MIKA KOHONEN

ASSESSMENT OF THE RADIAL ARTERY IN CORONARY BYPASS SURGERY

ACADEMIC DISSERTATION
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ABSTRACT

The radial artery (RA) is widely used as a graft in coronary artery bypass surgery. It is easy to harvest and has excellent patency rates. However, there are some challenges concerning its harvest and utilisation. In its natural position the RA supports the circulation of the hand together with the ulnar artery. Prior procurement of the RA it is important to ensure that the removal of the RA will not cause circulatory deficit in the hand. Another issue is that, as a muscular artery, the RA is prone to atherosclerosis, which affects all patients with coronary artery disease. The atherosclerotic involvement may compromise the RA as a bypass graft.

Traditionally the circulation of the hand is assessed preoperatively with the Allen test (AT). The AT is a simple clinical test that is easy to perform bedside and does not require any additional resources. It has been criticised for being subjective and not being reliable enough. The first aim of the present thesis was to ascertain whether the AT can be used to assess the circulation of the hand. The second aim was to ascertain if the issues concerning the non-harvestable RA are confined to one hand only. Third aim was to find out the relationship between forearm artery atherosclerosis and carotid artery atherosclerosis. The final aim was to evaluate the usefulness of intraoperative pressure measurement of the RA as an additional screening method.

The study involved two sets of patients, both groups were scheduled for coronary artery bypass surgery. The first group consisted of 145 patients who underwent the AT, ultrasonography of the forearm vessels and pletysmography of the fingers before operation. Patients over 60 years of age and emergency cases were excluded. The second group consisted of 90 patients who underwent the AT and modified AT, pletysmography of the index and ring fingers both pre- and postop-
eratively. A questionnaire concerning symptoms in the hand and forearm was also completed pre- and postoperatively. In the second group no patients over 75 years were included.

The study revealed that the AT has good specificity rate and fairly good sensitivity rate. If the AT is negative it is safe to harvest the RA. In patients with diabetes mellitus or peripheral vascular disease the result of the AT may not be conclusive and additional ultrasonography of the forearm arteries is recommended. The issues concerning the non-harvestable RA are often bilateral. If a non-harvestable RA is found, the risk that the other RA is also non-harvestable is doubled. The atherosclerotic involvement in the forearm vessels is associated with atherosclerotic changes in the carotid arteries. When atherosclerotic changes are found in forearm arteries the risk for carotid artery atherosclerosis can be eightfold. Intraoperative pressure measurement of the RA stump may be useful screening tool in selected situations.
TIIVISTELMÄ

Abstract in Finnish


Perinteisesti käden verenkiertoa on arvioitu ennen leikkausta Allenin testillä. Allenin testi on yksinkertainen kliininen koe, joka on helppo suorittaa missä tahansa eikä se vaadi laitteita tai muita ylimääräisiä panostuksia. Allenin testiä on arvosteltu siitä, että se on subjektiivinen eikä tarpeeksi luotettava. Väärtöskirjatyö pyrkii selvittämään, voidaanko Allenin testiä käyttää arvioimaan käden verenkiertoa luotettavasti. Lisäksi pyritään selvittämään, onko värttinävaltimon käytön sepelvaltimosiirteenä estävät tekijät toispuoleisia, vai ovatko yleensä molemmat värttinävaltimot käyttökelpottomia, ja onko kynärvarren valtimoiden ja kaulavaltimoiden valtimokovettumataudilla yhteyttä. Lopuksi pyritään vielä selvittämään leikkauksen aikaisen värttinävaltimon paineenmittauksen käyttökelpoisuutta värttinävaltimon siirrekelpoisuuden arvioinnissa.

Tutkimukseen osallistui kaksi potilasryhmää. Molempien ryhmien potilaat olivat tulossa sepelvaltimo-ohitusleikkaukseen. Ensimmäiseen ryhmään kuului 145 potilasta, joille tehtiin Allenin testi, kynärvarren valtimoiden ultraäännitutkimus sekä sormien verenpainemittaus. Yli 60-vuotiaita ja päivystystyöskentelijä
ei otettu mukaan tutkimukseen. Toinen ryhmä käsitti 90 potilasta, joille tehtiin Allenin testi ja sen modifikaatio sekä verenpaineen mittaus etusormesta ja nimet-tömästi ennen ja jälkeen leikkauksen. Lisäksi potilaat täyttivät kyselyn kädentä ja kynärvarren oireista ennen ja jälkeen leikkauksen. Toiseen ryhmään ei otettu yli 75-vuotiaita potilaita. 

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<th>Description</th>
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<tr>
<td>AT</td>
<td>Allen test</td>
</tr>
<tr>
<td>CABG</td>
<td>Coronary artery bypass graft</td>
</tr>
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<td>CAD</td>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>DBI</td>
<td>Digital-brachial index</td>
</tr>
<tr>
<td>DPA</td>
<td>Deep palmar arch</td>
</tr>
<tr>
<td>EDV</td>
<td>End diastolic velocity</td>
</tr>
<tr>
<td>fRITA</td>
<td>Free right internal thoracic artery</td>
</tr>
<tr>
<td>IMT</td>
<td>Intima-media thickness</td>
</tr>
<tr>
<td>ITA</td>
<td>Internal thoracic artery</td>
</tr>
<tr>
<td>IVUS</td>
<td>Intravascular ultrasound</td>
</tr>
<tr>
<td>LITA</td>
<td>Left internal thoracic artery</td>
</tr>
<tr>
<td>LACN</td>
<td>Lateral antebrachial cutaneous nerve</td>
</tr>
<tr>
<td>LCX</td>
<td>Left circumflex coronary artery</td>
</tr>
<tr>
<td>OCT</td>
<td>Optical coherence tomography</td>
</tr>
<tr>
<td>PSV</td>
<td>Peak systolic velocity</td>
</tr>
<tr>
<td>PVD</td>
<td>Peripheral vascular disease</td>
</tr>
<tr>
<td>PVR</td>
<td>Pulse volume recording</td>
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<tr>
<td>RA</td>
<td>Radial artery</td>
</tr>
<tr>
<td>RAC</td>
<td>Radial artery compression</td>
</tr>
<tr>
<td>SPA</td>
<td>Superficial palmar arch</td>
</tr>
<tr>
<td>SRN</td>
<td>Superficial radial nerve</td>
</tr>
<tr>
<td>SVG</td>
<td>Saphenous vein graft</td>
</tr>
<tr>
<td>UA</td>
<td>Ulnar artery</td>
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</table>
LIST OF ORIGINAL COMMUNICATIONS

This dissertation is based on the following communications, referred in the text by their Roman numerals I – IV.


INTRODUCTION

The introduction of coronary surgery changed the course of coronary artery disease (CAD). For several decades CABG was the only invasive treatment modality for severe CAD. Later years has seen the raise of percutaneous coronary interventions but CABG is still the gold standard for the treatment of multivessel CAD. The radial artery as a bypass graft was introduced to coronary surgery by Carpentier 1973 but it soon fell into oblivion due to poor patency rates (1973). After twenty years in limbo the RA was reintroduced by Acar and has gained wide popularity ever since (1992).

The function of the RA in its natural position is to provide for the circulation of the hand. Therefore, the preoperative screening of the hand circulation is important to avoid ischaemic complications. Traditionally this has been done with the Allen test (AT) which is a simple clinical method that can be applied bedside and needs no additional resources. The AT has been criticized for being subjective and for not producing any written document to refer to in case of complications. More objective tests used in the RA screening include biplane ultrasonography, doppler ultrasonography and pletysmography. They provide information about the vessel anatomy and function. However, they are laborious and costly and the availability may be limited. Limited availability may become a problem when treating emergency cases outside office hours.

All patients with CAD are victims of atherosclerosis. Atherosclerosis seldom affects only one location. In addition to the coronary arteries, the supra-aortic vessels and their direct off-springs are important sites of atherosclerotic involvement. Involvement of the carotid arteries may cause important clinical manifestations such as cerebrovascular embolic stroke. The risk of stroke is further increased in
conjunction with cardiac surgery. Involvement of the forearm arteries may com-
promise the use of RA as a graft, either due to the poor quality of the RA or due
to insufficient ulnar artery (UA). The relationship between the atherosclerotic
involvement of the carotid arteries and the forearm arteries is not fully under-
stood. Likewise, the relationship of contraindications concerning the harvesting of
the RA within the same individual is not clear.

The present study aims find out if the AT is a valid screening test by compar-
ing it to more objective, metric measurements. The second purpose is to ascertain
whether the non-harvestable RA is a bilateral phenomenon. The third purpose is
to discover the relationship of atherosclerotic involvement of the forearm arteries
and carotid arteries. Finally this study investigated if there is a feasible intraopera-
tive method to assess hand circulation when there are no preoperative scanning
methods available.
1. CORONARY ARTERY SURGERY

1.1. General

The history of coronary artery surgery is a series of parallel and concurrent events. The first symptomatic surgical treatment for CAD was thoracocervical sympathectomy, followed by thyroidectomy to reduce metabolic stress on the heart. Alexis Carrel led the way in vascular surgery and started experimental work with the aorta and coronary arteries in 1910. Contemporary techniques did not allow direct anastomosis in human so Claude Beck narrowed the coronary sinus and used the pectoralis muscle or omentum for epicardial grafting purposes. Although it had been performed by Goetz some years earlier, Kolessov was the first to report left internal thoracic artery (LITA) anastomosis on a beating heart in 1964. The same year, Garret and Debakey performed their first coronary bypass operations using vein grafts. Sabiston had used a vein graft to right coronary artery successfully 1962. By 1971, Favaloro had already reported a series of 741 cases treated with CABG (Borst and Mohr 2001, Loop 2005). In Finland the first coronary bypass operation was performed by Pekka T. Harjola at Helsinki University Hospital in 1971. In the Tampere Central Hospital which later became Tampere University Hospital, Pekka Kuusinen followed suit in 1979.

Since those early years CABG has become standard treatment for CAD with an impressive number of procedures being performed every year. Development in cardiopulmonary bypass technology, the resurgence of beating heart surgery and increased use of arterial grafts among other advances has paved the way for
improved results. Recent years have seen the rise of PCI and the increase in the number of CABG has halted. However, CABG is still the gold standard in the treatment of multivessel CAD.

