The role of preoperative radial artery ultrasound and digital plethysmography prior to coronary artery bypass grafting


Department of Cardiothoracic Surgery, Jefferson Medical College, Suite 607, 1025 Walnut Street, Philadelphia, PA 19107, USA

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Abstract

Objective: Doppler ultrasound and digital plethysmography are used at our institution to determine the suitability of the radial artery for harvest prior to coronary artery bypass grafting (CABG). The purpose of this study is to determine the value of this preoperative evaluation.

Methods: A retrospective analysis of non-invasive radial artery testing was performed on 187 CABG patients. Criteria used to exclude radial arteries from harvest were anatomic abnormalities (size < 2 mm, diffuse calcifications), and perfusion deficits during radial artery occlusion (>40% reduction in digital pressure, non-reversal of radial artery flow, or minimal increase in ulnar velocity). A questionnaire was used to determine the incidence of postoperative hand ischemia or rehabilitation.

Results: In 187 patients, 346 arms were evaluated. Ninety-four arms (27.1%) were excluded for harvesting. Anatomical abnormalities included size, 2 mm (1.5%), diffuse calcifications (8.7%), congenital anomalies (2.3%), and radial artery occlusion (0.3%). Circulatory abnormalities included non-reversal of flow (7.2%), abnormal digital pressures (5.5%), and inappropriate increase in ulnar velocity (1.7%). A total of 116 radial arteries were harvested. There were no episodes of hand ischemia. No patient required hand rehabilitation.

Conclusions: Doppler ultrasound and digital plethysmography identifies both perfusion (14.5%) and anatomical (12.7%) abnormalities that may make the radial artery less suitable as a bypass conduit. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Ultrasound; Plethysmography; Radial artery; Coronary artery bypass grafting

1. Introduction

Soon after the radial artery was introduced as a conduit for coronary revascularization in 1973, it was abandoned secondary to early failures [1,2]. However, long-term follow-up revealed acceptable patency rates, and the conduit appeared to be relatively free of accelerated atherosclerosis [3,4]. In view of these findings, interest in using the radial arteries for coronary artery bypass grafting has resurfaced and, for many surgeons, it has become the second arterial graft choice for coronary revascularization, after the internal mammary arteries.

Because of the risk of hand ischemia, preoperative evaluation of the adequacy of the collateral ulnar circulation is mandatory before radial artery harvest. There is no agreement on the most appropriate preoperative study. Ideally, a preoperative evaluation should be non-invasive, highly sensitive and specific, readily available and cost-effective. Because of its simplicity, many surgeons have relied on physical examination with the Allen’s test, and have reported good clinical results. However, there is a theoretical concern: Doppler ultrasound and the Allen test do not always correlate [5,6]. Furthermore, although rare, postoperative hand ischemia has occurred when the Allen’s test alone was used to assess the collateral circulation to the hand [7–9].

From January 1997 to January 1999, we evaluated every candidate for potential surgery with the radial artery as conduit with color Doppler ultrasonography. In addition, first and fifth digital pressures were measured using plethysmography. We reasoned that a thorough preoperative forearm evaluation would be a sensitive method to assess forearm collateral circulation. In addition, we hypothesized that additional information from the Doppler ultrasound might detect radial arteries not optimal for harvest.

2. Subjects and methods

2.1. Patient population and preoperative evaluation of radial artery

Between January 1997 and January 1999, 187 patients...
were considered candidates for coronary revascularization using the radial artery as one of the conduits. Doppler ultrasound was performed in 346 arms with 5–12 MHz probes (HDI 3000, ALT, Bothell, WA or Sonos 1000, Hewlett Packard, Andover, MA). Gray-scale ultrasound of the artery was performed first to assess vessel size and the degree of vessel calcification. Several anatomic criteria were used to exclude radial arteries: small size (<2 mm in diameter), diffuse calcifications, or anatomic variants. Radial artery diameter was measured in the proximal, mid, and distal segments. Vessels < 2 mm were arbitrarily excluded to avoid technical difficulties. Diffuse calcification was defined as multiple echogenic foci with shadowing or diffusely increased echogenicity of the vessel wall with luminal narrowing. Almost uniformly multiple calcifications were noted. Finally, anatomic variants such as a high takeoff of the radial artery in the arm were used as exclusion criteria until more experience was gained.

