REVIEW ARTICLE

Transcarpal Cardiac Catheterization

Torsten Schwalm

SUMMARY

Introduction: Even though the performance of coronary diagnostic and therapeutic procedures through the distal forearm arteries has become a well-established practice, only a small minority of procedures employ transcarpal approach. The aim of this review is to describe the state of art in cardiac catheterization through distal forearm arteries, to point out the advantages and disadvantages of this approach, and to discuss the specific aspects in which it differs from the transfemoral approach.

Methods: A Medline search up to January 2009 and the articles retrieved were selectively evaluated. Practical recommendations are given based on the authors' experience.

Results: The following advantages of the transcarpal approach to the coronary arteries, as compared to the transfemoral approach, were evident in 23 prospective randomized studies and registries: a lower risk of complications at the site of access (0.05% and 0.3% versus 2.3% and 2.8% [19, 20]), lower mortality (2.8% versus 3.9% [1]), greater patient comfort, lower cost (14% [22] and 15% lower [21]), and a shorter hospital stay (1.5 days and 3 days versus 1.8 days and 4.5 days [12, 21]). Its disadvantages include the potential need for conversion to a transfemoral procedure, higher radiation exposure of the physician, and an extended learning curve, so that procedure times are longer and rates of technical failure are higher until about 400 procedures have been performed (23).

Conclusions: The current data give a favorable view of this procedure as long as its specific requirements in terms of pretreatment, choice of materials, technique, post-procedural care, and expertise of the physician are taken into account.

Key words: coronary angiography, angioplasty, hemorrhage, patient-oriented treatment, learning curve

Coronary diagnosis and treatment by an approach through the distal forearm arteries is an established technique. Current registry data (1, 2) and subgroup analyses in randomized, controlled trials (3–6) document the superiority of the transradial to the transfemoral approach with respect to two important endpoints: hemorrhagic complications and mortality.

The author's own experience accords with study findings (7, 8) showing that an approach through the ulnar artery is safe for diagnostic cardiac catheterization and has a low rate of complications, as well as other specific advantages.

The aim of this review article is to describe the development of transcarpal (i.e., transradial or transulnar) diagnostic cardiac catheterization, with particular attention to its advantages and disadvantages and to the specific features that distinguish it from the transfemoral approach.

Methods

The Medline database was selectively searched for articles in English or German that appeared up to January 2009 and included the keywords "transradial coronary angiography/angioplasty," "transulnar coronary angiography/angioplasty," "approach complications," or "risk of hemorrhage." The retrieved literature included abstracts, case reports, review articles, retrospective studies, 23 prospective, randomized trials, two meta-analyses of these trials for a comparison of the two techniques, and one meta-analysis concerning three PTCA (percutaneous transluminal coronary angioplasty) registries. The author also gives practical recommendations based on his personal experience.

History

Diagnostic coronary angiography via the radial artery was first described by Campeau in 1989 (9). In 1993, Kiemeneij reported the first transradial coronary angioplasty and stent implantation (10, 11). In 1997, Kiemeneij performed the first randomized study on the subject, in which the transfemoral, transbrachial, and transradial approaches were compared in a total of 900 patients (12). The rates of procedural success were similar (radial approach 91.7%, femoral approach 90.7%), and the rates of MACEs ("major adverse cardiac events") were nearly identical (6.7% after a radial approach and 5.3% after a femoral approach), but there were fewer hemorrhages with the radial than with the femoral approach (0 vs. 2%, $p = 0.035$).

Early descriptions of transulnar coronary angiography appeared from 2001/2002 onward (e1, e2). In

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2006, the two transcarpal approaches were compared with each other (13).

Current state of the art

The highly refined and miniaturized technology now available in interventional cardiology and angiology makes it possible to perform many procedures, even complex ones, through a transcarpal approach (e3).

