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Radial Artery Diameter and Vasodilatory Properties After Transradial Coronary Angiography

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Background. The radial artery is proposed as an alternative conduit in coronary revascularization. During the last years the transradial approach has, in many centers, emerged as the preferred technique in percutaneous diagnostic and interventional coronary procedures. This induces a trauma to the radial artery that possibly could influence its suitability as a bypass graft. In this study we assessed by ultrasound the long-term effects of transradial coronary angiography on the radial artery diameter and vasodilatory properties.

Methods. Thirty patients were examined with high resolution ultrasound 10 to 14 months after a transradial coronary angiography. Radial artery baseline diameter and response to flow-mediated (FMD) and nitroglycerin-mediated vasodilation (NMD) were examined in the right radial artery with the unexposed left radial artery as control.

Results. Right radial artery diameter was reduced compared with the left radial artery (2.58 ± 0.38 vs 2.71 ± 0.32 mm, \( p < 0.01 \)). Both FMD and NMD were preserved in the exposed artery (FMD 8.4 ± 8.0 vs 8.0 ± 6.1%, NMD 15.5 ± 6.8 vs 16.7 ± 6.6%, both ns). Due to the reduced baseline diameter, the right radial lumen diameter remained significantly smaller after vasodilatory stimuli. Large interindividual differences were demonstrated.

Conclusions. The radial artery diameter is diminished one year after transradial coronary angiography while vasodilatory properties are preserved. The preserved vasodilatory capacity could favorably influence the suitability of the artery as bypass graft. However, with the long-term structural changes induced by transradial angiography, use of a catheter-exposed radial artery as a conduit in coronary artery revascularization should not be strongly recommended. With ultrasound, both structure and vasodilatory properties of a catheterization-exposed radial artery may be assessed in case the artery is considered as bypass material.

The radial artery (RA) was introduced as an alternative conduit in coronary surgery by Carpentier and colleagues in 1973 [1]. Although initial results were promising, the use of the RA as bypass graft was later abandoned due to others demonstrating increased occlusion rates [2, 3]. Later, improved harvesting techniques and use of antispastic agents led to a revived interest in arterial revascularization, including a resurgence in the use of the RA as conduit [4]. Recently, several studies with favorable clinical and angiographic results obtained with use of the RA as coronary bypass graft have been published [5–7], and the RA has become the second choice of arterial graft after the left internal mammary artery [8].

During the last years there has been an increased interest in the RA as an entry route during coronary angiography and percutaneous coronary interventions. The transradial approach has emerged as a standard in many centers due to less bleeding complications and earlier patient ambulation. A transradial catheterization induces a trauma to the RA that could possibly influence the function if subsequently used as a bypass graft. There is a paucity of data demonstrating the potential influence of transradial catheterization on long-term structure and vasodilatory properties of the RA. Such data could help in assessing whether the RA is still suitable as a coronary artery bypass graft after its use as entry route in interventional procedures. In this study we assessed by ultrasound long-term effects on the RA diameter and vasodilatory capacity after transradial angiography. Vasodilatory properties were measured by the response to flow-mediated (FMD) and nitroglycerin-mediated vasodilation (NMD).

Patients and Methods

This study was approved by the Regional committee for medical ethics and all patients gave their written informed consent (REK 076-04, approved May 5, 2004).

Patients

A total of 30 patients (23 males, 7 females) having undergone transradial coronary angiography one year earlier were included in the study. Patient characteristics are demonstrated in Tables 1 and 2. Patients with significant valvular heart disease and patients with previous transradial percutaneous coronary intervention were ex-
cluded, as were patients with more than one previous transradial procedure.

Catheterization Procedure

Standard transradial techniques were used during angiography. Prior to the procedure all patients were tested and a normal Allen's test was demonstrated. Lidocaine was used as local anesthesia. The right radial artery was cannulated using a 21-gauge needle and a transradial kit with a 6 French introducer (Radifocus, Terumo Europe, Leuven, Belgium) was used. The length of the introducer was 100 mm. With the introducer in place, 200 μg of nitroglycerin and 5,000 U of heparin was introduced into the side port of the sheath. An angiographic guidewire (220 cm × 0.97 mm, Kimal, Uxbridge, UK) was advanced to the aortic root and left ventriculography and coronary angiography were performed using standard techniques. At the end of the procedure the sheath was removed and a pressure bandage was applied for three hours.

