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Ulnar Artery as a Coronary Bypass Graft


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Background. The ulnar artery has been used as a coronary bypass graft in 8 patients when it was deemed unsafe to harvest the radial artery after evaluation of the arterial circulation in the forearm and hand.

Methods. The ulnar artery was removed from the lower three-quarters of the forearm, along with its satellite veins. Dissection was commenced distally near the wrist and extended proximally to where the ulnar artery passed between the two heads of origin of the flexor digitorum superficialis. The artery was divided distally above the wrist joint and proximally at a point immediately below the origin of the common interosseous artery.

Results. Ten ulnar arteries were removed for use as coronary bypass grafts; two were rejected, one because of severe calcification and the other because of atherosclerotic occlusion. The remaining eight ulnar arteries were grafted successfully to coronary arteries other than the left anterior descending. No early hand or cardiac complications were observed.

Conclusions. The ulnar artery is an alternative coronary artery bypass graft that may be used when the radial artery is dominant and cannot be removed without risk. The ulnar artery is in close proximity to the ulnar nerve and harvesting has the potential to injure the nerve. Therefore, until the use of the ulnar artery has been more fully evaluated it should be used only when other options have been exhausted.

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Recendy, the radial artery has become the focus of attention when used as a coronary artery bypass graft [1–8]. By contrast, the ulnar artery (UA), which is normally the dominant artery in the forearm, has received little consideration. Removal of the radial artery is based on the assumption that there is an adequate collateral blood supply to the hand from the ulnar artery. Unfortunately, in approximately 5% to 10% of patients, the radial artery cannot be removed safely because it is the main supply of blood to the hand [9]. In these patients the UA is the conduit of choice in the forearm. The arterial anatomy of the forearm and the dynamics of the blood supply to the hand are therefore of increasing importance to the cardiac surgeon. This article describes the anatomy and application of the UA.

Material and Methods

Anatomy
The UA originates in the cubital fossa as the larger of the two terminal branches of the brachial artery. It passes along the medial aspect of the flexor compartment of the forearm between the cubital fossa and the flexor retinaculum. The UA curves from its origin to the medial side of the forearm, lying directly on the lateral side of the ulnar nerve until its termination. A line joining the medial epicondyle of the humerus to the lateral side of the pisiform bone represents its course in the distal half of the forearm.

In the cubital fossa the UA lies on the brachialis muscle, and the median nerve crosses the UA from its medial side to lie laterally. The UA leaves the cubital fossa deep to the pronator teres and the median nerve, which passes between the two heads of the muscle.

In the flexor compartment of the forearm, the UA lies on the flexor digitorum profundus, to which it is bound by fascial bands. Before accompanying the ulnar nerve, the artery passes deep to the flexor digitorum superficialis under a fibrous arch between its humeroulnar and radial origins and the overlying flexor carpi radialis and palmaris longus. In the middle third of the forearm it is deep to the flexor carpi ulnaris, whereas in the distal third it is lateral to the tendon of that muscle, covered only by deep fascia, superficial fascia, and skin. On the flexor retinaculum, the artery lies deep to the palmaris brevis and the palmar cutaneous branch of the ulnar nerve.

Throughout its course the UA is accompanied by a pair of veins that link by numerous cross branches. At multiple levels the UA is supplied by sympathetic twigs from the ulnar nerve.

Branches. The UA has three named branches near its origin and three near its termination, as well as a variable number of smaller branches to surrounding muscles and to the ulnar nerve.

The anterior and posterior ulnar recurrent arteries arise in the cubital fossa and take part in the Anastomosis around the elbow joint. The common interosseous artery
is a short trunk arising just distal to the radial tuberosity, 2 to 3 cm from the origin of the UA. The common interosseous artery divides into the anterior and posterior interosseous arteries at the proximal border of the interosseous membrane. These arteries supply the bones of the forearm and muscles, as well as contributing to anastomoses around the elbow and wrist joints. The anterior interosseous artery gives off the median artery, a long branch that accompanies the median nerve and is sometimes much enlarged to reinforce the superficial palmar arch.