1.2. The radial artery in coronary bypass surgery

The radial artery in coronary bypass surgery was introduced by Carpentier (1973). Early patency rates varied between 50% and 65% and it was abandoned. Initial experience showed that the RA was prone to spasm and the development of intimal hyperplasia (Curtis et al. 1975). Unexpectedly, some patients showed good long-term results and Acar reinstated the use of RA as a bypass graft in coronary surgery (1992). Since the beginning of the nineties RA has attracted attention and a significant number of studies have been conducted on its status in coronary surgery.

Patency rates have improved considerably since the early experiences. Several groups have reported long-term (10-year) patency rates between 89% and 94% for RA grafts. At the same time these series report saphenous vein graft (SVG) patency rates between 74% and 92% and LITA patency rates between 97% and 99%. Short-term results are in general better due to short follow-up but mid-term (5-year) results are almost at the same level (Cameron et al. 2004, Buxton et al. 2003, Possati et al. 2003).

There are three randomised studies comparing RA graft patency to other grafts. The Radial Artery Patency and Clinical Outcome Study (RAPCO) involved two groups of patients (Buxton et al. 2003). The first group consisted of 285 patients under 70 years of age. The first graft the patients received was LITA and the second graft was either RA or free right internal thoracic artery (fRITA) depending on the randomisation. Subsequent grafts were SVGs. The second group had 153 patients aged 70 years or older. In the second group the second graft was either RA or SVG. Demographics in both study groups did not differ between the randomisation subgroups. Five-year interim results did not support the hypothesis that
RA would have superior patency rates compared to SVG or fRITA. The study was underpowered, however.

The Radial Artery Patency Study (RAPS) was a multicentre study involving 531 patients (Desai et al. 2004). Patients were under 80 years and randomised to two revascularisation strategy: RA to left circumflex (LCX) territory and SVG to right territory or vice versa. Grafts were compared to each other, e.g. every patient functioned as their own control. Demographic data did not differ between the groups. In this study the RA grafts had higher patency rates after one year.

The Radial Artery Versus Saphenous Vein Patency Study (RVPS) compared RA to SVG in the LCX territory (Collins P. Webb CM. Chong CF. Moat NE. Radial Artery Versus Saphenous Vein Patency (RSVP) Trial Investigators 2008). Altogether 142 patients were randomised and 103 were available for angiographic control five years later. No significant differences regarding the demographics between the groups were detected. RA patency was clearly superior to SVG in the LCX system. The results of three randomised studies are summarised in table 1.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Trial</th>
<th>N</th>
<th>%N</th>
<th>Graft (Patency rates)</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RA</td>
<td>SVG</td>
</tr>
<tr>
<td>Buxton</td>
<td>2003</td>
<td>RAPCO</td>
<td>68</td>
<td>24%</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46</td>
<td>86%</td>
</tr>
<tr>
<td>Desai</td>
<td>2004</td>
<td>RAPS</td>
<td>440</td>
<td>78%</td>
<td>91.8%</td>
<td>86.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>String 7.0%</td>
<td>String 0.9%</td>
</tr>
<tr>
<td>Collins</td>
<td>2008</td>
<td>RSVP</td>
<td>103</td>
<td>73%</td>
<td>98.3%</td>
<td>86.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Narrow 10%</td>
<td>Narrow 23%</td>
</tr>
</tbody>
</table>

N number of patients in the follow-up
%N proportion of follow-up vs. original study population
'String' and 'Narrow' patent with very narrow lumen
Clinical outcomes in terms of survival and freedom from cardiac events seem also to favour the use of RA graft. Event-free survival at 18 months was significantly better in patients with RA graft compared to SVG patients in a randomised setting (Muneretto et al. 2004). In contrast, the RAPCO study did not find any significant difference in outcomes between the groups (Hayward et al. 2008). A retrospective study of 925 patients with RA grafts and 925 propensity-matched controls with SVGs showed similar survival in both groups up to six months. Hence, the RA group did much better. At six years survival was 92.1% vs. 86.8% (p<0.03). The survival benefit was even more evident in women, diabetics, younger patients (<65 years) and triple-vessel patients. Use of the RA was an independent predictor of mortality, risk ratio 0.675 (95% CI 0.984 – 0.462) (Zacharias et al. 2004). Longer follow-up further emphasizes the benefit of total arterial revascularisation. At twelve years risk ratio was 0.60 (95% CI 0.48 – 0.75) in patients with all arterial revascularisation with ITA and RA compared to ITA and SVG (Zacharias et al. 2009).

Target vessel and patient characteristics affect RA patency. Low-grade coronary stenosis is detrimental to RA patency. Royse et al. found the patency rates were considerable poorer if the RA was anastomosed to a vessel with less than 70% stenosis (2000). Patency rates comparable to historic results regarding LITA patency were achieved by Desai et al. when RA was anastomosed to a vessel with 80 to 85% stenosis. Target vessel territory did not affect the patency but peripheral vascular disease was detrimental and the authors advise against using RA in patients with peripheral vascular disease (PVD) (Desai et al. 2007). Traditionally, there has been some concern about using RA in diabetics due to the impaired endothelium of the RA. The results from in vitro studies are contradictory (Choudhary et al. 2007, Wendler et al. 2001). Clinical series, however, show that the use of RA has protective effect on outcome in diabetics, and that this effect is even more pronounced compared to non-diabetics (Zacharias et al. 2004, Singh et al. 2008).
The forearm and hand are mainly supported by two arteries, the RA and UA. Both of these arteries arise from the brachial artery. The UA has major branches contributing to the circulation of the forearm. Anterior and posterior ulnar recurrent arteries support the brachialis, pronator teres and other adjacent muscles. They also form a collateral network together with the inferior ulnar collateral artery, which is a branch of the brachial artery. Further down the common interosseous artery branches from the UA and divides to anterior and posterior interosseous artery. Along its course medial to the radial nerve on the flexor digitorum profundus muscle it sends off muscular branches to the medial side of the forearm. At the first branch of the RA, the radial recurrent artery branches approximately 1 cm below the radial edge of the bicipital aponeurosis and participates in the collateral network around the elbow joint together with the radial collateral artery, a branch of the profunda brachii artery. In the cubital area the RA runs between the biceps tendon and bicipital aponeurosis. On the proximal half of its course the RA passes under the edge of brachioradialis muscle and is covered with loose connective tissue. Along its course it sends off small perforating branches to the interosseous muscles and to the lateral aspect of the forearm. There are an average of 4.2 branches in the proximal half of the RA and an average of 9.6 branches in the distal half (Reyes et al. 1995). At its distal part the RA lies in a groove formed by the tendon of the brachioradialis muscle and radial bone laterally, the tendon of the flexor carpi muscle medially, and the belly of the flexor pollicis longus dorsally. On the volar aspect it is covered with skin and superficial fascia only. The superficial palmar artery is the second major branch of the RA and it branches from the main trunk at the level of the wrist crease. In contrast to the UA there are no major vessels arising from the RA between the cubital fossa and wrist that would contribute to the circulatory support of the forearm, see figure 1. Traditionally, the UA has been considered larger than the RA, but this view has been challenged by a cadaver study (Riekkinen et al. 2003).
Innervation of the forearm is provided mainly by three nerves. The ulnar nerve, median nerve and radial nerve are all branches of the brachial plexus. In addition, there is a large branch of the lateral cord, musculocutaneous nerve that participates in the sensory innervation of the forearm. The ulnar nerve supplies most small muscles of the hand and skin on the ulnar side of the hand. The median nerve supplies the flexor muscles of the forearm and a large part of skin of the hand. The radial nerve gives motory branches to the brachioradialis muscle and to the extensor muscles of the forearm. Sensory innervation of the radial and volar aspect of the forearm is provided by the lateral antebrachial cutaneous nerve (LACN), a branch of the musculocutaneous nerve, which enters the forearm between the biceps tendon and cephalic vein. It runs along the border of the brachioradialis muscle in the fascial sheath. The superficial radial nerve (SRN) supports the sen-
sory innervation of the radial aspect of the thumb and dorsum of the hand. The SRN runs in close proximity to the RA.

The circulation of the hand has been ascertained in detail in several studies (Bilge et al. 2006, Loukas et al. 2005, Ruengsakulrach et al. 2001b). The main arteries providing blood supply for the hand are the UA and RA. A third artery, the median artery, can be found but it is not always present. Sometimes even the interosseus vascular system provides support to the hand. Anastomotic connections between the RA and UA are provided by four arterial arches. The two carpal arches, anterior and posterior, are located at the level of the carpal bones. The posterior carpal arch is the only one located on the dorsal aspect of the hand. Both palmar arches are on the volar aspect of the hand at the midpalmar level. According to their location they are referred to as the deep palmar arch (DPA) and the superficial palmar arch (SPA). The DPA is complete on most individuals. The complete classic DPA connects the terminal part of the deep palmar branch of the RA with the deep palmar branches, inferior and superior, of the UA. This configuration could be found on 90 – 100% of the subjects studied. The SPA is much more prone to variation. The complete classic SPA is formed by superficial palmar branches of the RA and UA. The prevalence of classic complete SPA varies between 10 – 55.9% in different studies. The complete arch in its classic expression can be further divided into radial-dominant, ulnar-dominant or equal type. The SPA may be complete even without the contribution of the RA if it supports all the fingers. Incomplete SPA may be present with anatomical variation. The UA always contributes to the SPA but lateral support can arise from the median artery, RA, DPA or from a combination of these vascular systems. It is apparent that the circulatory system of the hand is complex and that there is considerable variation from individual to individual in the anastomotic connections between the RA and UA. There should, however, be at least one major connection between the two vessels.

The circulation of the thumb is most often supplied by the first volar metacarpal artery (80%) which is the first branch of the DPA. Occasionally it may be supplied by the first dorsal metacarpal artery (15%) or by the second volar metacarpal artery (5%).
3. DISTRIBUTION OF ATHEROSCLEROTIC DISEASE IN THE SUPRA-AORTIC ARTERIES

Atherosclerosis is a systemic disease affecting the arterial system. The vessel endothelium in atherosclerotic patients is susceptible to trauma, which leads to a progressive build-up of atherosclerotic plaques. Atherosclerosis becomes clinically manifest when these plaques interfere with the flow in the vessel. Some vessels are more prone to the atherosclerotic involvement than others. The coronary arteries and carotid arteries are well-known sites for atherosclerosis with important clinical implications such as myocardial infarctions and cerebrovascular embolic stroke.

