Anatomic Variations of the Radial Artery in Patients Undergoing Transradial Coronary Intervention

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Anatomic variations of the radial artery and their effect on the use of the radial artery as a route for transradial coronary intervention (TRI) were studied. Ultrasonography of the radial artery was performed prospectively in 115 patients selected to undergo elective TRI. Anatomic variations were observed in 11 of 115 patients (9.6%). Variations included six tortuous configurations (5.2%), two stenoses (1.7%), two hypoplasias (1.7%), and one radioulnar loop (0.9%). The hypoplastic radial arteries and the radioulnar loop were inaccessible for catheterization, and coronary intervention was planned via the femoral artery. The transradial approach was attempted in the remaining 112 patients (97.4%) with only one instance of access failure, in a patient who had a stenotic vessel. These findings indicate that anatomic variations of the radial artery is not rare, and that preoperative ultrasound examination may help to exclude patients with inaccessible arteries and those at high risk for access failure. Cathet. Cardiovasc. Intervent. 49:357–362, 2000.
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INTRODUCTION

Previous studies have demonstrated the feasibility of using the radial artery as a route for transcatheter coronary interventions [1–3]. The major advantages of this strategy over conventional transfemoral and/or transbrachial techniques include the lower risk of access site-related complications [4], which may be attributed to the unique anatomy of the radial artery. First, because the radial artery is superficial, hemostasis can be easily achieved by local compression. Second, no large veins or nerves exist near the radial artery, which minimizes the chance of injury of such structures. Lastly, collateral blood supply via the palmar arch usually precludes hand ischemia even when the radial artery becomes occluded by thrombosis.

Access failure via the radial artery occurs in 1% to 5% of cases [1,4–8]. Failure to access the brachial artery using the percutaneous [4,9] or cutdown [10] technique is less common. This discrepancy may be explained in part by the small caliber of the radial artery. It must be considered, however, whether other factors related to the anatomy of the radial artery may also contribute to the incidence of access failure in patients undergoing transradial coronary intervention (TRI). One highly experienced French group recently suggested that technical failures are due mainly to anatomic variations, such as radial loops, rather than small caliber [11]. Despite the need for this type of information, the anatomy of the radial artery has yet to be studied systematically from the perspective of using it as a route for catheter access. Accordingly, we prospectively performed ultrasonography to delineate the anatomic features of the radial artery as a way to determine the feasibility of using it as a route for coronary intervention.

MATERIALS AND METHODS

Patient Selection

One hundred fifteen patients scheduled to undergo elective coronary intervention via the radial artery were

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included in this study. All patients had a palpable radial artery pulse, and hand perfusion via the ulnar artery was assessed using the modified Allen’s test. Briefly, the patient was asked to repeatedly clench the fist to squeeze the blood out of it while the examiner compressed both the ulnar and radial arteries. The patient then relaxed the fist, and ulnar compression was released. The test was considered normal if hand color returned within 10 sec, indicating that blood supply to the hand via the ulnar artery and the palmar arch was satisfactory. Written informed consent was obtained from all patients prior to enrollment, and the study protocol was approved by the institutional ethics committee.

Ultrasonography of Radial Artery

Ultrasonography of the radial artery was performed in all patients the day before TRI using a Sequoia 512 (Acuson, Mountain View, CA) with a 5- or 8-MHz linear transducer. If not contraindicated, the patients received oral vasodilators, including calcium channel blockers and nitrates, at the time of examination according to institutional angioplasty protocol. With the patient at rest in the supine position, the entire radial artery was scanned in both the longitudinal and transverse planes from the palmar arch to the brachial artery using two-dimensional and color Doppler echography. The luminal diameter was measured 2 cm proximal to the styloid process with the transducer positioned perpendicular to the vessel wall. Pulsed Doppler examination was performed at the same site with the probe positioned at less than 60° to the vessel wall to determine the flow velocity in the radial artery. Ultrasonography was repeated post-TRI in patients who successfully underwent TRI. A consensus reading was performed by at least two investigators. All quantitative data were obtained by calculating the mean of four measurements from four cardiac cycles.

