Anatomical Study of Forearm Arteries With Ultrasound for Percutaneous Coronary Procedures

Zhen-xian Yan, MD; Yu-jie Zhou, MD; Ying-xin Zhao, MD;
Zhi-ming Zhou, MD; Shi-wei Yang, MD; Zhi-jian Wang, MD

Background: In recent years, the radial artery (RA) has become an alternative vascular access site for percutaneous coronary procedures, and the ulnar artery (UA) is another possibility. The objective of this study was to investigate the anatomy of the forearm arteries with ultrasound (US) and to evaluate the effect of the anatomy of the right RA (RRA) on the outcomes of transradial coronary procedures.

Methods and Results: The 638 patients undergoing transradial coronary procedures were examined with US for measurement of the diameters of the forearm arteries and determination of their anatomical abnormalities before the procedures. The next day the incidence of RA occlusion was recorded. The diameters of the radial and ulnar arteries were similar ($P>0.05$). The procedure time was longer in patients with anatomical abnormalities ($P<0.05$) and whose RRA had a diameter <2 mm ($P<0.05$). The incidence of procedure failure, and of RA occlusion one day after the procedure was also higher in patients with an anatomical abnormality of the RRA ($P<0.01$ and $P<0.05$, respectively) and whose RRA diameter was <2 mm ($P<0.05$ and $P<0.05$, respectively).

Conclusions: The diameters of the forearm arteries of Chinese people are similar. The small diameter and anatomical abnormalities of the RRA could result in longer procedure time, more incidence of procedure failure and RA occlusion. (*Circ J* 2010; **74**: 686–692)

Key Words: Anatomical abnormalities; Radial artery; Ulnar artery; Ultrasound

The femoral artery (FA) is the most common approach for percutaneous coronary procedures, but in recent years, the vascular access site for percutaneous coronary procedures has been changing to the forearm arteries with the advent of new types of smaller sized catheters with bigger lumens. Transradial coronary procedures, including coronary angiography (CAG) and percutaneous coronary intervention (PCI), have gradually gained the attention and been adopted by interventional cardiologists in some countries. The radial artery (RA) has become the first vascular access for percutaneous coronary procedures in some larger interventional centers,^{1–3} and recently, a few interventional cardiologists have successfully performed transulnar coronary interventions. However, transradial or transulnar coronary procedures are not popular in the interventional field of coronary artery disease (CAD),⁴ because of the technical difficulties resulting from the smaller lumen and anatomical abnormalities.^{5,6}

The normal parameters and anatomical abnormalities of the RA and ulnar artery (UA) in Chinese people are unknown,^{7,8} the aim of this study was to investigate this using ultrasound (US) and to evaluate the effect of the anatomy of the RA on the outcomes of transradial coronary procedures.

Methods

Study Patients

From June 2007 to December 2007, 638 consecutive patients with a normal Allen test who were to undergo CAG and/or PCI via the RA were studied. Patients with a negative Allen test, surgical trauma of the forearm arteries, peripheral vessel disease, previous transradial CAG or PCI, or previous hemodialysis were excluded. Written informed consent was given by the patient or family member(s) before the transradial procedure.

Examination of Forearm Arteries With US

The ultrasonic examination of the forearm arteries were performed by an experienced cardiologist using a LOGIQ9 ultrasound (GE, Milwaukee, WI, USA) and 9.0–14.0 MHz linear transducer (GE). The diameters and anatomical abnormalities of the forearm arteries were recorded before the transradial coronary procedure and one day after the incidence of right RA (RRA) occlusion was noted. In addition, the vascular access time, the procedure time, puncture failure, procedure failure and the hemostasis time were recorded.

The patients lay supine with both arms naturally abducted.

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Department of Cardiology, Beijing Anzhen Hospital Affiliated to the Capital University of Medical Science, Beijing, China
Mailing address: Yu-jie Zhou, MD, PhD, FACC, Department of Cardiology, Anzhen Hospital, Capital Medical University, Anzhenli district, Beijing, 100029, China. E-mail: yjzhou@hotmail.com

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The bilateral UA and RA were examined from palm to brachial artery. The diameter of the RA was measured at 1 cm proximal to the styloid process of the radius, while that of the UA was measured at 1 cm proximal to the styloid process of the ulna. The transducer was placed vertical to the artery wall. Anatomical abnormalities of the forearm arteries were detected by color Doppler imaging with less than 60° between the transducer and the artery wall.