The arterial wall consists of three layers: the intima, media and adventitia. The intima is an inner lining of endothelial cells based on basal lamina. Typically for muscular arteries there is scarce connective tissue in this layer and the basal lamina may be in direct contact with the internal elastic lamina. The media consists of smooth muscle cells and collagenous fibres. Smooth muscle cells are arranged in a spiral form and their contraction regulates the tonus of the vessel. The adventitial layer is connective tissue and in muscular arteries as thick as the media. Between the media and adventitia is a layer of elastic material, the external elastic lamina. Coronary arteries together with the RA have relatively thick media, whereas in the internal thoracic arteries the medial layer is much thinner. The difference may explain their different susceptibility to atherosclerotic disease.

The relationship between CAD and carotid artery disease is well established (Craven et al. 1990). Carotid artery disease is found in 21% of coronary patients whereas on controls without CAD it is found in only 7% of cases. In general population with suspicion of CAD the prevalence is between 16.6% and 19.6%. The severity of CAD is reflected in the prevalence of carotid disease. Tanimoto et al. found that the extent of CAD had a strong association with ultrasonographic carotid disease, odds ratio 1.933 (95% CI 1.571 – 2.379, P<0.0001). If the carotid disease was evident even in angiographic evaluation the association was even stronger, odds ratio 2.336 (95% CI 1.647 – 3.313, p<0.0001) (Tanimoto et al. 2005). A similar
increase in the prevalence of carotid stenosis according to the severity of CAD was seen by Doonan and colleagues with the highest prevalence of carotid stenosis in patients with left main CAD (2007). Conversely, 68% of patients with angiographically proven significant carotid stenosis have CAD (Wu et al. 2007).

The subclavian artery is affected by atherosclerotic disease less frequently than the carotid arteries. The prevalence of subclavian artery stenosis was 7.1% in a clinical cohort and 1.9% in a community cohort in a large population study. In coronary patients the corresponding figures were 6.0% and 1.5%. PVD, a marker of manifest atherosclerotic disease, is associated with high risk of subclavian stenosis (Shadman et al. 2004). Peak systolic velocity (PSV) in the subclavian artery is higher in CAD patients (Doonan et al. 2007).

Studies on the atherosclerotic involvement of the forearm arteries are mostly confined to CAD patients scheduled for CABG. Ruengsakulrach found calcification in the RA in 24.7% and echogenic plaques in 6.8% of patients, overall vessel wall pathology was found in 31.5% (2001d). Others have reported lower figures, around 8% (Rodriguez et al. 2001, Oshima et al. 2005).

4. HARVEST OF THE RADIAL ARTERY

4.1. Preoperative assessment

The radial artery has a major function in the circulation of the hand. Ischemic complications related to the harvest of RA are rare but may have deleterious consequences for the patient. Correct functioning of the RA as a coronary bypass graft is of vital importance to the patient. The consequences of graft failure are even more serious than ischemic complications of the hand. Both problems can be avoided with careful preoperative planning and proper selection of RAs to be harvested. Several techniques are available for this purpose.
4.1.1. The Allen test

The Allen test was first described by Edgar V. Allen as a diagnostic test for occlusive disease of the ulnar circulation in 3 patients with thromboangiitis obliterans in 1929 (Allen 1929). In his article Dr. Allen states: “If obstruction of the ulnar artery is suspected, the radial arteries are located by their pulsations; the examiner places one thumb behind the patient’s wrist, thus holding the wrist lightly between the thumb and fingers. The patient closes his hands as tightly as possible for a period of one minute in order to squeeze the blood out of the hand; the examiner compresses each wrist between his thumb and fingers, thus occluding the radial arteries; the patient quickly extends his fingers partially while compression of the radial arteries is maintained by the examiner. The return of color to the hand and fingers is noted. In individuals with an intact arterial tree the pallor is quickly replaced by rubor of a higher degree than normal.” The principles for performing the test have not essentially changed over the decades. Modified AT refers to an AT performed together with Doppler test on a hand artery, preferably in the snuff box. Some technical considerations should be kept in mind while performing the test. The wrist should be kept in a neutral position to avoid hyperextension as this may produce false-positive result by occluding the UA or impairing its flow. On the other hand, to avoid false negative results, compression of the RA should be sufficient to ensure total occlusion of the RA while compression on the UA is released. Finally, the hand should be kept at the level of the heart to exclude any hydrostatic pressure changes. Dr. Allen did not specify any cut-off point for the return of the pallor. Several different cut-off points have been suggested varying between 3 and 10 seconds.

Ruengsakulrach et al. verified the AT with 71 patients using ultrasonographic flow measurements as a reference (2001c). Flows in the UA, SPA and thumb artery were recorded before and during compression of the RA. Flow patterns were divided into groups: no flow, decreased flow, reversed flow and increased flow. The cut-off point at the AT was set at 10s. Depending on the artery measured, sensitivity and specificity varied between 28.6 – 100% and 96.6 – 97.1%, respectively. Best
results were obtained from the thumb artery, the diagnostic accuracy being 97.2%. The authors conclude that the AT accurately predicts the ultrasonographic flow patterns, especially in the thumb artery. In case of positive AT ultrasonographic evaluation enables safe harvest of the RA.

Somewhat different conclusions were drawn by Jarvis et al in their series of 97 patients (2000). Doppler waveform of the princeps pollicis artery was recorded before and during compression of the RA and classified as triphasic, biphasic, monophasic or absent. Triphasic waveform was defined as a marker of sufficient ulnar collateral flow. A cut-off point of 3s in the AT gave a sensitivity of 100% and specificity of 27%, diagnostic accuracy 52%. At 5 s sensitivity was 75.8% and specificity 81.7%, diagnostic accuracy 79.6% and at 6s the corresponding figures were 54.5%, 91.7% and 78.5%. According to the authors the AT is not reliable and should be replaced with more objective tests.

Candidates for radial artery harvest were examined prior to CABG by Agri-foglio et al. (2005). In addition to the AT with a 10s cut-off point, an ultrasonographic study was performed. PSV on the UA, flow in the snuff box and in the SPA was recorded before and during compression of the RA. All 150 patients had negative AT but eight patients (5.3%) had contraindication for radial artery harvest in the ultrasonographic examination, defined as failure to display increased peak systolic velocity in the UA or absent reverse flow in the snuffbox or SPA. The authors advocate preoperative ultrasonographic evaluation of the hand circulation and justify their opinion with medicolegal aspects. Recently, Vuković et al. reported their series of 113 patients with a 10s AT and a comprehensive ultrasonographic examination (2008). In addition to earlier reports reviewed here, morphologic assessment of the RA was also done. In comparison with ultrasonographic findings authors report a sensitivity of 66.6% for the AT and specificity of 94.2%. Altogether 34 patients (30.1%) had a contraindication for RA harvest.

Asif and Sarkar tested more than 600 patients using a 6s cut-off point and a three-digit compression on the RA (2007). In this series no vascular insufficiency of the hand was encountered postoperatively in patients with RA harvested.
4.1.2. Ultrasonography

Ultrasonography is a method for the evaluation of morphology and flow velocity. It is non-invasive and thus virtually harmless to the patient. However, the equipment is costly and the examination procedure requires conversance with the associated learning curve. The examination itself may be arduous and time-consuming depending on the extent of the parameters measured. Ultrasonography utilises ultrasound that is generated by a piezoelectric transducer within a frequency range of 2 to 18 MHz. Ultrasound penetrates the soft tissues and gives an echo, which is recorded. Based on the time elapsing between transmission and echo, focal length for the phased array and strength of the echo, an image is formed. B-mode gives a two-dimensional image on one plane of the scanned organ. M-mode combines these images in a period of time and creates a live image. Flow velocities can be calculated on the Doppler principle; ultrasound is transmitted at an angle to the erythrocytes circulating in the vessel and the ostensible frequency change in the echo reveals the velocity at which the erythrocyte is travelling.

Ultrasonographic contraindications for radial artery harvest were outlined by Pola et al. (1996) and Rodriguez (2001). Based on their research with 188 patients, Pola and his group established guidelines for Doppler flow measurements that should be fulfilled before accepting the RA for harvesting. They found that during compression of RA, the PSV in UA should increase at least 20%, and that there should be reverse flow at the level of SPA at the same time. Further information is obtained from the flow velocities in the common digital palmar arteries. Absence of reverse flow in the SPA strongly suggests insufficient palmar collaterals between the UA and RA. According to the authors the main contraindication for RA harvest is, at any rate, inadequate increase of ulnar flow; other criteria are secondary and should co-exist instead of being considered separately.

The following morphological criteria were set by Rodriguez et al: vessel size < 2mm in diameter at any point, diffuse calcifications or anatomic variations such as a high takeoff of the RA or RA agenesis (Rodriguez et al. 2001). A total of 346 arms of 187 patients were screened, 12.7% of the arms were rejected due to morphologi-
Calcified RAs were found in 8.7%, congenital anomalies in 2.3%, small vessel in 1.5% and 0.3% had occluded RA. High bifurcation of RA was the most common congenital anomaly.

The prevalence of pathologic changes in the RA wall was studied using ultrasonography by Ruengsakulrach (2001d). Echologic findings were divided into two groups: calcifications, either intimal or medial and echogenic plaques. Overall prevalence was 31.5% (23/73), 18 arms were affected with calcifications and five arms with plaques. Patient’s risk profile for vascular disease was recorded to identify prognostic factors for RA pathology. Age, male sex and carotid artery disease predicted RA calcification. RA pathology was best predicted by a carotid disease and peripheral vascular disease. This study showed a much higher rate of wall pathology than earlier histologic studies, but the histopathology is confined to one, often short segment of the artery, thus potentially missing some of the changes.

A Japanese group in Tokyo studied the ulnar flow before and after RA harvests (Manabe et al. 2002). After 10s AT patients were assessed with Doppler ultrasonography. Mean flow velocity was determined in the RA and in the UA with and without radial artery compression (RAC). The UA was measured again postoperatively. Vessel diameter was also measured. Values were converted into millilitres/minutes using the formula: blood flow = (internal diameter/2)²*π*mean flow velocity. In the AT positive group (n=9) flow increased from 37.2 ml/min to 74.5 ml/min during RAC, in the AT negative group (n=71) the increase was from 56.5 ml/min to 83.6 ml/min. However, the variation in the AT positive group was much higher. RA was harvested from all patients in the AT negative group. One of the patients with low UA flow during RAC (<40 ml/min/m²) developed thumb ischemia postoperatively and was treated with iloprost. In the majority of patients preoperative ulnar blood flow during RAC was correlated with postoperative flow. Ulnar blood flow below 40 ml/min/m² is a risk factor for hand ischemia; according to the authors this group has similarities with the group where increase in ulnar blood flow is insufficient.