In the period from 1979 to 1982, percutaneous transluminal coronary angioplasty (PTCA) still had a relatively high mortality (1.1%) because of high rates of acute coronary occlusion (4.8%) and emergency aortocoronary surgery (6%). Medicine today now faces an entirely different spectrum of complications. With the increasing use of coronary diagnostic and therapeutic techniques, and with the availability of new options for

TABLE

Main results of meta-analyses comparing the transradial and transfemoral approaches for coronary diagnostic and therapeutic procedures

	Author and year of publication		
	Agostini et al. (2004) (20)	Chase. et al. (2008) (1)	Jolly. et al. (2009) (19)
Study type	Meta-analysis of 12 randomized. controlled trials. 1994–2003	Meta-analysis of prospectively obtained registry data. 1995–2003	Meta-analysis of 23 prospective. randomized trials. 1993–2006
Number of patients	3 224	32 822	7 020
Approach-related complications (%) radial femoral p	0.3 2.8 < 0.0001	N.A. N.A. N.A.	0.05 2.3 < 0.001
Transfusions (%) radial femoral p	N.A. N.A. N.A.	1.4 2.8 < 0.01	N.A. N.A. N.A.
MACE rates (%) radial femoral p	2.1 2.4 0.7	N.A. N.A. N.A.	2.5 3.8 0.058
30-day mortality (%) radial femoral p	N.A. N.A. N.A.	1.0 1.7 < 0.01	N.A. N.A. N.A.
1-year mortality (%) radial femoral p	N.A. N.A. N.A.	2.8 3.9 < 0.01	N.A. N.A. N.A.
Radiation exposure times (min) radial femoral p	8.9 7.8 < 0.001	N.A. N.A. N.A.	0.4 min longer N.A. < 0.001
Crossover ^{*1} (%) radial femoral p	7.1 N.A. N.A.	N.A. N.A. N.A.	5.9 ^{*4} 1.4 < 0.001
Length of hospital stay (days) radial femoral p	1.8 2.4 < 0.001	N.A. N.A. N.A.	0.4 days shorter N.A. < 0.001
Coronary (c) or procedural (p) failure (%) ^{*2} radial femoral p	(p) 7.2 ^{*3} 2.4 < 0.001	N.A. N.A. N.A.	(c) 4.7 ^{*5} 3.4 0.2

^{*1}“Crossover” is defined as a forced move to a new puncture site due to inability to enter the vessel or to access the coronary ostia (switch from a radial to a femoral puncture, or vice versa).

^{*2}“Procedural failure” includes inability to enter the vessel; “coronary failure” refers to diagnostic or therapeutic failure after successful vascular entry, due, e.g., to lack of access to the coronary ostia, inability to place a guide catheter in a good position, or inability to carry out balloon dilatation or stenting.

^{*3}The rate of procedural failure declined over the course of the studies (but is not quantified any more precisely).

^{*4}The crossover rate was lower in studies performed from 1999 onward (the odds ratio [OR] for radial-to-femoral crossover was 5.63 in studies up to 1999, 2.96 in studies from 1999 onward).

^{*5}The rates of coronary success for the two procedures were similar when they were performed by experienced examiners (not any more specifically defined) (OR = 1.18).

“N.A.” = data not available.

antiplatelet therapy, even complex coronary interventions can be performed with acceptably low cardiac complication rates. Nonetheless, complications relating to the route of approach are an important cause of associated morbidity and mortality (1–6).

When an approach-related complication arises, the patient's prognosis worsens: severe bleeding after a PTCA (588 of 10 974 patients, or 5.4%) raises the in-hospital mortality from 0.6% (in patients who have not had a hemorrhage requiring transfusion) to 7.5% (in patients who have had such a hemorrhage) (2). The occurrence of severe bleeding is an even better predictor of 1-year mortality than acute myocardial infarction (2). The 30-day mortality of patients who have had a post-interventional hemorrhage is also higher: 5.2% vs. 0.2% in one study (5), 7.3% vs. 1.2% in another (6). A meta-analysis of current studies of PTCA in the presence of an acute coronary syndrome revealed that the 30-day mortality of patients who had a hemorrhage requiring transfusion (2401 of 24 112 patients, or 10%) was 8.0%, while the corresponding figure in patients who did not have such a hemorrhage was 3.1%. The reported rates of complications relating to femoral puncture, independently of other associated problems, range from 2% to 8% (12, 14). Even when modern occluding systems are used, the risk of hemorrhage is higher after femoral than after radial puncture (3.7% vs. 0%) (15). An analysis of studies available up to 2003, including four randomized, controlled, multicenter trials, revealed that the rate of mild complications ranged from 2.1% to 7.6%, while the rate of major complications ranged from 1.8% to 4% (depending on the particular system used), and an inability to obtain hemostasis was seen in 2% to 12% of cases (e5).

Problems with the transfemoral approach can also be encountered in patients with stenosing peripheral arterial occlusive disease, thoraco-abdominal vascular loops, and abdominal aortic aneurysms, as well as in markedly obese patients and patients taking anticoagulants.