Definitions

According to the definition of Uglietta et al, the anatomical abnormalities of forearm arteries are divided into anomalous branching, tortuosity, hypoplasia, radial-ulnar artery loop and stenosis.⁹

Anomalous branching included high origin of the RA, high origin of the UA, double RA and double UA. A high origin of the forearm arteries was defined as the RA or UA not diverging from the lever of the neck of the radius, but from above the middle of the upper arm, from the brachial or axillary artery. Tortuosity of the forearm arteries was defined as the RA or UA having 2 or more bends with $\geq 45^\circ$ from the styloid process of the radius or ulna to the bifurcation of the RA or UA. Hypoplasia was defined as the distal segment of the RA or UA being very small. A radial-ulnar artery loop was defined as the proximal end of the RA or UA entangled in an annulus connected with the brachial artery. Stenosis was defined as the cross-sectional area of the artery lumen decreased $\geq 50\%$ compared with the reference segment of the artery. RA occlusion was defined as no blood flow in the artery.

The vascular access time was defined as the time from skin anesthesia to arterial cannulation. The procedure time was defined as the time from patient arrival at the catheterization room to completion of the procedure.

Reproducibility of Measurements of Forearm Artery Diameters

To assess the intra-observer agreement, a single examiner measured the forearm artery diameters in 25 patients twice on the same occasion.

Statistical Analysis

Statistical analysis was performed with SPSS 13.0 (Chicago, IL, USA). Continuous variables are expressed as mean $\pm$ standard deviation, and categorical variables are expressed as frequency. Continuous variables were compared with Student's t-test or variance analysis of a single factor, and the differences between categorical variables were examined by chi-square test. Multiplicity was performed with logistic regression analysis. A probability level <0.05 was considered statistical significant. Intra-observer agreement was examined using intraclass correlation coefficients (ICC) and their 95% confidence intervals (CI).

Results

Baseline Clinical Characteristics

The average age of the 638 patients was 60.6 ± 11.3 years, and 78.1% were male. There were 126 patients (19.7%) with stable angina, 417 (65.4%) with unstable angina, 59 (9.2%) with old myocardial infarction and 36 (5.6%) with other diagnoses (Table 1).

Distribution of the Diameters of Forearm Arteries

Figure 1 shows the histograms and normal curve diagrams of the diameters of the RRA, left RA (LRA), right UA (RUA)

Table 1. Baseline Clinical Characteristics

	n=638
Age (years)	60.6 $\pm$ 11.3
Male (%)	498 (78.1%)
Height (m)	1.67 $\pm$ 0.08
Weight (kg)	70.3 $\pm$ 10.5
Body surface area (m ²)	1.67 $\pm$ 0.17
Body mass index (kg/m ²)	23.7 $\pm$ 2.9
Arm circumference (cm)	
Right	29.3 $\pm$ 2.4
Left	28.8 $\pm$ 2.4
Risk factors of cardiovascular disease (%)	
Hypertension	204 (63.9%)
Diabetes	137 (21.4%)
Hyperlipidemia	161 (25.2%)
Smoking	261 (40.9%)
Clinical diagnosis (%)	
Stable angina	126 (19.7%)
Unstable angina	417 (65.4%)
Old myocardial infarction	59 (9.2%)
Other	36 (5.6%)
Medications (%)	
Aspirin	537 (84.2%)
Clopidogrel	39 (6.1%)
Angiotensin-converting enzyme inhibitor	342 (53.6%)
Angiotensin-receptor antagonist	41 (6.4%)
β receptor block	465 (72.9%)
Calcium antagonist	203 (31.8%)
Nitrate	561 (87.9%)

and left UA (LUA). The diameters of the forearm arteries were in normal distribution. The range of the RRA diameter was 1.3–3.6 mm (mean, 2.38 ± 0.56 mm).

Table 2 shows that the mean diameters of the LRA and LUA, RRA and RUA were similar. Although the mean diameters of the RRA and LRA were larger than those of the RUA and LUA, there was no significant difference ($P>0.05$).

In this study, the diameters of the RA and UA were similar in 47% patients, the diameter of the RA was larger than that of the UA in 31% patients, and the diameter of the UA was larger than that of the RA in 22% patients.