Almost all the studies conducted in this field have been done with RA harvest candidates scheduled for CABG. As an exception, 40 healthy volunteers partici-
pated in a study where correlation between ulnar flow velocity changes and digital pressures was ascertained (Sullivan et al. 2003). PSV was measured as usual before and during RAC. Corresponding blood pressures on the first and second digit were measured using photoplethysmography. Measurements were repeated with a random sample of the volunteers to test the reproducibility of the method. Mean increase of PSV during RAC was adequate in both dominant and non-dominant arms. Likewise, the mean decrease in blood pressure in the fingers was logical. However, changes in the individuals were scattered and there was no correlation between PSV changes and digit blood pressures. In conclusion, UA PSV changes predict poorly the harvestability of RA; blood pressure on the first and second digit is the preferred screening tool.

An Italian research group measured intima-media thickness (IMT) of the RA with ultrasonography and performed graft angiography postoperatively to find out whether IMT has any effect on graft patency (Gaudino et al. 2003). Forty-two patients scheduled for CABG were assessed; IMT on the RA was 0.56 ±0.12 mm and RA diameter 1.99 ±0.58 mm. Control patients without CAD had similar IMT and diameter. Angiographic control of the grafts was done 61 ±7 months after the operation for 30 patients. One RA showed a string sign and one was occluded, others were perfectly patent. In this relatively small study there was no correlation between IMT and patency of the graft. Measurement of IMT can be challenging with ultrasonography, thus making it difficult to reproduce the results. Another noteworthy matter is that the mean RA diameter was less than 2 mm in the operative group.

Intravascular ultrasound is a technique applied by interventional cardiologists in the coronary arteries to determine the grade of stenosis in borderline cases. Oshima et al. applied this technology to the RA (2005). Lumen diameter, lumen area, vessel diameter, vessel area, plaque area and extent of calcium deposition were recorded. The study was performed in conjunction with transradial coronary intervention on 58 patients. Mean diameter was distally 3.00 ±0.70 mm; one patient had RA less than 2 mm in diameter. Plaque area greater than 50% was
observed in five patients (8.6%); however, the disease was often discrete and only one RA was left unharvested. Calcium deposits were found in five patients (8.6%); on two patients the calcifications were extensive and the RA was rejected. IVUS provides detailed information about the graft but it is costly and invasive, in the worst case it may compromise otherwise an usable graft.

4.1.3. Plethysmography

First and second digit pressures were evaluated by Starnes et al. in a study on 129 patients; both arms were examined, except for one patient (1999). In addition to plethysmography a modified AT was performed. Compared with modified AT, a 40 mmHg decrease in digit pressure in the nondominant hand reached a sensitivity of 50.5% and a specificity of 96.4%, with diagnostic accuracy of 90.6%. According to the ROC curve analysis in the dominant hand the authors found that the ideal pressure reduction limit for dichotomisation was 36 to 37 mmHg. With this limit sensitivity, specificity and diagnostic accuracy reached values of 57.1%, 85.2% and 82.2%. The advantage of plethysmography is that it is objective and, according to this study, reproducible.

Plethysmographic contraindication for RA harvest was set at a 40% decrease in systolic digital blood pressure by Rodriguez (2001). This criterion was based on an earlier study on patients with dialysis grafts. The current series included 187 patients, again, candidates for CABG, both arms were examined. Ultrasonographic results are reported in Section 4.1.2. Plethysmography on the first and fifth digit was performed on 294 arms. In 40 cases patients’ clinical condition did not allow plethysmographic examination. Positive findings were made in 19 arms. Sixteen arms had more than 40% reduction in the first digit and three in the fifth digit. All 19 patients had normal ultrasonographic scan, i.e. reverse flow in SPA and adequate increase in ulnar flow. In this study both plethysmography and ultrasonography are recommended as preoperative screening tools.
4.1.4. Other methods

A group from Hungary has proposed the use of scintigraphy in screening the palmar circulation prior to RA harvest (Garai et al. 2006). Scintigraphy images were recorded from both the patient’s hands after injection of radioactive isotope. At the time of the injection both RA and UA were occluded, after 30 seconds the UA was decompressed and, finally, the RA was decompressed at 120 seconds. Images were obtained for up to 240 seconds, one image per second. A total of 35 patients were examined. Based on the images ulnar perfusion index (UPI) was calculated, also radial perfusion index (RPI) both for the palmar area and for the finger area. In addition, fingers-to-palm ratio (FPR) was calculated to reflect the microcirculation of the fingers. There was no statistically significant difference between the AT-positive and AT-negative group in FPR. Both palmar and finger UPI was significantly lower in the AT positive group. Based on an earlier study on patients with Raynard’s symptom, an FPR threshold of 0.45 was used for discrimination. There were eight hands with FPR less than 0.45, only two of these had positive AT. Twelve RAs were harvested, all from left arms. Postoperative scanning showed that the perfusion of fingers remained normal. Isotope scanning is a novel technique in this context and, according to the authors, a sensitive and objective indicator of palm circulation.

Roentgenogram of the forearm to exclude dystrophic calcification of the RA in patients over 70 years of age was proposed by Deshpande et al (2000). There have been no reports of the results. The idea of pulse oximetry of thumb or index finger during AT has been put forward by many (Johnson et al. 1998, O’Mara and Sullivan 1995). Interventional cardiologists have done large series to verify the method but there have been no systematic studies in the surgical setting (Barbeau et al. 2004).

In addition to preoperative screening methods some intraoperative methods have been described to facilitate decision-making during surgery. Roberts and associates exploited transit time flow meter by exposing the RA first via a small incision and placing a probe around the artery (2002). Both UA and RA were then
compressed for 1 minute and after decompression of both arteries the flow curve was recorded. The procedure was repeated with RA compression only and the flow curves were compared. If the two curves were similar, i.e. the hyperaemic response was also seen after mere RA compression the RA was left unharvested. Further, Birdi reported a “squirt” test where the RA was exposed and after closing the proximal artery the RA was opened with a small arteriotomy (2002). The squirt height was then used to assess the collaterals. In a series of 700 patients 695 RAs were harvested with no ischaemic complications.

4.2. Harvesting methods

4.2.1. Open vs. endoscopic

Surgery in general has become less invasive in recent years. This trend is seen even in cardiac surgery with the introduction of new methods like minimally invasive valve surgery and thoracoscopic surgery for atrial fibrillation. Minimally invasive graft harvesting in CABG has been developed to reduce morbidity and to improve cosmetic results. Minimally invasive techniques have even been applied to the RA harvest. The approach has been described in detail by Connolly and associates (2002). A 3-4 cm longitudinal incision is usually made at 1 cm proximal to the wrist crease. The RA is exposed and the dissection of the canal is continued cephalad with the help of an endoscopic retractor. Carbon dioxide insufflation is occasionally applied to enhance visibility. Side branches are divided with clips or with a Harmonic scalpel. Proximally the vessel is clipped or ligated with endoloop suture and divided, sometimes an accessory incision at the cubital region is utilised. Open technique involves an incision from the wrist crease to the cubital region to expose the RA. The incision is often curvilinear to mimic the border of the brachioradialis muscle. Dissection of the subcutaneous tissue is performed carefully to avoid LACN. The muscular fascia is opened and the RA is exposed by retracting the brachioradialis and flexor carpi muscles. The RA is then gently lifted and the side
branches are clipped. After the RA has been totally dissected both ends are ligated and divided accordingly. The wound is closed in the standard manner. A detailed description of the technique is provided by Reyes et al (1995).

Aziz et al. reviewed all comparative studies published on minimally invasive conduit harvesting (2006). Regarding RA harvesting eleven papers were found between 1995 and 2005, of which none were randomised and only two were prospective studies. The others were observational studies. The results were reviewed regarding infection, other healing disturbances, post-operative pain, neurological disturbance, mobility, patient satisfaction, conduit quality and long-term patency. Due to the nature and number of the publications the authors found only insufficient evidence on the infection rates, healing disturbances, post-operative pain and neurological disturbances, macroscopic quality of the graft and patient satisfaction. There was no evidence at all on the microscopic quality of the graft or on the long-term patency of RA grafts harvested with minimally invasive techniques. There was only little information available on the cost of procedures.

Since the review by Aziz a randomised study concerning the functional and histological quality of the graft has been published (Shapira et al. 2006b). The series, however, is small with three groups (endoscopic, open electrocautery and open Harmonic) with 18 patients in each. Vascular relaxation was tested in an organ bath with acetylcholine (endothelium-independent) and nitroglycerin (endothelium-dependent), vasoconstriction with thromboxane analog. Endothelial integrity was assessed with microscopy and immunohistochemistry. There was no difference between the groups in baseline demographics or clinical outcomes. Sensory deficits were confined to the innervation area of SRN in the endoscopic group, whereas in the open group paresthesias and numbness were also reported in the area of LACN. Vasoreactivity was similar in all groups; neither did the microscopic examination reveal any significant differences between the groups. Adhesion molecule expression did not differ between the groups in immunohistochemistry. In this well conducted but small study, harvesting method did not have any affect on the functional or histological quality of graft.
Three observational retrospective studies on neurological complications have been conducted in recent years. Kim et al. compared the outcomes of 100 patients with endoscopically harvested RA to those of 157 patients with RA harvested using open technique (2007). They found that there were significantly fewer neurologic complaints in the endoscopic group in the innervation area of LACN. In SRN there was no difference. Harvesting-related complications, such as haematomas or infections did not differ significantly between the groups. In their study Bleiziffer et al. found more neurological complications in the endoscopic group (2008). Both groups included 53 patients. Distribution of the neurologic sequelae was as in the results from earlier studies, but the overall rate of complaints was higher in the endoscopic group (34 pts vs. 22 pts). Both groups still prefer endoscopic technique due to the superior cosmetic results. Similar conclusions were drawn by Shapira et al. (2006a). They found no difference between the groups in reported neurological complications. Subjective cosmetic results were significantly better in the endoscopic group. Endoscopic harvest time was longer but came down with experience and in the third tercile there was no longer a difference. Clinical outcomes were similar.

