicians, that a bypass operation would prevent all future coronary events. However the realization that the disease persisted and would progress made the obvious happen. Postoperatively there was continuation of preoperative medications taken for lipid and blood pressure control as well as aspirin, smoking cessation and appropriate lifestyle interventions. As a consequence vein graft patency has improved in the last two decades and likely will continue to do so. Although my personal focus has been to tout the patency advantage of arterial grafts and desirability of all arterial grafting in appropriate clinical settings I have not lost sight of the usefulness of the saphenous vein bypass graft which will always be a friend of the cardiac surgeon.

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