The posterior and anterior ulnar carpal arteries arise near the pisiform bone to take part in the posterior and anterior carpal arches, respectively, which form an anastomosis around the wrist joint. The deep branch of the UA accompanies the deep branch of the ulnar nerve and completes the deep palmar arch.

The UA provides numerous muscular branches. Some of these cross the ulnar nerve, particularly near the wrist, before sending a recurrent branch to supply the nerve [10]. The UA provides small branches to the ulnar nerve (arteriae nervorum). In a study of 37 forearms by Sunderland [10], the mean number of branches was 7 (range, 2 to 19). They were usually short and stout, resulting in the ulnar nerve being securely attached to the UA, particularly in the distal half of the forearm.

Anastomoses. The main anastomoses with the radial artery are via four arches in the hand and wrist (the superficial and deep palmar arches, the anterior and posterior carpal arches) and between their metacarpal and digital branches.

Variations. A superficial UA is usually associated with a high origin and passes over the muscles arising from the common flexor origin. It is generally covered by deep fascia, but occasionally is even superficial to the deep fascia. The common interosseous and recurrent arteries are given off by the radial trunk.

A variation in the size of the UA is generally accompanied by a compensatory variation in the size of the radial artery. A typical superficial palmar arch is present in about 30% of cases and may be formed solely by the UA. The median artery enters into its formation in about 8% of individuals [11].

Patterns of Arterial Supply to the Forearm and Hand. The dynamics of the blood supply to the forearm and hand are variable. In a study of 100 normal hands using the Allen test and an ultrasonic Doppler flowmeter, Little and associates [9] concluded that the collateral circulation in the hand would generally maintain the viability of the fingers when either the radial artery or UA was occluded at the wrist. In 6% of hands there was a drastic reduction in the circulation when the radial artery was occluded at the wrist and the same occurred in 9% with occlusion of the UA. The Allen test was positive in only 3% of hands, and in each, the Doppler ultrasound confirmed the dependence of the digital circulation on only one artery at the wrist. This study suggests that the radial artery or UA cannot be removed with safety in all patients. Preoperative clinical testing is therefore mandatory before removing a forearm artery. The Allen test is a practical means of assessing the safety of removing the radial or ulnar artery [12]. Doppler ultrasonography, oximetry, and digital blood pressure measurement may be equally efficacious [6, 13, 14].

Physiologic assessment of the forearm blood supply defines several circulatory patterns that determine the most appropriate forearm artery for use as a bypass graft. Normally there is a mixed pattern; both the radial artery and UA supply blood to the hand, with an effective collateral circulation that allows either artery to supply the hand. In most patients, the UA is the larger of the two divisions of the brachial artery and is the major source of blood to the hand, allowing the radial artery to be removed safely. In a small number of patients the radial artery is dominant. Under these circumstances, the UA is the smaller artery and can be removed without risk of hand ischemia. Theoretically, a fourth pattern exists in which both arteries are of normal size but the collateral circulation is so poorly developed that neither artery can be removed from the forearm with safety (Table 1).

Operative Technique

The UA may be harvested in an isolated procedure before the chest is opened or removed at the same time as the median sternotomy and mobilization of the left internal thoracic artery. In patients in whom there was a different arterial pattern on each side, the UA was removed at the same time as the radial artery was harvested from the other arm.

The technique is similar to that used for removing the radial artery [7, 15, 16]. The arm is abducted to 90 degrees and placed in full external rotation with the hand supinated. The incision commences about 3 cm above the wrist along a line between the lateral border of the pisiform bone and the medial epicondyle. The incision runs along the lateral border of the tendon of the flexor carpi ulnaris. Near the midpoint of the forearm the incision curves anteriorly in the direction of the bicipital tendon and stops approximately 3 cm below the elbow joint (Fig 1A). The posterior branch of the medial cutaneous nerve of the forearm may be seen lying subcutaneously as it passes anterior to the medial epicondyle before turning around to the back of the forearm and descending to the wrist.