Mid-term outcomes of RA grafts harvested endoscopically were analysed in a series of 50 patients (Bleiziffer et al. 2007). Patients were examined one year postoperatively with multislice CT, ECG and echocardiography. Control patients were randomly selected from the centres database. Baseline demographic data was comparable. Clinical outcomes were similar, no cardiac reoperations in either group occurred. Graft patency for RA was 78% in the endoscopic group compared with 76% in the open group (p=.812). There were three RA occlusions in the open group and one in the endoscopic group. Echocardiography revealed normal left ventricular function in 39 patients and ECG sinusrhythm in 47 patients in the endoscopic group. Corresponding data for the open group was not provided. Further analysis showed that the only significant factor predicting the patency of RA graft is the target vessel stenosis rate.
4.2.2. **Harmonic scalpel vs. conventional methods**

The harmonic scalpel utilises ultrasonic coagulation of the tissue. Ultrasonic energy is created through mechanical vibration of the metal head in the instrument. The frequency of the vibration is 55 kHz. Denaturation of proteins is achieved with temperatures below 80 degrees Celsius, whereas in conventional diathermy the temperature is often over 300 degrees. The instrument can be shaped like a dissecting hook, a blade or like scissors, or shears, where one blade of the scissors vibrates and the other blade fixes the tissue firmly to the instrument.

The first report of the Harmonic scalpel in the use of RA harvest was presented by Psacioğlu and colleagues (1998). Twenty RAs were harvested, 10 with Harmonic scalpel and 10 with conventional method using scissors, clips and minimal electrocautery. This descriptive series had less spasm and shorter harvesting time in the Harmonic group.

Ronan et al. reported a series of 62 patients with their RAs harvested from their nondominant arm (2000). There was no randomisation; the decision was based on the availability of the Harmonic generator. Twenty-one patients had the RA removed using a conventional technique and 41 with the Harmonic scalpel hook. Free flow was measured at three different timepoints. There was no difference between harvest times but the number of clips used was significantly lower in the Harmonic group (3.2 vs. 74). Measured flow was significantly better at all times in the Harmonic group. The authors believe that there is less spasm in the conduit if harvested with a Harmonic scalpel.

In a retrospective series, Moon et al compared long-term neurologic complications of the hand between two groups (2004). The first group with 422 patients had their RAs harvested by conventional methods between 1995 and 1997. In the second group of 360 patients operated on between 1998 and 2000 the Harmonic scalpel with dissecting hook was utilised. Follow-up groups were 312 and 290 patients respectively. There was a difference between the groups in the baseline characteristics; patients in the Harmonic group were older, had more peripheral vascular disease and diabetes, and were more frequently smokers. In a survey the
incidence of neurological complications defined as thumb weakness, dorsal hand symptoms and palmar hand symptoms did not differ between the groups. Smokers and diabetics had more hand symptoms in both groups. Fortunately disabling symptoms were rare, even though the overall frequency of neurological symptoms in this series was quite high (9.0% ±2.3%) four years postoperatively.

Endothelial damage caused by the Harmonic scalpel vs. conventional methods has been studied by two Turkish groups. The first series from 2001 had fourteen patients, seven in each group (Cikirikcioglu et al. 2001). Discarded segments of RA were exposed to different vasoconstrictors and vasodilators in an organ bath. Endothelial integrity was examined by electron microscopy. There was no statistically significant difference between these two groups in vasoreactivity or endothelial integrity. Only in vitro results were considered. The second series consisted of 101 patients randomly divided into a Harmonic group (n=51) and a conventional group (n=50) (Erkut et al. 2008). There was no difference between the groups in baseline demographics or operative data. Histopathological evaluation showed less endothelial damage in the Harmonic group. Harvesting time did not differ from that in the conventional group, but the number of clips used was smaller and free flow measured by transit time doppler was higher in the Harmonic group.

The largest study to date to compare Harmonic scalpel and conventional methods in a randomised trial was presented by Oz and colleagues (2007). Two hundred patients were randomised into two equally sized groups. In the conventional group clips and electrocautery were used and in the Harmonic group shears were used. Demographic data did not differ between the two groups. Neurological complications occurred at a similar rate in both groups. Harvesting time was shorter in the Harmonic group (23.7 vs. 33.4 min), spasm rate was lower (2 vs. 8%) and the need for postoperative analgesia was likewise lower (5 vs. 17%).

Endothelial damage intraoperatively was assessed by Brazio and colleagues using optical coherence tomography (OCT) (2008). OCT is an imaging modality that measures the reflection of emitted infrared radiation. It is useful when estimating the intimal integrity, but also gives information about the luminal borders, thus allowing the measurement of vessel capacity. The authors compared 15 RAs
harvested by Harmonic scalpel to 29 RAs harvested by electrocautery. The vessels were estimated with OCT before harvest and reassessed after harvest. Endothelial damage found was validated with histology and vessel volume was measured. The results showed a difference in endothelial damage in random histological specimens. When OCT was used to guide the samples 73% of RAs harvested by Harmonic scalpel had intact intima compared with 31% in the electrocautery group (p=.011). Most intimal defects were at branching points. Vessel volume did not differ between the groups prior to harvest but after harvest there was a significant difference in favour of the Harmonic group (921 mm$^3$ vs. 559 mm$^3$, p=.003). Postoperative CT scan showed no difference in graft patency between the groups. Patients in this series were not randomised, and the sample size is too small to show differences in graft patency.

4.3 Spasmolytic treatment of the radial artery

As a limb artery the RA has abundant amount of contractile tissue in the medial layer and, thus, is prone to spasm. Several pharmacological strategies have been proposed to reduce the tendency for postoperative spasm. Attaran et al. reviewed different agents used for the purpose and found that verapamil-glycerine trinitrate (VTG) solution used intraoperatively for the preparation of the graft would be most beneficial. Compared with papaverine VTG causes more rapid vasodilatation and better preserves endothelial function (2008). In addition the effect of VTG has longer duration. Topical VTG seems also reduce incidence of RA graft occlusion (Yoshizaki et al. 2008). Systemic use of calcium channel blockers postoperatively is not encouraged by the current literature (Patel et al. 2006).
5. RESULTS AFTER RADIAL ARTERY HARVEST

5.1. Complications

5.1.1. Vascular complications

Ischemic complications after RA harvest for CABG are rare. Two severe ischemic complications have been reported. Nunoo-Mensah reported on a 68-year man with CAD who underwent CABG for three-vessel disease (1998). Preoperative AT was normal and the RA was harvested. Two days after the procedure the patient began complaining of a pale, cold hand. The pain increased and an angiography revealed an aplasia of the UA. He received a reconstruction of the RA with cephalic vein and recovered well. An almost identical case with similar outcome and treatment was reported by Fox (1999).

Aside from the above mentioned case reports, the only reported event of hand ischemia is from Manabe (2002). One patient in their series developed thumb ischemia several days postoperatively and was treated with iloprost. There was no report of the outcome. No other series in this review reports ischemic events after RA harvest. There have been case reports of deep venous thrombosis affecting the upper extremity after RA harvest (Hata et al. 2002b) and compartment syndrome leading to forearm muscle necrosis (Chattar-Cora 2007).

5.1.2. Neurological complications

Neurological complications after RA harvest occur more frequently than vascular complications. Self-reported incidence of sensory disturbances varies between 3 and 70% in different series. Table 2 summarises self-reported incidence of neurological complications in the literature. Sensory disturbances are mostly limited to the innervation area of LACN and SRN. The most probable cause of the mechanism for sensory disturbances is direct nerve injury during the harvest procedure.
This is illustrated in the series comparing open and endoscopic harvest techniques. In most series there is a difference in the reported nerve injury pattern. Patients with RA harvested endoscopically have more problems in the thenar and thumb area, which are innervated by SRN. SRN is adjacent to the RA in the carpal area. On the other hand they have fewer problems in the forearm, which is innervated by LACN. Endoscopic dissection takes place underneath the fascial plane where LACN is located (Bleiziffer et al. 2008, Shapira et al. 2006a).

The median nerve is in close proximity to the RA in the carpal area but should not be encountered during the RA harvest. Nevertheless, thumb weakness is reported by 0.5 – 7% of the patients and even palmar sensory abnormalities occur. Besides, these two injury patterns are correlated. Ischemic neuropathy could explain the median nerve injury. The median nerve receives its circulatory support both from UA and RA and after RA harvest a circulatory insufficiency may develop. Another possible explanation is the occurrence of carpal tunnel haematoma or oedema (Denton et al. 2001).

The incidence of sensory impairment measured by objective findings tends to be lower than the self-reported incidence. Royse et al. tested sensation within the LACN and SRN innervation area with Semmes-Weinstein filaments (Royse et al. 1999). Complaints in the LACN area were reported by 15.5% of patients whereas only 2.1% had a deficiency in the actual testing. The corresponding figures in the SCN area were 11.3 % and 0.3%. A later study reported similar results (Chong et al. 2003). Dogan et al. used EMG to document functional changes in the nerves of the forearm after RA harvest (2006). All 40 patients were asymptomatic three months after surgery. In the RA harvest group there was a significant drop of motor and sensory conduction amplitudes in the median and radial nerves. Motor velocity impairment of the median nerve was also significant. Changes in the ulnar nerve were similar in both the RA harvest group and the control group. Ikizler did not find any significant change between overall pre- and postoperative conduction velocities or amplitudes but patients with neurological complaints had an impairment of the related nerve (2005).
Diabetes, smoking, hypertension and congestive heart failure are associated with reported and documented neurological complications after RA harvest (Denton et al. 2001, Siminelakis et al. 2004). Neurological complaints seem to decline over time and seldom interfere with daily living (Hata et al. 2002a). A severe neurological complication, complex regional pain syndrome, leading to permanent disability has been described (Schmid et al. 2002).