If the artery was of good size and quality, color flow was used to determine radial artery reversal of flow during radial artery compression and to detect if there were any radial artery stenoses (if found these were confirmed with spectral Doppler through the area of narrowing). The degree of stenosis was based on the increase in peak systolic flow velocity from the prestenotic segment to the site of stenosis. A doubling of the velocity was used to indicate a significant stenosis [10]. Subsequently, ulnar artery spectral Doppler tracing was performed with and without proximal radial artery compression. In order to demonstrate an increase in ulnar velocity, the radial artery was compressed near the wrist, where it is most accessible. To demonstrate flow reversal in the distal radial artery, the artery must be compressed more proximally, in the mid or proximal forearm. An increase in ulnar flow velocity of less than 20% was interpreted as abnormal [11]. If the ultrasound tests were normal, plethysmography pressure measurements for the first and fifth digits were obtained with and without radial artery compression. A 40% decrease in digital systolic pressure was considered abnormal. The threshold of a 40% decrease in digital pressure was based upon experience with dialysis grafts in patients with steal syndrome [12]. Average length of time for bilateral arm examination was approximately 20–30 min per patient.

Digital plethysmography was not performed in 80 (23%) of the arms examined. These patients were unable to be transported to the ultrasound department due to their clinical condition. Therefore, ultrasound examination was performed at the bedside. The portable unit is not able to perform digital plethysmography.

Patients were examined late in the afternoon on the day of catheterization. If this was not possible a technician would examine the patients early the next day, before their arrival in the surgical holding area. The average cost of the examination, including overtime, when required, was US$200 per patient.

2.2. Surgical procedure

Radial arteries were harvested with the arm(s) abducted to 60°, concomitant with the harvesting of the internal mammary arteries and the saphenous veins. Shoulder elevation with a towel was avoided. All branches of the artery were divided between hemoclips, as well as the cut edges of the accompanying veins at each end of the conduit. During the latter part of the study, the volar surface of the radial artery was marked with methylene blue, to help eliminate twisting of the graft. Upon removal, the radial artery was first flushed with a nitroglycerin solution (3.3 μg/ml) and then placed in this solution until it was time for the anastomoses. The subcutaneous tissue was closed in a single layer, followed by the skin, and a dressing placed, usually during the bypass run. Usually the arm was not tucked, which was inconvenient, but not critical, for the first assistant.

Postoperatively, the patients received isosorbide mononitrate 30 mg once a day for 6 months. This medication was started as soon as patients were tolerating intake by mouth.

2.3. Postoperative evaluation

Patients that underwent radial artery harvesting were interviewed by telephone in order to assess postoperative hand function, need for rehabilitation, and evidence of ischemic pain or claudication.

3. Results

The radial artery was used in approximately 60% of patients. Radial artery harvest was avoided in 26.7% of patients because of testing abnormalities, and in 14% of patients because of surgeon preference to use other conduits.

3.1. Patient demographics

The demographic characteristics of those patients that underwent radial artery harvesting are shown in Table 1.

3.2. Ultrasound findings

A total of 346 arms were examined in 187 patients. Ninety-four arms evaluated (27.1%) were excluded for radial artery harvest secondary to either anatomical
(12.7%) or circulatory (14.5%) abnormalities (Fig. 1). Anatomical abnormalities included: calcified radial arteries (8.7%), congenital anomalies (2.3%), small size < 2 mm (1.5%), and radial artery occlusion (0.3%). The congenital anomalies included seven arms with high bifurcating radial arteries and one arm demonstrating radial artery agenesis. The circulatory abnormalities found during radial artery compression were divided between non-reversal of palmar arch flow (7.2%), inappropriate compensatory increases in ulnar velocity (1.7%), and abnormal digital pressure (5.5%).

A total of 19 arms demonstrated more than a 40% decrease in systolic first ($n=16$) or fifth ($n=3$) digital systolic pressures during radial artery compression as their only abnormality. Further analysis of the arms with abnormal digital pressures revealed that the average decrease in systolic pressure was 71 ± 6% from baseline digital pressure. The digital systolic pressure, during radial artery compression, was ≤ 60 mmHg in 11 out of the 19 arms that had abnormal digital pressures. Furthermore, seven arms demonstrated complete blunting of the digital pressure waveform during radial artery compression (Fig. 2).