Advantages of the transcatheter technique

In addition to improved patient comfort, a major advantage of the transcatheter technique is the low risk of bleeding even when the patient is receiving "aggressive" antiplatelet treatment. It is precisely the patients receiving the strongest platelet-inhibiting treatment who stand to benefit the most from a transcatheter approach. For patients with an acute coronary syndrome receiving combined therapy, including glycoprotein IIB/IIIa inhibitors, major differences were seen in the risk of bleeding not requiring a blood transfusion (0% [e6, e7], 0 vs. 4.4% [15]), the risk of bleeding requiring a transfusion (0 vs. 5.5% [16]), and the length of the hospital stay (4.5 vs. 5.9 days [16]). The transcatheter approach is safe even in orally anticoagulated patients (bleeding not requiring a transfusion was encountered in 1.5% [17]).

Patients receiving the platelet aggregation inhibitor prasugrel and requiring a PTCA because of an acute coronary syndrome were found to have a significantly

lower rate of major adverse cardiac events than patients receiving clopidogrel (9.9% vs. 12.1%), although they had a higher risk of hemorrhage requiring transfusion (4% vs. 3%) and of life-threatening hemorrhage (1.4% vs. 0.9%) (18). According to registry data, performing the procedure by a transradial rather than transfemoral approach is the only way to reduce hemorrhagic complications enough to lower the 1-year mortality significantly (2.8% vs. 3.9%) (1).

Figure 1:
Positioning of the
arm for a transcatheter
study

The *Table* is based on three comparative meta-analyses of the two techniques (1, 19, 20) and shows the relevant differences between them. The transradial technique has fewer approach-related complications, and there is a trend toward lower rates of major adverse cardiac events as well; these advantages come at the cost of a more frequent forced switch from radial to femoral puncture (crossover rate). Moreover, studies up to 1999 (19, 20) documented lower rates of procedural and coronary success (procedural difficulties were encountered both with the puncture itself and with the advancement of the catheter). This means that the intended diagnostic or therapeutic procedure sometimes could not be carried out successfully even though good vascular access had been achieved, e.g., because of lack of access to the coronary ostia, because of a suboptimally positioned guide catheter, or because of the inability to perform balloon dilatation or stenting.

The transcatheter approach is suitable for ambulatory procedures, but it can be used to perform complex coronary interventions as well (e8). Its periprocedural costs are lower than those of the transfemoral approach (15% lower in one study [21] and 300 dollars—or 14%—lower in another [22]). The reasons for this include shorter hospital stays (3 vs. 4.5 days [21], 1.5 vs. 1.8 days [12], the less common need for transfusion (16) or surgical revision (16), and elimination of the need for occluding systems.

Figure 2: Sideboards for arm positioning and for laterally extending the table as a positioning surface

Post-procedural care after the transcatheter approach does not require bed rest. The patient is fully mobile, does not need a bulky, movement-restricting pressure dressing, has less pain at the puncture site, and is more easily able to go to the toilet comfortably (22). For all these reasons, a large majority of patients prefers the transcatheter approach (75% [12], 87% [22]).

The radial artery is now being increasingly used as a graft donor site for aortocoronary bypass surgery (e9–e11). Previously performed transradial procedures are associated with intimal damage that may limit the suitability of the artery for grafting. If the Allen test is abnormal—as is the case in 5% to 15% of all patients studied (21, e13)—then ulnar arterial puncture is an alternative route to a successful transcatheter approach.

Technique

The current state of technological development permits nearly all of the procedures that can be performed transfemorally to be performed through a transcatheter approach as well, with the use of 4 to 6 French catheters or, in rarer cases, 7 French (e16) or 8 French (e17).

Transcatheter diagnostic and therapeutic procedures require specialized knowledge of the particular features of this approach in its four phases: patient preparation, arterial access, coronary intubation, and post-procedural care.

Patient preparation

In addition to general information regarding the procedure, the patient should also be informed about all possible approach-related complications. The performance of a (reverse) Allen test is obligatory.

Allen test: The two forearm arteries are tightly compressed above the wrist. The patient forcibly makes

a fist multiple times so that the hand blanches. The distal ulnar compression is then released. In a positive test, this leads to full reperfusion, with visible reddening of the hand indicating an intact palmar arch. The reverse Allen test involves release of compression of the radial artery, rather than the ulnar artery (e13–e15).

The patient's chosen arm is then positioned on a special, well-padded sideboard with the wrist fixed in mild extension (*Figure 1*). A second sideboard lying parallel to the table provides an adequate surface for necessary equipment (*Figure 2*). The puncture site is disinfected and locally anesthetized.