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>No. of patients</th>
<th>Overall neurologic symptoms</th>
<th>Sensory disturbance</th>
<th>Follow-up time</th>
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<tr>
<td>Tatoulis</td>
<td>1998</td>
<td>192</td>
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<td>10%</td>
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<tr>
<td>Royse</td>
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<td>328</td>
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<td>16%</td>
<td>12 mo</td>
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<tr>
<td>Meharval</td>
<td>2001</td>
<td>3977</td>
<td>6.5%</td>
<td></td>
<td>3 mo</td>
</tr>
<tr>
<td>Denton</td>
<td>2001</td>
<td>560</td>
<td>30%</td>
<td>18%</td>
<td>15 mo</td>
</tr>
<tr>
<td>Saeed</td>
<td>2001</td>
<td>127</td>
<td>70%</td>
<td>68%</td>
<td>8 mo</td>
</tr>
<tr>
<td>Greene</td>
<td>2001</td>
<td>338</td>
<td>11%</td>
<td></td>
<td>At discharge</td>
</tr>
<tr>
<td>Connolly</td>
<td>2002</td>
<td>300</td>
<td>9%</td>
<td></td>
<td>1 mo</td>
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<tr>
<td>Hata</td>
<td>2002</td>
<td>155</td>
<td>13%</td>
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<td>12 mo</td>
</tr>
<tr>
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<td>2004</td>
<td>288</td>
<td>23%</td>
<td></td>
<td>Not reported</td>
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<tr>
<td>Moon</td>
<td>2004</td>
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<td>11%</td>
<td>12 mo</td>
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<tr>
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<td>16 mo</td>
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<tr>
<td>Ikizler</td>
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<td>28%</td>
<td>32%</td>
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<tr>
<td>Shapira</td>
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<td>228</td>
<td>39%</td>
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<td>12 - 46 wk</td>
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<tr>
<td>Bleiziffer</td>
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<td>106</td>
<td>53%</td>
<td>41%</td>
<td>15 mo</td>
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</table>
5.2. Function of the forearm and hand

5.2.1. Circulatory changes after RA harvest

The radial artery is the second major artery supplying the forearm and hand. Removal of the RA will inevitably alter the circulatory conditions. Before the renewed interest in the RA in coronary surgery these circulatory changes were mostly confined to patients with forearm trauma (Gelberman et al. 1979) or to patients with forearm radial flap raised for tissue defects (Suominen et al. 1996). In general, these patients probably have a more favourable risk profile for atherosclerotic disease and, may also be younger than coronary patients. A number of studies have been conducted to ascertain the consequences of RA removal in CABG patients.

Circulation of the hand and forearm can be assessed by several techniques. Ultrasonographic studies have investigated the dynamic and morphologic changes in the forearm vessels after RA harvest. In UA significantly increased PSV and diameter have been found and these changes are concur with different studies (Serricchio et al. 1999, Lohr et al. 2000, Brodman et al. 2002, Gaudino et al. 2005). They even seem to be permanent as they are seen in a follow-up of ten years (Gaudino et al. 2006). Absolute flow, which can be derived from flow velocity and vessel diameter, was also increased (Royse et al. 2004). In the long term increased flow may accelerate the atherosclerotic process in the UA. IMT and prevalence of atherosclerotic plaques in the UA were increased in a ten-year follow-up (Gaudino et al. 2005). In a recent, much larger series this effect was not seen (Royse et al. 2008). In SPA the PSV was not significantly increased (Lohr et al. 2000).

Two available techniques for quantitative assessment of forearm circulation are isotope perfusion test and plethysmography. Rafael Sabada et al. reported lower perfusion rates in forearm and hand after RA harvest in a series of 20 patients using Tc-99m scintigraphy (2001). No preoperative measurements were performed and the contralateral arm was used as a control. In every patient the RA was harvested from the nondominant arm. According to an earlier study, there is no significant difference between nondominant and dominant hand in tissue perfusion with this
technique. Plethysmographic examination of forearm circulation did not reveal any significant difference between pre and postoperative measurements (Chong et al. 2003).

Plethysmography has also been used for the assessment of digital blood flow. Dumanian did not find any significant difference in the digital-brachial index (DBI) of the index and little finger in 28 patients (1998). Postoperative examination was performed 5 to 17 months after RA harvest. Lee analysed the PVR curve shape in the immediate postoperative period in 24 patients (2004). No preoperative measurement was performed; instead the contralateral hand was used as a control. The method was verified with 10 healthy volunteers. PVR curves were categorised into three groups: normal, intermediate and minimum blood flow. The results show an overall decrease in digital blood flow. Pulse amplitude analysis was congruent with PVR curve analysis. Interestingly, the thumb and index finger were preferred over the fourth and little finger, suggesting an autoregulation of the hand circulation. After three-year follow-up 15 patients were reassessed and a physiological adaption was seen (Lee et al. 2005). Digital blood flow had increased in all fingers with maximal flow to the thumb.

Microcirculation of the fingers was assessed by Knobloch et al. by measuring tissue oxygenation saturation using fibre-optic laser technology (2005). The first, third and fifth fingers were measured preoperatively and again on the second postoperative day. No differences were found on any of the parameters measured.

5.2.2. Functional outcome and perception

Good functional outcome of the forearm and hand and acceptable perception is essential for good surgical results when RA is used as a graft. Even if the revascularisation is complete and cardiac symptoms have disappeared can defectiveness of hand function may limit patients’ ability to return to work or to earlier hobbies.

Royse et al. examined 328 patients with their RA harvested and found that there was a 5% reduction in hand strength compared to the contralateral hand but when hand dominance was taken into account this reduction was within nor-
mal limits (1999). Scar tenderness and hypersensitivity were commonly reported (20%), sensation disturbances were also quite commonly reported (15.5%) but infrequently found on objective measurements (2.1%). Five percent of the patients reported some difficulty with daily activities but none had difficulties in returning to work.

Numbness was the most frequent complaint reported in a series of 3738 patients surveyed by Meharwal (2001). Paresthesia and weakness were also reported, but all these symptoms subsided within three months in a follow-up. Only nine patients (0.24%) had limitations in hand activity that persisted for longer than three months. Resolving of the symptoms was observed also by Saeed et al. in their survey of 127 patients (2001). At the time of first interview 67.8% of patients reported sensory problems and four patients had limitations in hand activity. Ten months later 50 patients were contacted and 37 reported that their symptoms had disappeared. One patient reported deterioration and the rest had persistent altered sensation but no limitations in daily activities. Patients’ health related quality of life was not related to symptoms caused by RA harvest.

Quality of life after RA harvest was assessed by SF-36 score by Allen and associates (2004). They found that patients with RA harvested had significantly higher scores in physical functioning, pain and social functioning, whereas limitations in physical health, general health, emotional well-being, limitation owing to emotional problems and energy/fatigue did not differ significantly from the control group. Patients also completed a Disabilities of the Arm, Shoulder and Hand (DASH) score measuring upper limb disabilities. DASH score was higher in the RA group. The incidence of peripheral sensory neuropathy did not differ between harvested and nonharvested extremities. RA group and control group were not randomised. Multivariate analysis revealed that patient variables such as diabetes, prior stroke, peripheral vascular disease, obesity and age were more predictive of quality of life and upper extremity disability than use of RA.
AIMS OF THE STUDY

The aims of the current study were to:

1. Define the validity of the Allen test when selecting radial arteries to be harvested for CABG by investigating its specificity, sensitivity and diagnostic accuracy.

2. Find out whether non-harvestable radial artery is a bilateral phenomenon.

3. Investigate the relationship between forearm vessel atherosclerosis and carotid atherosclerosis.

4. Find a simple intraoperative method for radial artery screening when the Allen test is positive and other preoperative screening methods are not available.
PATIENTS

The study population for Studies I – III was collected in Tampere University Hospital and for Study IV in Vaasa Central Hospital. The study population collected in Tampere is referred to as the Tampere population and patients collected in Vaasa are referred as to the Vaasa population. The Ethics Committee of Tampere University Hospital and the Ethics Committee of Vaasa Central Hospital approved the concerned study protocols.

1. STUDIES I – III

The patient population for Studies I – III consisted of 145 patients who were scheduled for CABG between October 2000 and April 2005. Patients older than 60 years were excluded as the RA as graft was considered for younger patients only. Emergency cases were excluded since screening facilities with ultrasonography and plethysmography were available only during office hours and with advance booking. Mean age of the patients was 52 years (SD 5.7). Male gender and right hand dominance were more prevalent (130 vs 15 and 136 vs 9 respectively). All 145 patients were included in Study I.

Forty patients among the 145 had a contraindication for RA harvest in the non-dominant hand. Thirty-three of them had their dominant hand screened as well. Due to practical reasons the dominant hands of seven patients were left unscreened. Additionally, both hands were screened in twelve patients without contraindication for RA harvest in the non-dominant hand. The 33 patients with contraindication for RA harvest in the non-dominant hand were included in Study II as a study group whereas the 12 without contraindication comprised a control group. There was no significant difference between the groups regarding age, gender, hand dominance or risk profile for atherosclerotic disease.
For the purposes of Study III 85 patients in the beginning of the series had their both carotid arteries screened. In this subgroup mean age was 52.2 years (SD 4.7) and male subjects were in the majority (75 vs 10).

Studies II and III focused on intra-individual distribution of abnormal findings within supra-aortic vessels and their direct off-springs. The focus of Study II was on contraindications for RA harvest and their accumulation on a single patient. Study III covered correlation between atherosclerotic changes in forearm arteries and carotid arteries. Both studies concentrated on young patients with CAD, thus having a marked predisposition to atherosclerotic disease.

2. STUDY IV

Ninety patients scheduled for elective CABG were enrolled in this study between January 2002 and November 2003. Exclusion criteria were age over 75 years, clinically detectable ischaemia of the hand, >70% stenosis of the subclavian artery and >30% pressure gradient between the arms. Mean age was 62.4 years (SD 7.4) and male gender was predominant (74 vs 16). Among different risk factors for atherosclerotic disease hypercholesterolema (88%) and hypertonia (59%) were the most common. Smoking (43%) and diabetes mellitus (26%) were less frequently encountered.
METHODS

1. THE ALLEN TEST

The Allen test was performed by asking the subject to clench his/her fist for one minute while both radial and ulnar arteries were compressed by the examiner. The patient was usually sitting. The wrist was held at the level of the heart and care was taken to avoid extension of the hand. The ulnar artery was released and the time that elapsed between the return of the ulnar flow and the recovery of normal pallor of the thumb and thenar area was recorded. Cut-off point was determined at six seconds. A positive test was reported when capillary filling of the thumb and thenar area was absent at 6 seconds.

The traditional Allen test was complemented with a handheld doppler in Study IV. The doppler probe was placed in the snuff box between extensor pollicis brevis and extensor pollicis longus tendons so that the arterial signal from the principis pollicis artery could be heard. The RA was then compressed and the doppler signal was observed. The test was positive if the signal was still heard after compression.

2. ULTRASONOGRAPHY

Ultrasonographic examination was performed in the laboratory of clinical physiology by an experienced physician. A transducer with emission frequency between 5 and 10 MHz was used, based on best visibility (Aloka Pro Sound 5500, Aloka Co Ltd, Tokyo, Japan). The non-dominant hand was examined first and if a contraindication for RA harvest was found the dominant hand was also examined.
2.1. Morphologic examination

The anatomy of the forearm arteries was assessed with biplane ultrasonography. The inner diameter of the RA and the UA was measured both proximally and distally. The wall structure of the arteries was studied and the presence of media sclerosis or intimal calcifications was noted. Anatomic variations such as high bifurcation of the RA, absence of UA or RA were also recorded. Morphologic contraindications for RA harvest are: inner diameter < 2 mm, diffuse medial or intimal calcification and anatomical anomaly. In the beginning of the series in Studies I – III both carotid arteries were screened as well and the findings were classified: no sclerosis, sclerotic changes without stenosis, mild stenosis (1-15%), moderate stenosis (16-49%), significant stenosis (50-75%), severe stenosis (76-99%) and total occlusion.