Radial Artery Cannulation and Angioplasty Procedures

The arm was positioned beside the body with the wrist hyperextended, and the radial artery was cannulated using the standard seldinger technique. Briefly, local anesthesia was established with 2% lidocaine. The radial artery was punctured at a 45° angle, 2 cm proximal to the styloid process with a 20-Gauge needle (Terumo, Tokyo, Japan), and a 0.025” straight guidewire (Terumo) was inserted through the needle. The needle was removed, and a 6 Fr sheath (length, 20 cm; Terumo) was introduced gently into the radial artery over the guidewire. When necessary, a 7 Fr sheath (length, 10 cm) was used instead of the 6 Fr sheath. Heparin (150 IU/kg) was administered via the introducer sheath immediately after its insertion. Additional heparin (75 IU/kg) was administered in hourly boluses throughout the procedure. No heparin was used after the procedure. When angioplasty was successful, the arterial sheath was removed in the catheterization laboratory immediately after the procedure. The puncture site was compressed with a Stepty-P elastic bandage (Nichiban, Tokyo, Japan) [12], which was originally developed for hemostasis after blood sampling from the radial artery. The bandage was removed 3 hr after the procedure. If bleeding from the puncture site continued, the radial artery was compressed for an additional 2 to 3 hr with gauze and a tourniquet. Throughout the period of compression, the patients were allowed to ambulate freely, but were asked to limit wrist movement.

Statistical Analysis

All data are expressed as mean ± standard deviation. Statistical analysis was performed using the Wilcoxon or Mann-Whitney nonparametric U-test. A P value less than 0.05 was considered significant.

RESULTS

Study Population

Of the 115 patients selected to undergo elective TRI, 83 (72.2%) were men. The mean patient age was 64.5 ± 9.7 years. Sixty-two patients (53.9%) had a history of myocardial infarction, and seven (6.1%) had undergone coronary bypass surgery (Table I).

Preoperative Ultrasound Examination of Radial Artery

All radial arteries except one, which formed a radio-ulnar loop, arose from the distal end of the brachial

| TABLE I. Demographics and Clinical Characteristics of Patients Undergoing TRI* |
|-------------------------|------------------|
| **n**                  |                  |
| Age (years)            | 64.5 ± 9.7       |
| Gender (male)          | 83 (72.2%)       |
| Previous myocardial infarction | 62 (53.9%)     |
| Previous coronary bypass surgery | 7 (6.1%)     |
| Risk factors           |                  |
| Diabetes               | 42 (36.5%)       |
| Hyperlipidemia (TC > 220 mg/dL) | 27 (23.5%) |
| Smoking                | 67 (58.3%)       |
| Hypertension           | 72 (62.6%)       |
| Extent of coronary artery disease |          |
| One vessel             | 76 (66.1%)       |
| Two vessels            | 27 (23.5%)       |
| Three vessels          | 12 (10.4%)       |
| Target lesions for TRI | 119              |
| Left anterior descending CA | 44 (37.0%) |
| Left circumflex CA     | 43 (36.1%)       |
| Right CA               | 29 (24.4%)       |
| Saphenous vein graft   | 3 (2.5%)         |

*Age is presented as mean ± SD. TC = total cholesterol; CA = coronary artery.
artery, usually below the bend of the elbow, and traveled to the wrist along the radius. The luminal diameter was measured 2 cm proximal to the styloid process in 113 of 115 patients (Fig. 1). The diameter of two hypoplastic radial arteries could not be determined. The luminal diameter ranged from 1.6 to 3.8 mm (mean, 2.6 ± 0.5 mm). The mean flow velocity in the radial artery was 54.4 ± 16.4 cm/sec. Anatomic variations were noted in 11 of 115 patients (9.6%). Variations included a tortuous configuration, stenosis, hypoplasia, and a radioulnar loop.

**Tortuous Radial Artery Without Stenosis**

A tortuous radial artery with a maximum angulation of more than 45° was demonstrated on two-dimensional and color Doppler ultrasonography in seven patients (6.1%; Fig. 2A, upper panel). Six of these patients (5.2%) showed a normal pulsed Doppler waveform associated with a dicrotic wave in early diastole (Fig. 2A, lower panel, arrow). This pulsed Doppler finding suggested the absence of significant stenosis in the vessel. In these six patients, angioplasty was performed successfully via the radial artery. The remaining one patient with a tortuous radial artery showed decreased flow velocity and no dicrotic wave on pulsed Doppler examination (Fig. 2B, middle panel), which suggested the presence of stenosis. In this patient, despite successful puncture of the radial artery, insertion of the introducer sheath failed due to the inability to advance the guidewire. Angiography performed at the time of radial artery cannulation confirmed the presence of severe proximal lesion (Fig. 2B, lower panel).