The diameters of the RRA, LRA, RUA, and LUA in female patients were all smaller than those in male patients ($P<0.05$, $P<0.01$, $P<0.05$, $P<0.01$, respectively).

Intra-Observer Agreement of Measurements of Forearm Artery Diameters

Table 3 summarizes the ICC on intra-observer agreement for measurements of forearm artery diameters. Intra-observer agreement was excellent for all measurements, with the ICC ranging from 0.95 (diameter of RUA) to 0.97 (diameter of RRA).

Factors Related to the Diameter of the RRA

The patients were divided into 2 groups according to the diameter of the RRA: diameter ≥ 2 mm; diameter <2 mm. There were significant differences in the sex, height, weight, body surface area, body mass index and arm circumference between the 2 groups, but there were no significant difference in the risk factors for cardiovascular disease and CAD

Table 2. Diameters of the Forearm Arteries			
	Min	Max	Mean
Right RA (mm)	1.1	3.6	2.38±0.56
Male	1.3	3.6	2.47±0.57
Female	1.1	3.1	2.17±0.48*
Left RA (mm)	1.4	3.5	2.38±0.47
Male	1.4	3.5	2.44±0.48
Female	1.4	3.0	2.07±0.41**
Right UA (mm)	1.1	3.5	2.36±0.49
Male	1.4	3.5	2.42±0.61
Female	1.1	3.1	2.22±0.71*
Left UA (mm)	1.4	3.6	2.35±0.48
Male	1.4	3.6	2.44±0.41
Female	1.2	3.0	2.06±0.58**

Compared with male patients *P<0.05; **P<0.01.
RA, radial artery; UA, ulnar artery.

Table 3. Intra-Observer Agreement for the Measurements of the Forearm Arteries	
	Intra-observer agreement ICC (95%CI)
Diameter of right RA	0.97 (0.94, 0.99)
Diameter of left RA	0.97 (0.93, 0.99)
Diameter of right UA	0.95 (0.90, 0.98)
Diameter of left UA	0.96 (0.91, 0.98)

ICC, intraclass correlation coefficients; CI, confidence interval.
Other abbreviations see in Table 2.

or medications in both groups (Table 4).
Logistic regression analysis using age, sex, height, weight, body surface area, body mass index, arm circumference, cardiovascular disease, CAD and medications showed that sex (odds ratio (OR) 2.064, 95%CI 1.427–3.185, P=0.018), height (OR 2.039, 95%CI 1.271–2.964, P=0.024), weight (OR 1.726, 95%CI 1.114–2.258, P=0.029) and arm circumference (OR 1.509, 95%CI 1.087–2.194, P=0.035) were the independent factors determining a diameter of the RRA ≥2 mm.

Table 4. Comparison of Right RA of Diameter ≥ 2 mm With Right RA < 2 mm

	Diameter ≥ 2 mm (n=479)	Diameter < 2 mm (n=159)	P value
Age (years)	60.1 $\pm$ 12.3	61.1 $\pm$ 10.2	0.758
Male (%)	391 (81.6%)	106 (66.7%)	0.009**
Height (m)	1.73 $\pm$ 0.14	1.62 $\pm$ 0.10	0.017*
Weight (kg)	75.4 $\pm$ 11.5	65.1 $\pm$ 9.8	0.029*
Body surface area (m ²)	1.75 $\pm$ 0.20	1.61 $\pm$ 0.34	0.021*
Body mass index (kg/m ²)	28.6 $\pm$ 3.2	20.9 $\pm$ 2.7	0.032*
Arm circumference (cm)	33.5 $\pm$ 3.5	26.3 $\pm$ 2.3	0.025*
Risk factors of cardiovascular disease (%)	96 (20.0%)	37 (22.3%)	0.531
Hypertension	302 (63.0%)	102 (64.1%)	0.437
Diabetes	96 (20.0%)	37 (22.3%)	0.531
Hyperlipidemia	113 (23.6%)	43 (27.0%)	0.428
Smoking	201 (42.0%)	62 (39.0%)	0.369
Coronary artery disease (%)	354 (73.9%)	112 (69.8%)	0.295
Taking medications (%)			
Aspirin	388 (81.0%)	135 (84.9%)	0.912
Clopidogrel	34 (7.1%)	9 (5.7%)	0.436
Angiotensin-converting enzyme inhibitor	244 (50.9%)	87 (54.7%)	0.726
Angiotensin-receptor antagonist	32 (6.7%)	9 (5.7%)	0.433
β receptor block	335 (69.9%)	119 (74.8%)	0.641
Calcium antagonist	164 (34.2%)	45 (28.3%)	0.737
Nitrate	426 (88.9%)	138 (86.8%)	0.825