2.2. Flow measurements

Circulatory measurements with Doppler ultrasonography included PSV and end diastolic velocity (EDV) of both RA and UA. A resistance index was calculated (PSV-EDV/PSV). These measurements were repeated on the UA while the RA was compressed. During RAC the distal part of the RA was controlled for reverse flow. Absence of reverse flow in the RA during RAC or < 20% increase in ulnar PSV during RAC were considered contraindications for RA harvest.

3. Pletysmography

Digital pressures in were measured with pletysmography (Finapres, Ohmeda, Eaglewood, Colorado, USA) both at rest and during RAC. Every finger was measured in Studies I – III. If the digital pressure decreased > 40% the RA was left unharvested. In Study IV second and fifth fingers were measured and a DBI was defined using brachial pressure measured at the same time.
4. INTRAOPERATIVE PRESSURE MEASUREMENT

In study IV the pressure of the RA was measured intraoperatively. The distal end of the RA was exposed surgically and cannulated with a small venous cannula (Neoflon 24 gauge) connected to a pressure line. The RA was then compressed proximally to the cannulation site and the pressure was measured. The contralateral RA was cannulated by the anaesthetist arterial cannula for haemodynamic surveillance. Simultaneous pressure recordings from RAs were compared and an index was calculated. If the index was < 0.5 the RA was left unharvested.

5. SUBJECTIVE SYMPTOM ASSESSMENT

In Study IV patients completed a questionnaire concerning symptoms in the forearm and hand. The specific questions asked were: sensation of the thumb, sensation of the ring finger, mobility of the fingers, sensation of the forearm, exercise tolerance of the hand and cold tolerance of the hand. Each question was answered on a five-point scale where one represented poor and five represented excellent. The questionnaire was completed preoperatively and six months postoperatively.

6. SURGICAL TECHNIQUE IN STUDY IV

The RA was harvested with its concomitant veins using Harmonic scalpel scissors (Ethicon Endo-Surgery Inc, Cincinnati, Ohio, USA). After full heparinisation (3mg/kg) the distal end was ligated and divided, the artery was rinsed with papaverin solution and left in the wound. The proximal end was divided just before anastomosing. The wound was closed in two layers, subcutaneous tissue with running resorbable 3-0 monofilament suture and skin with running resorbable intracutaneous 4-0 monofilament suture.
7. STATISTICAL METHODS

Statistical analysis was performed using Student’s t-test for parametric data and Fisher’s exact test for categorical data. Significance for paired proportions was tested using McNemar’s test. Two-tailed P-value < 0.05 was considered statistically significant and confidence intervals were calculated at 95% significance level. All analyses were performed using SPSS software (versions 15.0 and 16.0).
RESULTS

1. THE ALLEN TEST

Positive AT was found in 33 patients in the Tampere population (23%). In one patient no AT was performed. Ultrasonographic studies identified 40 patients (27.5%) with contraindications for RA harvest. Morphologic causes were found in ten patients (6.9%) and circulatory cause in 17 patients (11.7%). In addition, thirteen patients (9.0%) had several contraindications. Small RAs were few, only six patients had inner diameter less than 2 mm. Intimal calcification was seen in 12 patients and media sclerosis in seven patients. Changes in the finger pressures during RAC were significant in all fingers. Pressure decline greater than 40% in the thumb was seen in 33 patients and 19 of them had zero pressure during RAC. Positive AT compared with abnormal findings in subjective metric studies gave good specificity and sensitivity, 97.1% and 73.2% respectively. In the Vaasa population the incidence of positive AT was much lower, as only ten patients had positive AT (11%).

2. ABNORMAL FINDINGS IN SUPRA-AORTIC VESSELS

Among the 33 patients with contraindications for RA harvest in the non-dominant hand there were 24 patients (73%) with a contraindication for RA harvest in the dominant hand as well. The control group consisted of 12 patients with harvestable RA in the non-dominant hand. Only three of them (33%) had a contraindication in their dominant hand. Different contraindications were analysed separately to
The carotid and forearm arteries stand in close relation to each other due to their common origin. Besides their origin, Study III revealed that these vessels

<table>
<thead>
<tr>
<th>Contraindication</th>
<th>1.</th>
<th>2.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphological</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner distal diameter &lt; 2 mm</td>
<td>67</td>
<td>8</td>
<td>1.000</td>
</tr>
<tr>
<td>Inner proximal diameter &lt;2 mm</td>
<td>25</td>
<td>0</td>
<td>0.250</td>
</tr>
<tr>
<td>Intimal calcification</td>
<td>26</td>
<td>3</td>
<td>1.000</td>
</tr>
<tr>
<td>Sclerosis of the media</td>
<td>71</td>
<td>4</td>
<td>1.000</td>
</tr>
<tr>
<td>Anomaly</td>
<td>0</td>
<td>3</td>
<td>1.000</td>
</tr>
<tr>
<td>Morphological combined</td>
<td>70</td>
<td>15</td>
<td>0.289</td>
</tr>
<tr>
<td>Circulatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absence of reverse flow</td>
<td>29</td>
<td>7</td>
<td>0.289</td>
</tr>
<tr>
<td>&lt;20% increase of ulnar PSV</td>
<td>0</td>
<td>16</td>
<td>0.688</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig I)</td>
<td>59</td>
<td>22</td>
<td>0.065</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig II)</td>
<td>47</td>
<td>0</td>
<td>0.002</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig III)</td>
<td>63</td>
<td>0</td>
<td>0.031</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig IV)</td>
<td>90</td>
<td>0</td>
<td>1.000</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig V)</td>
<td>62</td>
<td>13</td>
<td>0.453</td>
</tr>
<tr>
<td>Circulatory combined</td>
<td>70</td>
<td>17</td>
<td>0.039</td>
</tr>
</tbody>
</table>

1. % of patients with bilateral contraindication
2. % of patients with contraindication in dominant hand only

find out if some of them could be used to predict the status of the other RA but no such connection could be found (Table 3).
share a susceptibility to atherosclerotic disease. Among 85 patients 11 (12.9%) had pathologic changes in their forearm arteries. Surprisingly the UA was more affected than the RA, as nine patients out of 11 had either intimal calcification or media sclerosis in their UA. Changes in the RA were confined to six patients. In four patients both arteries were involved. Atherosclerotic involvement in the carotid arteries was found in 19 patients. Thirteen patients had bilateral changes and six patients on the left side only. None of the patients had isolated right-sided carotid disease. The concurrence of the forearm and carotid artery pathology is summarised in Table 4.

Table 4.

_Ultrasonographic findings in patients with forearm artery pathology_

<table>
<thead>
<tr>
<th>Nr</th>
<th>Radial artery</th>
<th>Ulnar artery</th>
<th>Carotid arteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calcification</td>
<td>Calcification</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Calcification</td>
<td>Calcification</td>
<td>Mild stenosis in left</td>
</tr>
<tr>
<td>3</td>
<td>Calcification + sclerosis</td>
<td>Calcification + sclerosis</td>
<td>Mild stenosis in both</td>
</tr>
<tr>
<td>4</td>
<td>Calcification + sclerosis</td>
<td>Calcification + sclerosis</td>
<td>Total occlusion of right, significant of left</td>
</tr>
<tr>
<td>5</td>
<td>Sclerosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sclerosis</td>
<td></td>
<td>Significant stenosis in both</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Sclerosis</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Sclerosis</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Calcification</td>
<td></td>
<td>Mild stenosis in both</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Calcification</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Calcification</td>
<td></td>
</tr>
</tbody>
</table>

Mild stenosis 1-15%, significant 50-75%, total occlusion 100%
Occurrence of atherosclerosis in forearm arteries is associated with increased risk of having atherosclerotic carotid disease. When there was isolated RA involvement in the forearm the risk of carotid changes was eightfold and with isolated UA involvement sevenfold (Table 5).

Table 5. Results of statistical analysis. Correlation between forearm vessel pathology and carotid artery pathology.

<table>
<thead>
<tr>
<th>Disease in both UA and RA</th>
<th>P value</th>
<th>Odds ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial artery disease</td>
<td>.021</td>
<td>8.5</td>
<td>1.42 – 51.0</td>
</tr>
<tr>
<td>Ulnar artery disease</td>
<td>.012</td>
<td>7.5</td>
<td>1.60 – 35.1</td>
</tr>
<tr>
<td>Disease in both UA and RA</td>
<td>.013</td>
<td>5.6</td>
<td>1.49 – 21.3</td>
</tr>
</tbody>
</table>

CI, confidence interval
3. DECISION-MAKING IN RA HARVEST

Study IV aimed to identify a simple intraoperative method to be used in situations where the only screening method available is the AT. The AT has good specificity and if it is negative it is safe to harvest the RA. The sensitivity of the AT is not as good and despite positive AT the RA may still be harvestable. Preoperative ultrasoundography and pletysmography are decisive. However, at times this may prove difficult. Study IV aimed to identify a simple intraoperative method to be used in situations where only screening method available is the AT and further support for decision-making is needed.

Ten patients had positive AT and their intraoperative index (RA pressure/contralateral RA pressure) was 0.868 (SD 0.136). Seventy patients had negative AT with an intraoperative index of 0.885 (SD 0.109). The difference between the indices was not significant (P .68). Further supplementing of AT with handheld doppler did not winnow out patients with poor intraoperative index (0.892 vs 0.882, P .75). All patients had their intraoperative index > 0.5 and thus had their RA harvested. During follow-up exercise and cold tolerance was subjectively impaired but ischaemic complications did not occur.