3.3. Local complications from radial artery harvest

The non-dominant radial artery was harvested in all 113 patients, and three patients underwent bilateral harvesting. There were no acute ischemic complications of the hand. Two patients (1.8%) developed forearm wound infections. One severely diabetic patient developed a subcutaneous infection 14 days after surgery while in the hospital. It was treated with intravenous antibiotics and drainage, followed by flap coverage of forearm tendons by the hand surgery service. Another patient developed a wound infection 1 week after discharge, which was treated with antibiotics as an outpatient.

One patient (0.9%) developed shoulder weakness on the side of radial artery harvest. Further evaluation revealed a brachial plexopathy. The radial artery was harvested simultaneously with the internal mammary artery, and it is uncertain if this caused additional stretching of the brachial plexus. The patient is undergoing rehabilitation and continues to improve.

Finally, two out of 118 arms (1.7%) explored revealed diffuse calcifications that were not reported in their preoperative evaluation. These abnormalities were noted after the artery was removed. The radial arteries were discarded in these patients.

3.4. Outcome of patients with radial artery harvest

There were no mortalities in patients with their radial artery harvested. One patient suffered a sudden cardiac arrest approximately 30 min after arriving in the intensive care unit. A radial artery had been placed to the distal right coronary artery. He was returned to the operating room and an additional saphenous vein graft was placed to the posterior descending branch of the right coronary. Inspection suggested spasm of the radial graft. A biventricular Abiomed assist device (Abiomed Inc., Danvers, MA) was inserted. After several days, the device was weaned and after a prolonged course, the patient was discharged from the hospital.

Ninety-five patients were contacted by phone to assess hand function. The mean follow-up was 10.2 ± 6 months (range 1–24 months). There were no ischemic complications of the hand. No patient described any limitations in his daily activities secondary to hand dysfunction. The only rehabilitation required was for the patient mentioned previously with the brachial plexopathy who needed shoulder rehabilitation.

3.4. Outcome of patients with radial artery harvest

![Distribution of U/S Abnormalities](image)

**Fig. 1.** Distribution of circulatory and anatomical abnormalities found during Doppler ultrasonography and plethysmography in the 346 arms examined. These abnormalities excluded the arm for radial artery harvest.

![Representative waveforms of first-digit plethysmography](image)

**Fig. 2.** Representative waveforms of first-digit plethysmography. (A) Normal response; digital pressure is ulnar artery dependent. (B,C) Two different patients showing complete blunting of digital waveforms during radial artery compression. Patient in (B) shows radial and ulnar artery dependence while the patient in (C) shows complete radial artery dependence.
4. Discussion

Many cardiac surgeons now consider the radial artery as the second choice arterial conduit for coronary artery bypass grafting (CABG) after the internal mammary arteries. A principal concern when harvesting the radial artery is whether or not it will result in hand ischemia. Surgeons have relied predominantly on Allen’s test as their only preoperative evaluation to assess the safe removal of the radial arteries. However, the Allen’s test does not provide a foolproof evaluation of the hand circulation [5–8].

There are several reports of hand ischemia after radial harvest for CABG. One patient with a normal preoperative Allen’s test, developed acute hand ischemia [8]. Angiographic evaluation revealed an absence of the ulnar artery, which would be evident with Doppler ultrasound evaluation of the forearm. In another series, two patients (one with scleroderma and the other one with Raynaud’s disease) developed hand ischemia after evaluation by a modified Allen’s test [9]. These patients had ulnar collateral circulation times between 6 and 10 s. None of the patients with circulation times less than 5 s had ischemia. Another case of hand ischemia was reported in 1985, after a radial forearm muscle flap was performed [7]. All of these studies relied on the Allen’s test as the only preoperative evaluation to assess proper hand circulation. It appears that the Allen’s test predicts the great majority, but not all cases of hand ischemia. In addition, harvesting radial arteries of patients with collagen vascular diseases should be contraindicated.

At our institution, instead of the Allen’s test, we perform Doppler ultrasound and digital plethysmography of the radial artery prior to CABG. The rate of circulatory abnormalities identified by ultrasound (i.e. non-reversal of flow and compensatory ulnar velocities) is similar to that reported for an abnormal Allen’s test. Plethysmography excluded an additional 19 arms (5.5%) secondary to inadequate digital pressures during radial artery compression. These circulatory abnormalities were isolated and not associated with non-reversal of flow in the palmar arch or abnormal ulnar velocities.