Compared with diameter of right RA ≥ 2 mm *P<0.05; *P<0.01.
Abbreviation see in Table 2.

Table 5. Incidence of Anatomical Abnormalities of the Forearm Arteries

	Right	Left	Total
Branching abnormality (%)	55 (4.3%)	33 (2.6%)	88 (6.9%)
High origin of RA	21 (1.6%)	12 (0.9%)	33 (2.6%)
High origin of UA	17 (1.3%)	9 (0.7%)	26 (2.0%)
Double RA	15 (1.2%)	8 (0.6%)	23 (1.8%)
Double UA	2 (0.2%)	4 (0.3%)	6 (0.5%)
Tortuosity (%)	36 (2.8%)	25 (2.0%)	61 (4.8%)
RA	27 (2.1%)	19 (1.5%)	46 (3.6%)
UA	9 (0.7%)	6 (0.4%)	15 (1.2%)
Hypoplasia (%)	13 (1.0%)	17 (1.3%)	30 (2.3%)
RA	8 (0.6%)	6 (0.4%)	14 (1.0%)
UA	5 (0.4%)	11 (0.9%)	16 (1.3%)
Loops of RA and UA	0 (0%)	0 (0%)	0 (0%)
Stenosis (%)	9 (0.7%)	9 (0.7%)	18 (1.4%)
RA	6 (0.4%)	4 (0.3%)	10 (0.8%)
UA	3 (0.2%)	5 (0.4%)	8 (0.6%)
Anatomical abnormalities of RA (%)	77 (6.0%)	49 (3.8%)	126 (9.9%)
Anatomical abnormalities of UA (%)	36 (2.8%)	35 (2.7%)	71 (5.5%)
Anatomical abnormalities of forearm arteries (%)	113 (8.9%)	84 (6.5%)	197 (15.4%)

Abbreviations see in Table 2.

Anatomical Abnormalities of Forearm Arteries

The incidence of total anatomical abnormalities of the RA and UA was 15.4% (9.9% in RA, 5.5% in UA). The anatomical abnormalities included 6.9% of branching abnormalities, 4.8% of arterial tortuosity, 2.3% of arterial maldevelopment and 1.4% of arterial stenosis. High origin of the RA or UA, double RA, and tortuosity of the RA were the common types of anatomical abnormalities (Table 5, Figure 2).

Outcomes of Transradial Coronary Procedures

There were 77 patients with anatomical abnormalities of the RRA, among whom 8 had hypoplasia and 6 had stenosis of the artery, so the initial vascular access of these 14 patients was another artery (LRA, FA or UA). In total, 624 patients underwent the coronary procedure initially by the RRA.

The outcomes of the transradial coronary procedures are shown in Table 6. The vascular access time and procedure time both were longer in patients with an anatomical abnor-

Figure 2. Anatomical abnormalities of the forearm arteries. (A) High origin of the right radial and ulnar arteries (axillary artery level); (B) double radial arteries; tortuosity of the (C) right radial artery and (D) the right ulnar artery; (E) stenosis of the right ulnar artery; (F) maldevelopment of the left ulnar artery.

Table 6. Outcome of Transradial Coronary Procedures

	Anatomical abnormality		Diameter of right RA	
	No (n=561)	Yes (n=63)	≥2mm (n=479)	<2mm (n=145)
Vascular access time (min)	1.3±0.4	2.1±0.5*	1.2±0.3	1.8±0.4*
Procedure time (min)	53.7±12.6	71.1±13.5*	52.4±11.6	64.9±9.8*
RA puncture failure (%)	4 (0.7%)	3 (4.8%)**	3 (0.6%)	4 (2.7%)*
Transradial coronary procedure failure (%)	8 (1.4%)	5 (7.9%)**	8 (1.7%)	5 (3.4%)*
RA occlusion (%)	15 (2.7%)	4 (6.3%)*	11 (2.3%)	8 (5.5%)*

*P<0.05; **P<0.01.