Ultrasound Study

At a mean of 12 (10 to 14) months after transradial angiography the study group underwent an ultrasound examination of the RA using a VingMed Vivid 7 ultrasound system (GE Vingmed Ultrasound, Horten, Norway) with a 12 MHz linear array transducer. An electrocardiogram (ECG) was recorded and all images were stored digitally. Examinations were blinded before analysis. Both the right and the left RAs were examined and measurements from the left RA were used as a control as earlier studies have demonstrated no significant difference in diameter between right and left RAs [9, 10]. Each of the RAs was examined at baseline, after FMD and after NMD. A randomizing program determined which artery to start with in order to avoid systematic errors. The FMD was measured according to the recommendations of Coretti and colleagues [11]. Baseline recordings were performed after ten minutes of supine rest. The RA was localized and the diameter was measured three to five centimeters proximal of the styloid process of the radial bone proximal to the puncture site. After baseline measurements of both RAs, the brachial artery at the one side, defined by the computer, was occluded using a blood pressure cuff inflated to 250 mm Hg for five minutes. One minute after cuff deflation the RA was imaged. After another ten minutes of rest, the same procedure was repeated at the contralateral arm. Ten minutes after the last cuff deflation, 0.5 mg nitroglycerin was administrated sublingually. As peak vasodilation occurs three to four minutes after nitroglycerin administration [11], the first artery was imaged after three minutes before the examiner had to switch position to image the other artery within four minutes from nitroglycerin administration. The patients were at complete rest during this procedure.

Analysis

Radial artery diameter was measured at the peak of the R-wave in ECG. For each recording measurements were performed three times at one single peak in two different R-waves, a total of six measurements. The mean value from these six measurements was used for further analysis. Figure 1 gives an example of baseline recordings comparing the left and the right RA.

Statistics

Data are expressed as means ± SD unless otherwise indicated. Paired data were analyzed using a two-tailed paired t test. Values for p less than 0.05 were considered significant. Statistical significance was tested using SPSS 13.0 (SPSS Inc, Chicago, IL).

Results

The right RA was occluded in one patient (3.3%) without giving any symptoms. This patient was excluded, thus leaving 29 patients for further analysis. Table 3 shows

Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>60 ± 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male (n)</td>
<td>23</td>
</tr>
<tr>
<td>Female (n)</td>
<td>7</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.97 ± 0.15</td>
</tr>
<tr>
<td>Smoking (n)</td>
<td></td>
</tr>
<tr>
<td>Present smoker</td>
<td>7</td>
</tr>
<tr>
<td>Previous smoker</td>
<td>12</td>
</tr>
<tr>
<td>Never smoked</td>
<td>11</td>
</tr>
<tr>
<td>Diabetes mellitus (n)</td>
<td>4</td>
</tr>
<tr>
<td>Angina pectoris (n)</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2. Medication

<table>
<thead>
<tr>
<th>Antithrombotic medication (n)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylsalicylic acid</td>
<td>19</td>
</tr>
<tr>
<td>Warfarin</td>
<td>2</td>
</tr>
<tr>
<td>Clopidogrel</td>
<td>1</td>
</tr>
<tr>
<td>Statins (n)</td>
<td>20</td>
</tr>
<tr>
<td>Long acting nitrates (n)</td>
<td>4</td>
</tr>
<tr>
<td>Antihypertensive medication (n)</td>
<td></td>
</tr>
<tr>
<td>Beta blockers</td>
<td>17</td>
</tr>
<tr>
<td>Calcium antagonist</td>
<td>1</td>
</tr>
<tr>
<td>ACE-inhibitors</td>
<td>3</td>
</tr>
<tr>
<td>Diuretics</td>
<td>3</td>
</tr>
<tr>
<td>Angiotensin II receptor blockers</td>
<td>4</td>
</tr>
</tbody>
</table>

ACE = angiotensin-converting enzyme.
mean baseline diameters and diameters after FMD and NMD in right and left RAs. Baseline diameter was significantly smaller in the right compared with the left RA. In both arteries significant responses to FMD and NMD were obtained (Table 4). When expressed as the absolute diameter change in millimeters, the dilation was slightly larger in the control arm although this difference was not statistically significant. The relative change in artery diameter after dilation stimuli was similar for both arteries (Fig 2), resulting in the left RA diameter remaining significantly larger compared with the right RA artery after both FMD and NMD (Table 3).

When comparing men and women, RA diameters were smaller in women while vasodilatory responses were similar for both sexes. For both arteries NMD was significantly larger compared with FMD, the relative diameter increase expressed in percent after nitroglycerin was twice the increase after FMD (Fig 2).