We have chosen not to harvest the radial artery in patients with low digital pressures because it is difficult to assess digital reperfusion clinically, in particular to the thumb. It appears reasonable to exclude a few more patients with questionable radial artery dependence in exchange for more certainty concerning digital perfusion. The 5.5% of patients with abnormal digital pressures but with normal palmar arch reversal and ulnar increases with radial compression might be vulnerable to subtle changes from chronic ischemia. In our series, only one patient underwent postoperative arm rehabilitation, and this was secondary to a brachial plexopathy. This low rate of postoperative hand rehabilitation may be related to avoiding radial artery harvest in patients with abnormalities diagnosed during preoperative testing.

One rationale for preoperative testing is that digital ischemia is possible if testing is not done. However, our data suggest an uncertainty with regards to the value of digital plethysmography. We harvested 37 radial arteries that were not studied by digital plethysmography but had normal Doppler ultrasound evaluation, and none of these patients experienced digital ischemia or underwent postoperative rehabilitation. Complete blunting of the digital pressure waveform was observed in 2.6% of the arms examined. Therefore, we would have expected that one out of these 37 arms would have shown flattening of the digital pressures. Due to the small sample size it is difficult to draw any conclusions. Nevertheless, we remain reluctant to harvest the radial artery when there is complete blunting of the digital pressure waveform during radial artery compression. Further studies are needed to define objective ultrasound criteria, especially digital pressure parameters, to accurately predict patients at risk for hand ischemia after radial artery harvest.

An important limitation of the Allen’s test is its inability to detect approximately 10% of patients with anatomic abnormalities (e.g. diffuse calcifications, small size <2 mm, or congenital anomalies). Although high bifurcation of the radial artery or small radial artery size are not necessarily a contraindication to harvest, avoidance of its use reflects our conservative approach to radial artery harvesting.

The most common anatomical abnormality found during preoperative testing was calcification of the radial artery. Diffuse calcifications may represent atherosclerosis or Monkberg’s medial calcification. A recent histologic study reported that a significant number of radial arteries harvested in patients undergoing CABG showed atherosclerosis (5%) but a greater percentage showed medial calcifications (13%) [13]. Our preoperative evaluation showed an 8.7% incidence of radial artery calcification. Since a high frequency (>5 MHz) transducer was used, the methodology was sensitive in detecting both intimal and medial calcifications. Although the effect of Monkberg’s medial calcification on long-term radial artery patency is presently unknown, it is best to exclude such conduits until their long-term patency is determined.

It is reasonable to question whether a $200 preoperative test, such as Doppler ultrasound, is necessary before CABG, given the low rate of clinical sequelae when the Allen test is used. In addition, it might be argued that intraoperative testing performed by dissecting out the artery, temporarily occluding it, and nicking the artery distally to evaluate backflow affords a significant amount of protection without incurring additional expense. We feel preoperative ultrasound is warranted for several reasons. First, many patients, and surgeons, feel uncomfortable with even a small chance of hand ischemia. Preoperative ultrasound should help to further minimize this possibility, and may result in a greater use of this conduit. Second, preoperative ultrasound avoids an unnecessary forearm dissection in those 10% of patients with significant calcification or small size. Although introa-
perative testing might predict perfusion abnormalities, it would have difficulty detecting moderate intimal calcification and inadequate size, since arterial spasm occurs with manipulation. Assurance that the artery can be used may shorten the conduit harvest time, in particular when it is found to be inadequate during the operation. Finally, in some patients with few other conduits, it is important to know the adequacy of the radial arteries before starting the operative procedure.

Another reasonable question is whether Doppler ultrasound and plethysmography is better than preoperative evaluation by methods other than the Allen’s test. Digital pulse oximetry has been used to assess collateral circulation. However, pulse oximetry amplifies digital waveforms, and may overestimate collateral flow. Doppler ultrasound is the best method to visualize the ulnar artery.

In summary, using the preoperative radial artery evaluation, we excluded 27.1% of the arms examined for radial artery harvest. Other studies using some form of ultrasound evaluation have shown between 10 and 23% exclusion rate [10,14,15]. Almost half of the arms excluded in our study were secondary to anatomical abnormalities which we believe would have been missed by the Allen’s test and less thorough non-invasive studies.

References