Abbreviations see in Table 2.

malinity of the RRA ($P<0.05$ and $P<0.05$, respectively) and in patients whose RRA diameter <2 mm ($P<0.05$ and $P<0.05$, respectively). The incidence of RA puncture failure and of procedure failure was also higher in these patients (anatomical abnormality: $P<0.01$ and $P<0.01$, respectively; RRA diameter <2 mm: $P<0.05$ and $P<0.05$, respectively). In 5 patients with procedure failure because of anatomical abnormality of the RRA, 4 had RA tortuosity (6.3%) and 1 had double RA (1.2%).

One day after the procedure, RA occlusion occurred in 19 patients (3.0%), and the rate was higher in patients with anatomical abnormality of the RRA ($P<0.05$) and in patients whose rRRA diameter <2 mm ($P<0.05$). However, not 1 patient with RA occlusion had ischemic symptoms of the hand.

Logistic regression analysis showed that the RRA diameter (OR 0.529, 95%CI 0.381–0.825, $P=0.011$) and duration of RRA hemostasis (OR 2.135, 95%CI 1.069–3.283, $P=0.023$) were the independent risk factors of RRA occlusion after a transradial coronary procedure.

Discussion

The RA diameter is a very important factor in the success of both vascular puncture and the procedure of transradial CAG and PCI.^{10–12} To measure the RA diameter with US before these procedures is helpful for the cardiologist to select suitable patients and instruments for the transradial procedure, thus avoiding injury to the RA. This study showed that the range of RRA diameters in Chinese adult patients is 1.3–3.6 mm (mean, 2.38 ± 0.56 mm). Nagai et al found that the diameter of the RRA of Japanese measured with US was 2.4 ± 0.4 mm,¹¹ similar to our present result. Yoo et al found that the diameter of the RRA of Koreans measured with US was 2.60 ± 0.4 mm,⁵ which is larger than in our study.

The mean diameter of the LRA in this study was 2.38 ± 0.47 mm, which was similar to that of the RRA. This finding indicates that if puncture and procedure through the RRA failed, they can be accomplished via the LRA.

In 2002, Terashima et al first reported a successful case of transulnar CAG,¹³ after which there were some reports of transulnar coronary procedures.⁴ In this study, the mean diameters of the bilateral UA were similar, and the mean diameters of the UA were similar to those of the RA, which provides an anatomic basis for transulnar coronary procedures.

The UA was once regarded as the most largest artery of the forearm,^{15–17} but in a recent study of forearm arterial anatomy, Riekkinen et al performed CAG in 24 corpses and found that the mean diameter of the RRA was larger by 28% than that of the RUA, and the mean diameter of LRA was larger by 26% than that of the LUA.¹⁸ However, Haerle et al found that the mean diameters of the RA and UA of Germans were similar when examined with US at the level of the right wrist.¹⁹ In the present study, the diameters of the RA and UA were similar in nearly half of the patients, the diameter of the RA was larger than that of the UA in 31% of patients, and the diameter of the UA was larger than that of the RA in 22%.

We found that the mean diameters of the RA and UA in male patients were larger than those in females, which may be related to the bigger physique of males. The mean diameters of the RRA of male and female patients were 2.47 ± 0.57 mm and 2.17 ± 0.48 mm, respectively, which are similar to Nagai et al's findings (2.5 ± 0.4 mm in males, 2.2 ± 0.3 mm in females).¹¹

Although the diameter of the UA makes this vessel a potential entry site, it is more prone to complications than the RA because of the proximity to the median nerve, lack of surrounding bony structures and deeper course.

The diameter of the RRA in male patients was larger than that in female patients in this study. Multiplicity showed that sex was an independently related factor for the diameter of the RRA, and also suggested that height, weight and arm circumference were independent risk factors, which demonstrated that the diameter of the RRA increased with increased height, weight, and arm circumference, thus indicating that the diameter of the RRA correlates with the physique of the patient. However, the risk factors of cardiovascular disease, a diagnosis of CAD and a history of taking medications had no influence on the diameter of the RRA.