A large interindividual variation in FMD response was demonstrated. In the right RA three patients did not respond with any detectable vasodilation after FMD and for the rest there was a vasodilation with a maximum diameter increase of 17% in one patient. In the left RA, five patients did not demonstrate any detectable vasodilation response after cuff deflation while the rest had a vasodilation with a maximum diameter increase of 26% in one patient. The interindividual variation in NMD was less pronounced.

**Comment**

In this study we have demonstrated a significant decrease in RA diameter one year after transradial angiography, while the responses to FMD and NMD did not significantly differ between the catheterization exposed right and the unexposed left RA. Thus, both endothelial dependent and endothelial independent vasodilatory properties were preserved. Due to the reduced baseline diameter, there was a significantly reduced diameter after vasodilatory stimuli in the right compared with the left RA. Another observation was the large interindividual variation, particularly in FMD response. As this was the case in both RAs, this variation is probably caused by factors other than the previous catheterization procedure. Such factors could be diabetes, hypertension, hypercholesterolemia, smoking, and other factors known to negatively influence endothelial function [12–14]. Furthermore, calcification within the wall of the artery could be an important reason for absence of vasodilation in some patients.

**Structural Changes**

Our results are in accordance with other studies that have demonstrated structural changes induced in the RA

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Right Radial Artery</th>
<th>Left Radial Artery</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>2.58 ± 0.38</td>
<td>2.71 ± 0.32</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>After FMD</td>
<td>2.78 ± 0.37</td>
<td>2.93 ± 0.40</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>After NMD</td>
<td>2.97 ± 0.41</td>
<td>3.16 ± 0.36</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Absolute change in diameter (mm)</th>
<th>Right Radial Artery</th>
<th>Left Radial Artery</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>After FMD</td>
<td>0.20 ± 0.19</td>
<td>0.22 ± 0.16</td>
<td>ns</td>
</tr>
<tr>
<td>After NMD</td>
<td>0.39 ± 0.16</td>
<td>0.44 ± 0.16</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentage change in diameter (%)</th>
<th>Right Radial Artery</th>
<th>Left Radial Artery</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>After FMD</td>
<td>8.4 ± 8.0</td>
<td>8.0 ± 6.1</td>
<td>ns</td>
</tr>
<tr>
<td>After NMD</td>
<td>15.5 ± 6.8</td>
<td>16.7 ± 6.6</td>
<td>ns</td>
</tr>
</tbody>
</table>

FMD = flow-mediated vasodilation; NMD = nitroglycerin-mediated vasodilation.
after transradial catheterization [15, 16]. Histologic examinations of RAs having served as entry route for catheterization procedures indicate that intimal hyperplasia is the underlying mechanism for lumen diameter reduction [15]. In an ultrasound study of 162 patients examined at 2 and 95 days after a transradial catheterization, a diffuse stenosis developed in 22% during this period, indicating that there may be an ongoing intimal hyperplasia process for a prolonged period of time after the procedure [16]. Yoo and colleagues [17] demonstrated a decrease in RA diameter during a follow-up period of 4.5 months.

Suitability as Graft Material
Results obtained with arterial revascularization using the RA are encouraging, although results differ [3, 4, 6, 18, 19]. Possati and colleagues [18] reported excellent patency rates ten years after surgery using the RA and in an angiographic study the radial artery was demonstrated to have long-term patency similar to the internal thoracic artery [6]. Others have reported increased stenosis and occlusion rates in RA bypass grafts compared with left internal mammary arteries and saphenous vein grafts [19]. Kamiya and colleagues [15] examined 67 patients after coronary revascularization with RA grafts, 22 of them having received a transradial catheterization procedure prior to surgery [15]. In their study early graft patency was reduced in the group with transradial angiography.

It is not clearly defined how the structural changes induced in the RA after a transradial procedure influence the suitability of the RA as graft material. It has been demonstrated, however, that a small RA diameter and diabetes mellitus predispose for diffuse narrowing and occlusion of the artery after a transradial procedure [18], and with repeated procedures the risk of intimal hyperplasia increases [15]. Our study demonstrates a long-term structural change in the artery after a transradial procedure, and this could influence negatively the suitability of the RA as bypass graft.