**Hypoplastic Radial Artery**

Two patients had a hypoplastic radial artery (1.7%). In these patients, despite the presence of a radial pulse, two-dimensional and color Doppler examinations were unable to identify the distal half of the radial artery (Fig. 2C, upper panel). Accordingly, coronary intervention was performed via the femoral artery. Angiography of the radial artery performed at the time of angioplasty via the femoral artery documented hypoplasia (Fig. 2C, lower panel). It is interesting to note that the pulsations, which were thought to be in the radial artery, actually were due to a branch of the palmar arch (Fig. 2C, lower panel).

**Radioulnar Loop**

A radioulnar loop was observed in one patient (0.9%). The proximal radial artery was turned distally and arose from the ulnar artery instead of the brachial artery (Fig. 2D). In this case, the radial artery was considered to be inaccessible, and coronary intervention was performed via the femoral artery.

**Transradial Coronary Intervention**

Based on the ultrasonographic findings, coronary intervention was planned via the femoral artery in the patients who had a hypoplastic radial artery (n = 2) and the patient who had a radioulnar loop (n = 1). Angioplasty was attempted via the radial artery in the remaining 112 patients (97.4%). Puncture of the radial artery was successful in all patients. However, as described above, advancement of the guidewire failed in one patient who had radial artery stenosis. Insertion of the 6 Fr (n = 101) or 7 Fr (n = 10) introducer sheath, as well as advancement of the guiding catheters, was successful in all but this one case. The mean diameter of the radial arteries, into which the 6 Fr sheaths were inserted, was 2.6 ± 0.5 mm (range, 1.6–3.8 mm). This was not sig-
Figure 2.
nificantly different from the mean diameter of the radial arteries into which the 7 Fr sheaths were inserted (2.4 ± 0.5 mm; range, 2.0–3.4 mm).

One hundred nineteen lesions in 111 patients were treated with TRI (Table I). The intervention procedures included plain-old balloon angioplasty (n = 39), stent implantation (n = 76), cutting balloon angioplasty (n = 1), rotablator (n = 1), and rotablator followed by stent implantation (n = 2). Procedural success, defined as residual stenosis of less than 50% without precipitating a major cardiac event, including death, myocardial infarction, or emergent coronary bypass surgery, was achieved in 110 patients (99.1%). No access site-related complications developed.

**Postoperative Ultrasonography of Radial Artery**

Follow-up ultrasonography of the radial artery was performed in 95 of 111 patients (85.6%) in whom TRI had been attempted between 1 and 429 days after TRI (mean time to examination, 57.1 ± 90.7 days). Follow-up examination documented occlusion of the radial artery in six patients (6.3%), all of whom were asymptomatic. Except for radial artery occlusion, no evidence of vascular injury resulting from TRI, such as dissection and intimal hyperplasia, was identified. The mean luminal diameter of the radial artery post-TRI was 2.7 ± 0.5 mm in the 89 patients without occlusion. This was not statistically different from that prior to TRI (2.6 ± 0.5 mm).

Among 104 patients with a normal radial artery who underwent TRI, 88 had follow-up ultrasound (84.6%). Occlusion of the radial artery was observed in five patients (5.7%). Among the seven patients who had an anatomic variation (six tortuous radial artery and one stenotic radial artery), the patient with the tortuous radial artery developed occlusion (1/7, 14.3%). No statistically significant difference was observed in the occlusion rate between normal radial arteries and those with an anatomic variation.

Fig. 2. Anatomic variations of the radial artery. A: Tortuous radial artery. Upper panel, color Doppler ultrasound showing a tortuous radial artery. Lower panel, pulsed Doppler ultrasound showing a normal flow waveform associated with a dicrotic wave (arrow). The peak flow velocity was 60 cm/sec in this patient. B: Stenotic radial artery. Upper panel, color Doppler ultrasound showing a tortuous radial artery. Due to the tortuosity of the lesion, two-dimensional and color Doppler examinations failed to identify the site of the stenosis. Middle panel, pulsed Doppler ultrasound showing a reduced systolic flow velocity of 30 cm/sec. Waveform analysis disclosed no dicrotic wave in early diastole. Lower panel, angiography confirming the presence of high-grade stenoses (arrows) in the proximal radial artery. C: Hypoplastic radial artery. Upper panel, color Doppler ultrasound fails to visualize the distal half of the radial artery. Lower panel, angiography of the radial artery confirming the existence of hypoplasia of the radial artery. Note that the pulsations, which were thought to be in the radial artery, were generated by a branch of the palmar arch (arrow). D: Radial-ulnar loop. Upper panel, color Doppler ultrasound showing that the proximal radial artery turned around distally. Lower panel, angiography demonstrating the connection to the ulnar artery instead of the brachial artery (arrow). The proximal radial artery ended as a recurrent branch in the upper arm.