Arterial access

Radial puncture: The vessel lies superficially, and the major structures near it are at a distance from the puncture site. The artery is punctured about 1 cm proximally to the styloid process.

Ulnar puncture: The ulnar artery lies on the ulnar side of the wrist between the flexor tendons of the flexor carpi ulnaris muscle and the flexor digitorum superficialis muscle, and partially below these tendons. The ulnar nerve lies below the artery for part of its course. The puncture is performed proximally to the pisiform bone. A 22-gauge puncturing needle is used, through which a 0.0018-inch, soft guide wire is intraluminally advanced with the Seldinger technique (*Figure 3*). This guide wire is then used for the introduction of a sheath over a dilator.

5 French seems to be a suitable catheter size. Smaller catheters have a less stable position in the ascending aorta and are more likely to become dislodged from the coronary ostia. If a 5 French sheath is used, PTCA can be performed in the same sitting. A 6 French sheath can generally be introduced without difficulty. Larger sheaths can be used as well, but are only needed for special diagnostic purposes. The ratio of sheath diameter to arterial size is an important predictor of post-procedural occlusion of the punctured vessel: a sheath/artery quotient above 1 is unfavorable (23, e18).

Coronary intubation

For the placement of the diagnostic catheter, a 200-cm guide wire with a diameter of 0.035 inches is used, which stably keeps its position in the ascending aorta while the catheter is being introduced or exchanged.

A further strategy for reducing vascular manipulations involves using diagnostic catheters that can potentially intubate both ostia.

The transcatheter approach from the left side resembles the transfemoral approach to the ascending aorta. Thus, the types of catheters used for the transfemoral approach can generally also be used to intubate the coronary ostia via the left transcatheter approach. The left transcatheter approach may be an uncomfortable one for a performing physician standing on the right side of the patient. Placing the arm to be punctured on the patient's abdomen makes the procedure easier to perform.

Bypass vessels can be well demonstrated through a transcatheter approach. In particular, the left internal

mammary artery, which is often used as a bypass graft, can be selectively displayed without any problem through a left transcarpal approach.

Post-procedural care

Graded compression is applied after removal of the sheath. The applied pressure should be the lightest pressure that is needed to achieve reliable hemostasis, and compression should also be maintained for the shortest necessary time. The patient can stand up immediately after a successful study. Modern compression systems make hemostasis easy and reliable (Figure 4).

Post-procedural care is considerably simplified by the patient's full mobility after the procedure, the ease of assessing the puncture site, and the easy detection of hemorrhage when it occurs.

Potential problems and their treatment

Vasospasm

The forearm arteries, unlike the femoral artery, are small in caliber and have many alpha receptors (7); for both of these reasons, they tend to undergo vasospastic contraction when they are punctured. Vasospasm is especially likely to occur in a tense, anxious patient, or if pain arises during the study because of manipulations of the catheters and sheath.

The occurrence of vasospasm is correlated with the risk of later vascular occlusion. Contraction of the arterial tunica media is one cause of friction; further causes are arteriosclerotic changes, a narrow vascular lumen, and a tortuous vascular course.

The occurrence of vasospasm and thrombotic complications can be reduced with the intravenous administration of 2.5 mg of midazolam during the procedure, and the administration of 5000 IE of unfractionated heparin and 0.2 mg of nitroglycerine through the arterial sheath.

Possible further means of avoiding friction, manipulation, and vasospasm include:

- choosing a narrow sheath caliber
- choosing a longer sheath
- inserting a J-shaped, curved, 200-cm long, 0.025-inch thick wire into the ascending aorta
- using sheaths with side holes for the application of vasodilating drugs (e.g., nitroglycerine 0.2 mg combined with verapamil 5 mg [e19])
- using catheters that can intubate both coronary ostia
- having the procedure performed by an experienced physician, so that the study time will be shorter, fewer puncture attempts will need to be made, and the overall procedure will be less traumatic.

Tortuosity of the supra-aortic vessels

Having the patient inspire deeply will make the angles of entry of the brachiocephalic trunk on the right side and of the subclavian artery on the left side more obtuse, enabling access to these vessels with the

Figure 3: Puncture of the ulnar artery with the Seldinger technique

Figure 4: Removal of a 5 French guide tube from the ulnar artery with simultaneous placement of a pressure cushion to serve as a transparent compression bandage

catheter. It is a good idea to use an easily steerable diagnostic catheter with a JR4 curve for the primary placement of the guide wire.