The UA is removed by commencing the dissection distally. The pedicle containing the artery and its adjacent veins is identified after dividing the deep fascia,
where the artery lies between the tendons of the flexor carpi ulnaris medially and the flexor digitorum superficialis laterally (Fig 1B). In the distal two-thirds of the forearm the vascular pedicle containing the UA is closely applied to the adjacent ulnar nerve. Care is required to avoid handling the ulnar nerve, which may be obscured by the UA and the venae commitantes. Division of small branches of the UA to the ulnar nerve (arteriae nervorum) is not avoidable and so far has not been associated with any neurologic dysfunction. The vascular pedicle is mobilized by dividing the small arterial and venous branches between clips. The pedicle is dissected proximally by separating the flexor carpi ulnaris from the flexor digitorum superficialis. In the upper third of the forearm, the ulnar artery leaves the ulnar nerve and is shown lying on the flexor digitorum profundus before passing beneath the median nerve and the flexor digitorum superficialis and overlying the palmaris longus and flexor carpi radialis. As it passes proximally, the UA lies on the flexor digitorum profundus to which it is tightly bound. Retraction of the superficial from the deep forearm muscles exposes the UA immediately distal to where the UA and median nerve pass under the fibrous arch between the two heads of origin of the flexor digitorum superficialis. Several muscular branches require division before the UA is freed. Once sufficient length of the UA has been obtained, it is clipped and transected and the artery stored in the papaverine solution (Fig 1D). It is important that it is divided distal to the origin of the}

parts of heparinized blood and Ringer’s lactate solution, with a final concentration of papaverine $10^{-3}$ mol/L, or 40 mg/dL. After clipping, the UA is allowed to dilate passively.

The upper end of the UA is dissected to the level of the median nerve and common interosseus artery. The UA separates from the ulnar nerve in the proximal third of the forearm before passing beneath the flexor digitorum superficialis and the overlying palmaris longus and flexor carpi radialis. As it passes proximally, the UA lies on the flexor digitorum profundus to which it is tightly bound. Retraction of the superficial from the deep forearm muscles exposes the UA immediately distal to where the UA and median nerve pass under the fibrous arch between the two heads of origin of the flexor digitorum superficialis. Several muscular branches require division before the UA is freed. Once sufficient length of the UA has been obtained, it is clipped and transected and the artery stored in the papaverine solution (Fig 1D). It is important that it is divided distal to the origin of the
common interosseous artery, which is an important collateral supply to the forearm. The wound is then closed and bandaged.

Results

Early experience has been limited to the removal of a single UA from 10 male patients with a mean age of 68 years (range, 52 to 84 years). Each patient had a dominant radial artery, removal of which was considered unsafe. In the first 2 patients the UA was not usable. One patient had severe atherosclerosis, diabetes mellitus with a previous history of peripheral vascular disease requiring amputation, and a bilateral carotid endarterectomy. The other patient was elderly, and the artery had a normal diameter but was heavily calcified, precluding its use as a graft. In the remaining 8 patients, each UA was of excellent quality, measured 2 to 3 mm in diameter and about 15 cm in length (approximately 3 cm less than that of a radial artery graft). It was used to bypass lesions in the diagonal branch of the left anterior descending coronary artery, circumflex marginal branches, and the right coronary artery. No patient had evidence of myocardial ischemia suggesting early graft failure. In none of the 8 patients was there evidence of neurologic dysfunction as the result of handling the ulnar nerve or from ischemia as a result of division of the arterial branches supplying the ulnar nerve. No patient had hand ischemia. Follow-up has been limited to 3 months and there has been no angiographic assessment.

Comment

The ability to use the UA when the radial artery cannot be removed safely provides the surgeon with an alternative arterial conduit, rather than resorting to the use of a saphenous vein graft. The desire to use arterial grafts follows the excellent late patency, measured 2 to 3 mm in diameter and about 15 cm in length (approximately 3 cm less than that of a radial artery graft). It was used to bypass lesions in the diagonal branch of the left anterior descending coronary artery, circumflex marginal branches, and the right coronary artery. No patient had evidence of myocardial ischemia suggesting early graft failure. In none of the 8 patients was there evidence of neurologic dysfunction as the result of handling the ulnar nerve or from ischemia as a result of division of the arterial branches supplying the ulnar nerve. No patient had hand ischemia. Follow-up has been limited to 3 months and there has been no angiographic assessment.