In this study, we demonstrated that nearly 10% of patients undergoing TRI had an anatomic variation of the radial artery. Even so, TRI was performed safely in the majority of patients. It should be noted, however, that there was a small group of patients in whom the radial artery was inaccessible due to anatomic variations, including hypoplasia (1.7%) and the presence of a radio-ulnar loop (0.9%). In these patients, advancement of the guidewire and the introducer sheath would have been impossible or extremely complicated. Considering the fact that the reported incidence of access failure to the radial artery (1 to 5%) [1,4–8] is quite similar to the incidence of these anatomic variations in our study (2.6%), a significant percentage of access failures results from these anomalies of the radial artery.

Other observed anatomic variations of the radial artery included a tortuous configuration (5.2%) and stenosis (1.7%). It must be pointed out that the presence of these lesions does not necessarily preclude the possibility of catheter access and that a significant number of these patients can be treated via the transradial route. Advancement of the guidewire and insertion of the introducer sheath was successful in all patients with a tortuous radial artery in this study, and insertion of the 20-cm-long introducer sheath straightened these tortuous arteries. Nevertheless, caution must be exercised when advancing a guidewire or introducer sheath through a tortuous radial artery because the risk of dissection and perforation is real [13].
Arterial cannulation failed in one of the two patients with radial artery stenosis. In this patient, stenosis could not be documented either by two-dimensional or color Doppler ultrasonography, probably due to the highly tortuous configuration of the radial artery. In such cases, pulsed Doppler examination may be more sensitive for detecting stenosis.

The radial artery diameter prior to TRI ranged from 1.6 to 3.8 mm (mean, 2.6 ± 0.5 mm). Horning et al. [14] recently have reported that mean radial artery diameter 15 cm proximal to the wrist was 2.8 mm in healthy volunteers. Since our measurements were made more distally than in that study, the slight difference in the mean diameter seems to be reasonable.

The incidence of radial artery occlusion after TRI has been reported to range from 2% to 10% [1,15,16]. In the current study, follow-up ultrasonography documented an occlusion rate of 6.3%. No patient developed symptomatic hand ischemia. Given the dual blood supply of the hand, it is not surprising that symptomatic hand ischemia is rare. Nevertheless, radial artery occlusion should be avoided whenever possible to maintain a patent vascular access site. The reason why some patients developed an occlusion has not been determined yet. Some authors have suggested that radial artery occlusion may be related to cannulation time, the size of the artery, and the heparin regimen [17,18]. We found that a small radial artery and a large sheath/artery ratio correlated with the development of occlusion. Further investigations will be required to better define this relationship.

Ultrasonography of the radial artery is quick and easy to perform and requires no special techniques. It usually takes only 5 min to examine the whole radial artery, and even when anatomic variations are present, 15 min is the maximum length of the examination. Thus, this examination appears suitable for use as a noninvasive screening test of the radial artery to exclude patients at high risk for access failure and/or occlusion post-TRI. On the other hand, radial artery ultrasonography costs 5,000 Japanese Yen (approximately 50 USD). Since access failure occurs in < 1% of cases in the hands of experienced operators, ultrasonography may not reduce the rate of access failure for this group. Nevertheless, routine ultrasonography may help reduce the incidence of post-TRI occlusion by identifying patients at high risk for this complication.

In summary, ultrasonography of the radial artery documented anatomic variations in nearly 10% of patients undergoing TRI. Hypoplasia and a radioulnar loop, considered contraindications to TRI, were found in 2.6% of patients. A tortuous and/or stenotic radial artery, which is considered a high-risk factor for vascular complications and access failure, was observed in 6.9% of patients. Ultrasonography of the radial artery is a useful screening tool to help select appropriate patients for TRI.