Anatomical variants

The anatomy of the forearm arteries is highly variable. In particular, tortuosity and a steep angle of entry into the brachial artery are common findings. Even vessels that appear to be impassable on visual inspection often become straighter and are able to admit the catheter when the guide wire is introduced. Sometimes, a more hydrophilic wire has to be used so that this can occur.

The performing physician's learning curve

Many physicians learn the transfemoral technique first and find the transcarpal approach to be technically more demanding. If there are anatomical considerations making the transcarpal approach difficult or impossible to use, or if the arterial puncture or catheter advancement proves difficult, an early switch to the opposite side—or to a femoral approach—is advisable to minimize patient discomfort. After an unsuccessful attempt to puncture a forearm artery, one should not switch to the ipsilateral carpal puncture site.

KEY MESSAGES

- Transcatheter cardiac catheterization is advantageous with respect to: patient comfort, length of hospital stay, cost, and hemorrhagic complications.
- Diagnostic cardiac catheterization through the distal forearm arteries is a safe procedure.
- The transcatheter approach to the coronary arteries involves special considerations with respect to: pre-procedural care, choice of materials, technique, post-procedural care, and the expertise of the physician performing the procedure.
- At the end of a learning curve with up to 400 procedures, the technical success rate is identical to that of procedures employing the transfemoral approach.
- More data are needed, particularly on the transulnar approach, before general recommendations for routine clinical practice can be formulated.

When the transcatheter approach was used in 22 patients, the mean study time was 40.6 min, and the mean radiation exposure time was 9.7 min (e20). In a group of 116 patients, the corresponding times were shorter: 30.5 min and 6.6 min, respectively (9, 22). The study time was even shorter in 383 patients (23.1 min) (e21) and in 415 patients (19.1 min) (23). The latter figure is no different from the mean study time needed after a femoral approach. The same holds for the overall success rate of the procedure (19, 20, 23).

The overall duration of the study, including the time needed to achieve hemostasis at the puncture site, is significantly shorter when a transradial, as opposed to transfemoral, puncture is used (47.6 min vs. 31.4 min, $p < 0.001$) (22).

Disadvantages, limitations, and contraindications

Radial artery occlusion rates ranging from 1% to 7% have been described in the literature. Radial artery occlusion is asymptomatic in the vast majority of cases (24, e18, e22–e24), because arterial blood enters the hand from twin sources, the superficial and deep anastomotic arches. Nonetheless, major, function-limiting ischemia of the hand has been described in case reports (e25). Radial artery occlusion is more common in women, in narrower arteries, when heparin is not given (23), and when larger sheaths are used. Almost half of all occluded arteries can become spontaneously recanalized later on (12). The procedure can be repeated if the vessel is occluded distally but a pulse is still palpable more proximally. Immediate removal of the sheath after a transcatheter study increases the likelihood that perfusion will remain intact; this likelihood is also increased by the anticoagulation and antiplatelet therapy that many patients are already receiving.

Damage to the tunica intima of the radial artery, making the vessel less suitable for use as an arterial bypass graft, has been described after transradial coronary arteriography. Damage to the radial artery can be avoided by performing the primary puncture in the ulnar artery.

The implantation of an intra-aortic balloon pump, or of a sheath in the femoral vein, requires puncture at a second site if a transcatheter approach has been chosen. The presence of an acute coronary syndrome is not a limitation in hemodynamically stable patients; the decisive advantage in such cases is provided by augmented antiplatelet therapy.

Contraindications to the transcatheter approach include, among others, a pathological Allen test or hemodialysis on the same arm.

The greater radiation exposure of the performing physician (15.1 vs. 13.1 Gy $\times$ cm² [e26]) is a problematic aspect of the transcatheter approach. The radiation dose to the performing physician can be higher even when the radiation time is similar to that of a transfemoral procedure. This is possibly due to the shorter distance between the physician and the radiation source and to a larger amount of scattered radiation from the patient's pelvis and thighs (e26). Special shielding devices lower radiation exposure (25).

The frequent need to switch from a radial to a femoral puncture and the lower rate of procedural success (documented mainly in the studies published before 1999) are disadvantages of the technique (19, 20). As the performing physician gains in experience, and as the materials that are used undergo further development, these problems are likely to become rarer (19, 20, 23).

Conflict of interest statement

Dr. Schwalm has received lecture honoraria from Terumo.

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REVIEW ARTICLE

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