There is a reciprocal relationship between the size of the UA and radial artery. Normally, the UA is the larger of the two forearm arteries and the major source of blood for the hand (ulnar dominant). In these patients the radial artery can be removed without the risk of ischemia. In a small number of patients the radial artery is the dominant artery. In these patients the UA is either congenitally small, injured, or diseased. Although it may be desirable to use the UA in patients with a dominant radial artery, it is axiomatic that in at least some patients, the UA will be too small. However, in many patients who have a dominant radial artery, the UA is of a suitable size for use as a coronary artery bypass graft.

The hand is normally assumed to have a double circulation such that collateral vessels will supply the circulation to the fingers if either the radial artery or UA is occluded. Little and colleagues [9] have shown that the radial artery cannot be removed in all patients without major changes in the hand circulation in some patients; whether these acute changes are important in the long term is unknown. Measurement of the digital blood pressure 3 months after operation in a group of patients who had a normal Allen test and who had a radial artery harvested for use as a coronary artery bypass graft showed that the mean systolic blood pressure in the thumb was reduced by about 5% [14]. Although the mean reduction was small, there was a wide range in the blood pressure measurements and there were patients in whom the blood pressure in the thumb fell to near ischemic levels after removal of the radial artery.

Assessment of the circulation in the forearm and hand is mandatory before removal of the radial artery. The collateral circulation from the UA after occlusion of the radial artery at the wrist can be assessed effectively in many ways, for example by the Allen test, angiography, Doppler ultrasonography, oximetric plethysmography, and digital blood pressure measured with a transducer and photoplethysmography [14]. The pulse oximeter should be used with caution as it is programmed to augment the pulse wave when small, and may overestimate the pulse volume in patients with radial artery occlusion. Patients with a poor collateral supply to the hand when the distal radial artery is occluded are candidates for harvesting of the UA.

Harvesting the UA may cause injury to the ulnar nerve because of the proximity and attachments of the UA to the ulnar nerve. Unlike the radial artery, which has no important structures nearby except the terminal lateral cutaneous nerve of the forearm and superficial radial nerve, the UA lies next to the ulnar nerve, which carries important motor fibers supplying the small muscles of the hand. Careful dissection is required to avoid handling the nerve or exerting excessive traction, and the UA should be harvested by the surgeon. We have not observed any neurologic deficit after the division of the arteriae nervorum; prominent longitudinal vascular anastomoses within the nerve may protect it from ischemia [10]. The length of the UA removed from the flexor compartment is usually less than that of the radial artery, but is sufficient to reach most distal coronary arteries without mobilizing the artery in the cubital fossa. The UA is sectioned distal to the origin of the common interosseus artery, which contributes to the circulation of the hand through anastomoses with the carpal and palmar arches, thereby preserving this important collateral in the hand. Because the UA has a thick muscular media, and like the radial artery may be prone to spasm, the use of topical and long-term systemic vasodilation is advisable. Anastomotic techniques are identical with those used for the radial artery. At present we have limited clinical experience with the UA, using a single distal anastomosis and grafting it directly to the aorta proximally. It is expected that the UA could be used as a T or Y graft from
the internal thoracic artery in the same way as the radial artery.

In summary, the ability to use either forearm artery provides the cardiac surgeon with greater flexibility in the choice of arterial conduits than using the radial artery alone. The UA can be removed in patients who have a dominant radial circulation in the forearm and hand. The UA has similar physical characteristics to those of the radial artery. It has been used as a single graft but it is anticipated that it could be used as a sequential or T graft in the same way as the radial artery, thereby extending the use of arterial grafts that can be harvested from the forearm. A major concern is the potential for injury to the ulnar nerve, either through inadvertent handling or possibly through ischemia resulting from division of the branches of the UA, which supply the adjacent ulnar nerve.

Addendum

After initial acceptance of this manuscript, three further ulnar arteries have been harvested and used successfully as coronary artery bypass grafts. One patient complained of pain and hand weakness in the distribution of the UA, which emphasizes the need to use the UA cautiously when other conduits are not available.

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