Although Nagai et al¹¹ and Yoo et al⁵ have reported the diameters of the RRA of Japanese and Koreans, we also measured the diameters and anatomical abnormalities of the LRA, and the RUA and LUA. We found that the diameters of the RA and UA are similar, which suggests all could be vascular access for percutaneous coronary procedures, thus giving more choice to the operator.

In this study, the incidence of the total anatomical abnormalities of the RA and UA was 15.4%; the incidence of anatomical abnormalities of the right forearm arteries was greater than that of the left forearm arteries (8.9% vs 6.5%), and the incidence of anatomical abnormalities of the RA was greater than that of the UA (9.9% vs 5.5%), mainly because of high origin of the RRA and RUA occurred more often than for the left arteries (2.9% vs 1.6%), and there were more right double radial arteries than there were for the left (1.2% vs 0.6%). The incidence of anatomical abnormalities of the forearm arteries in this study was similar to that reported by Huzjan et al who examined with color Doppler US.²⁰ However, the incidence (11.9%) of anatomical abnormalities of the UA reported by Vassilev et al was much higher,²¹ and 1 reason for that is they examined using angiography, which is more accurate than US.

Among the branching abnormalities, the high origin of the RA was common. High origin of the RA often coexisted with high origin of the UA, and the rate of high origin of the UA was 2.0%, among which there was 84.6% of patients who also had high origin of the RA. Double radial arteries were also a common branching abnormality of the forearm arteries: 2.0% in this study.

In this study, the rate of RA tortuosity was 3.6%, which was lower than previously reported;^{5,6} the rate of UA tortuosity was 1.2%, which was lower than that of the RA; the rate of RA maldevelopment was 1.0%, which was lower than that reported in the literature; the rate of UA maldevelopment was 1.3%, which was higher than that of the RA; the rate of stenosis of the RA and UA was similar at 0.8% and 0.6%, respectively. Loops of the RA and UA were not detected by US in this study, may be because they are not easily recognized by this imaging modality.

In an early randomized comparison, Kiemeneij et al reported that the failure rate of transradial coronary procedures was 1–5%,²² the main reason being the learning curve. Other reasons are the smaller diameter of the RA in individual patients and anatomical abnormalities of the RA in some patients.^{23,24} Our study found that a smaller diameter (<2 mm) of the RA and anatomical abnormalities could result in longer vascular access time and procedure time, more RA puncture failures and procedure failures, and more incidence of RA occlusion. RA tortuosity was mostly related to pro-

cedural failure, followed by the double RA, so it seems like that high origin of the RA does not influence the outcome of the procedure.

The results of our study suggest that examining the anatomy of RA with US before a transradial coronary procedure to rule out those patients whose RA diameter is too small or who have serious anatomical abnormalities has significant value in increasing the procedural success rate and decreasing the incidence of local vascular complications, which is important for the development and use of the transradial coronary procedure. The RA can also be used as a graft in coronary artery bypass grafting and as a new access point for radiofrequency catheter ablation of left-sided atrioventricular accessory pathways, but the procedure failure rate will be higher if the RA has a small diameter and anatomical abnormalities, so examining the anatomy of the RA with US before any of these procedures will be helpful for a successful outcome, especially those patients who have undergone a prior transradial coronary procedure.^{25–27}

Study Limitation

Firstly, angiography was not performed before the transradial coronary procedure, so we could not compare the accuracy of US and angiography in detecting anatomical abnormalities of the RA. Second, we did not follow up patients to detect RRA occlusion, so we did not have any information about the relationship between mid- and long-term occlusion and the diameter of the RRA. Another limitation was that we did not perform the interobserver variability test for quality control. However, we performed the intraobserver variability test, which showed that intraobserver agreement was excellent.

In conclusion, the diameters of the RA and UA were similar in the study population of Chinese patients, and the diameters of both arteries were larger in males than in females. Sex, height, weight and arm circumference were independently related factors for the diameter of the RRA. The incidence of total anatomical abnormalities of the bilateral RA and UA was 15.4%, and the incidence of anatomical abnormality of the RA was higher than that of the UA. We also found that a small diameter and anatomical abnormalities of the RRA could result in longer procedure time, more incidence of procedure failure and RA occlusion. Examination of the RA with US before interventional procedures is important for selection of a suitable vascular access site.

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