Vasodilatory Properties
To the best of our knowledge there are no studies having assessed the vasodilatory properties of the RA after a transradial procedure. According to our results these properties, including the endothelial function estimated by response to FMD, are preserved. As endothelial function of the coronary artery bypass graft is believed to be important for the long-term graft patency [20], our results could indicate that a catheterization-exposed RA may still be suitable as bypass graft material. With the RA being a muscular artery it is more prone to vasospasm. Accordingly, an intact endothelial function is of importance both to counteract vasospasm in the resting condition and for the capacity to dilate in conditions with increased flow demands.

Compared with the left internal mammary artery the RA produces less nitrogen oxide both at basal and stimulated situations [21]. However, in a study by Al-Bustami and colleagues the in vivo endothelial function of the RA was evaluated when used as a coronary graft, and the FMD was comparable with that of the left internal mammary artery [22]. The study showed an improvement of vasomotor function of the RA after six months, indicating that capacity for nitrogen oxide release increases with time. It was also demonstrated that when used as a coronary artery bypass graft the baseline diameter of the RA increased with time.

Preoperative Assessment
If the RA being exposed to a catheterization procedure is a candidate for coronary artery graft, the structure and function of the artery should be evaluated by ultrasound, especially if repeated procedures through the artery have been made. By comparing with the unexposed left RA, the degree of intimal hyperplasia as well as any reduction of the vasodilatory response may be assessed. However, whether structural and functional changes of the RA after a transradial procedure differ as predictors for graft function warrants further study.

Limitations of Study
In this study the left RA was used as a control assuming that RA diameters do not differ between the two arms. According to previous studies there are no significant differences in diameter between the left and right RAs [10, 11]. The FMD is influenced by a series of conditions like hypertension, hypercholesterolemia, diabetes, and smoking that, to a variable degree, were present among the patients studied. As these factors act systemically they should not influence our results with the left RA serving as control. Medication was not stopped before examination of FMD and NMD in this study. However, with the contralateral arm as control neither should this affect our conclusions.

Patients in this study were examined at a mean of 12 months after transradial angiography. It is not known from our study whether there still is an ongoing process in the arterial wall at this point. Therefore, it remains unanswered whether different results would have been obtained with examination at a later stage. However, according to the results from other studies, it looks as if the maximum response to trauma of the artery is earlier in the course [16]. It could therefore be anticipated that our findings at one year after the catheterization procedure represent the maximum affection, and it may even be that the trauma response to some degree has declined at this time. Last, there could be structural and functional changes in the artery after a transradial procedure which are not revealed by the methods used in this study.

Conclusion
After transradial coronary angiography structural changes are induced in the exposed artery. One year after the catheterization procedure the diameter of the radial artery is significantly reduced compared with the contralateral unexposed artery, while flow-mediated and nitroglycerin-mediated responses are preserved. The preserved vasodilatory capacity could favorably influence the suitability of the artery as bypass graft. However, with the long-term structural changes induced after
transradial angiography, use of a catheter-exposed radial artery as bypass graft should not be strongly recommended. With ultrasound both structure and vasodilatory properties of a catheterization-exposed RA may be assessed in case the artery is considered as bypass material.

References

INVITED COMMENTARY

The article by Madsen and colleagues [1] examines a most important question. Cardiologists and interventional radiologists seek to reduce the morbidity of femoral arterial puncture and possibly to reduce the dislodgement of aortic arch atheroma during their procedures by cannulating the radial artery prior to coronary angiography or other procedures. After all, the radial artery is easily accessible, and allows for simple compression bandaging and rapid mobilization of the patient. The question is whether this may compromise subsequent use of the same radial artery as a conduit for coronary artery bypass surgery.

In this study these authors found that at 1 year post-angiography, the right radial artery which was cannulated was significantly smaller than the noncannulated left radial artery by a small degree, yet the response to ischemic or nitroglycerin induced vasodilation remained the same for both left and right sides. Patients with multiple radial artery canulations were excluded. The site of this imaging was proximal to the side of cannulation for angiography and represents the distal segment of the radial artery that would be used in the coronary bypass graft. These results are both encouraging and of some concern.

At 1 year after angiography, there seemed to have been complete recovery of the endothelial function of the radial artery. Wide individual variation may have reflected multiple causes including some calcification within the radial artery that was not documented in the study. This is encouraging for the cardiac surgeon for it represents normal radial artery vascular function proximal to the puncture site, validating use of the radial artery as a conduit after this approach to angiography.

However, it would be expected that the radial artery of the dominant hand would be up to 6% larger than the nondominant side. These authors found that the right radial artery representing the dominant side was significantly smaller than the nondominant side, suggesting that scar formation at the site of radial artery puncture had caused some degree of stenosis with some degree of...
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