Harvest of the RA is a stepwise process which begins with the evaluation of the patient and ends with completed revascularisation. The decisions involved are also made stepwise. Studies I, III and IV follow the flow of decision-making and are summarised in Figure 2.
Figure 2

Decision-making in RA harvest based on the present study and current literature.
1. SCREENING METHODS

Traditionally, the AT has been used to screen RAs to be harvested. It is inexpensive and simple to perform. The AT can easily be done bedside and outside of office hours. The time required for the testing is minimal and no extra resources are needed. However, the AT is a subjective test and therefore dependent on examiner’s experience. It contains several possible biases in addition to subjectivity, such as hyperextension of the hand and hydrostatic pressure of the blood if the hand is not placed at the level of the heart. Furthermore, the measurement does not provide any written document of the result, an aspect that is indeed significant in the current medicolegal climate. For the reasons mentioned above it has been suggested that the AT should be replaced with more objective tests.

Ultrasonography provides means to assess both morphology and flow velocity. Morphologic contraindications to RA harvest include small inner diameter of the RA, pathologic changes in the wall of the vessel and anatomic anomalies. Small inner diameter of the RA may cause present problems in the harvest of the vessel as it may be more susceptible to trauma during handling of the graft. Other problems can be anticipated while performing the anastomosis. A small RA cannot be detected with the AT. However, small size itself is not an absolute contraindication if the above-mentioned problems can be overcome. On the contrary, small size can be an advantage in the longer perspective as the lack of discrepancy in size may enhance patency.

Pathologic changes in the wall of the artery may compromise the use of the RA. Calcifications of the intima are associated with atherosclerosis, and thus may
lead to poor patency of the graft. The role of medial calcifications or sclerosis of
the media in the development of atherosclerotic plaques in the RA is not as well
defined as the intimal calcifications. In practice, these two are difficult to distin-
guish in the ultrasonographic examination. Nonetheless, the distribution of the
pathology can be estimated. In theory, intravascular ultrasonography would pro-
vide a superb tool for this estimation but the cost may be too high as in the worst
case it may compromise the whole graft. Insignificant changes without luminal
compromise do not necessarily preclude the use of RA. Wall pathology cannot be
recognised with the AT but it can be suspected in patients with co-morbidities like
diabetes mellitus or PVD. In diabetics and patients with PVD ultrasonography
should be considered in addition to the AT.

Anatomic anomalies present a problem that cannot be solved without objec-
tive measures like ultrasonography or angiography. Angiography is invasive and
carries a risk of complications whereas ultrasonography is virtually harmless to the
patient. The AT gives no indication of anatomic variations, especially in the arm
region. Mercifully these anomalies are rare and seldom pose a problem when the
RA is considered as a graft.

Adequate collaterals between the RA and the UA are required for the safe
harvest of the RA. The collateral network is complex and subject to considerable
variation. The only direct method to assess the collaterals on a living subject is
angiography. It is a costly and invasive procedure associated with a risk of compli-
cations. The collateral network can be assessed indirectly by studying the circula-
tory changes in the hand during RAC. During RAC the circulation of the hand
is dependent upon the UA or on the UA and the median artery if such exists.
When the arterial supply of the RA is cut off the UA has to supply a consider-
ably larger vascular bed. The flow in UA has to increase to supply the increased
demand. Within the immediate period the flow in the vessel can be increased only
by accelerating the current. PSV in the UA measured with ultrasonography should
increase by 20% during RAC as a sign of a larger vascular bed.

Another indirect measure of the collateral network is digital blood flow, which
can be measured either by visualising the digital arteries with ultrasonography or
by measuring the blood pressure of the fingers. Although such studies have been
performed, the digital arteries are small and their reliable visualisation may prove difficult, especially if additional manoeuvres such as RAC are planned (Pola et al. 1996). Pletysmography provides a reproducible method to measure finger pressures which in turn can be used to interpret the flow in the measured fingers. At the time of RAC blood flow in the fingers decreases and the measurable blood pressure drops. This effect is more pronounced in the radial fingers as their principal arterial support is based on the RA. A moderate pressure drop is acceptable in the immediate phase. Earlier studies have set a 40% pressure decrease in any finger as a contraindication for RA harvest. Pressure decrease of the thumb should be considered with care. The present study indicates that if the pressure drops to zero in the thumb during RAC it should be considered an absolute contraindication. Lack of reverse flow in the RA stump during RAC is a substantially parallel situation to absence of pressure of the thumb. In that case the collaterals are insufficient to support the lateral aspect of the hand and there is no back flow in the RA.

Persistent median artery and dominating superficial dorsal branch of the RA with high onset can lead to false negative results with the given methods if the pressure during RAC is applied too distally. The AT, ultrasonography and pletysmography are equally affected by these anatomic variations. The median artery is present in 5-21% of cases but not all of them are involved in the palmar arches as some of them terminate at the level of the wrist. The superficial dorsal branch of the RA is the main connection in SPA between the RA and the UA in 18% of cases but not all of them have high onset (Loukas et al. 2005, Ruengsakulrach et al. 2001b). Screening the whole length of the RA with ultrasonography and adding local extra compression to the presumed median artery during RAC has been suggested to overcome these shortcomings (Ruengsakulrach et al. 2001a).

The AT has some obvious limitations and it has been criticized for not being reliable enough. Some reports strongly suggest that it should be replaced with more objective examinations (Jarvis et al. 2000, Agrifoglio et al. 2005). However, as pointed out above, even the most sophisticated metric studies have their limitations. The ultrasonographic evaluation in combination with pletysmography of the fingers is to be regarded as a gold standard but the full range of studies is both time consuming and expensive. In the present study the AT had a specificity of 97.1%.
Contraindications detected with ultrasonography only raised specificity slightly up to 97.6%. Similar rates have been reported in earlier studies (Ruengsakulrach et al. 2001c, Jarvis et al. 2000). Advocates of more objective studies refer to cases where an ischaemic complication occurred after RA harvest and the AT was normal (Kochi et al. 2003). Complications have occurred even after ultrasonographic examination (Manabe et al. 2002). To get cast-iron certainty that ischaemic complications are not going to happen one should have a test with no false negative results. In other words the test should have a specificity of 100%. No such test is available. Based on the current results the AT is a good and valid screening test of RAs to be harvested. If it is negative it is safe to harvest the RA. In selected cases, like patients with diabetes mellitus or PVD it is advisable to perform ultrasonography preoperatively even when the patient has a negative AT as these patients are more prone to vessel wall pathology even in the forearm arteries.

The sensitivity of the AT was 73.2% when all contraindications found in ultrasonographic and pletysmographic examinations were taken into account. Out of the individual contraindications zero pressure in the thumb during RAC reached best sensitivity, 89.2%. Therefore, a positive AT does not signify a non-harvestable RA. In the light of the present study lack of reverse flow in the RA during RAC and pressure of the thumb are the best available indirect indicators of adequate collateral network of the hand. This is moreover supported by an earlier study (Ruengsakulrach et al. 2001c). In case of a negative AT further examinations are recommended, either pletysmography of the thumb or ultrasonography for reverse flow of the RA during RAC.

Ideally, screening of the RA is performed preoperatively, well in advance. This would enable optimal planning of the revascularisation strategy. However, the proportion of acute and emergency cases among CABG patients has increased to half of all patients and they may present at any hour. Ultrasonography and pletysmography are available only during office hours and entail advance reservation. Other screening methods should be available if the AT is positive and ultrasonography and pletysmography are unavailable. Regarding emergency cases such a method needs to be easy to perform and it should not delay the treatment. Intraoperative
pressure measurement of the RA stump during RAC would be such a method as it is analogue to reverse flow in RA and should reveal collaterals in the hand.

Some other methods have been suggested for intraoperative screening (Roberts et al. 2002, Birdi and Ritchie 2002). They require either opening of the RA or more extensive surgical exposure. Cannulation of the RA with a 24-gauge needle is a fairly atraumatic procedure compared to transverse arteriotomy. Pressure measurement also provides numeric values to lean on in decision-making. The present study could not demonstrate a significant relation between the AT and the pressure index in the intraoperative pressure measurement. During the follow-up ischaemic complications did not occur for up to six months. Therefore it seems safe to harvest the RA if the stump pressure in the RA is at least 50% of the contralateral radial pressure.

2. DISTRIBUTION OF ATHEROSCLEROTIC DISEASE AND CONTRAINDICATIONS FOR RA HARVEST

Contraindications for RA harvest have been found to be present in 7.5 – 27.1% of patients in earlier series. In our own series the prevalence was 27.7%. The morphology and pathology of the RAs within the same individual has been studied earlier. Doscher found that hand dominance has no significance for vessel size or flow although they may vary within individual subjects (Doscher et al. 1983). In a series of 244 patients 43 patients (15%) underwent ultrasonography of the left forearm due to positive AT. Five patients had findings that prevented the harvest of RA. These patients had their right arm scanned as well and in two patients the findings were bilateral. In both cases there was stenosis of the RA bilaterally (Abu-Omar et al. 2004). To the best of the author’s knowledge this is the only study reporting the intra-individual distribution of contraindications for RA harvest in addition to the present series.

The present study showed that the risk for contraindication in the contralateral arm is increased when evidence that the RA should be left unharvested is found in the non-dominant arm. The risk of having contraindication in the dominant
arm is at least double compared to that of patients with harvestable RA in the non-dominant arm. Not a single contraindication predicting the connection could be found. Body size and thus the vessel size affect both arms in equal manner. Likewise, atherosclerosis is a systemic disease and none of the RAs is spared. Circulatory contraindications like absence of reverse flow or low pressure in the thumb during RAC are dependent on the collateral network between the RA and the UA. Supposedly the collateral network is subject to a greater variation than vessel size or atherosclerotic affection.

When atherosclerotic disease becomes clinically evident apparent as in patients with CAD requiring invasive treatment it is unlikely that the disease is confined to one location only. The connection between CAD and carotid artery atherosclerosis is well established in clinical studies as well as in autopsy observations (Craven et al. 1990). Furthermore, patients with CAD have lower ankle-brachial indices as a marker of PVD. The severity of CAD is reflected in other arterial locations. Patients with left main CAD have lowest ankle-brachial indices and highest prevalence of carotid stenosis. Interestingly, stenosis of the subclavian artery does not seem to be affected by CAD (Doonan et al. 2007, Shadman et al. 2004). The approach to coronary surgery is affected in many respects by the atherosclerotic involvement in the supra-aortic vessels. Carotid artery stenosis is known to increase the operative risk and atherosclerotic changes in the RAs may compromise their use as grafts.

The relation of atherosclerosis in the forearm arteries to carotid artery atherosclerosis has been unclear. The opposite relation has been demonstrated earlier (Ruengsakulrach et al. 2001d). Patients with carotid stenosis run an increased risk of having RA atherosclerosis as well. The present study shows very clearly that atherosclerosis of the forearm arteries is related to carotid artery disease. The relation is evident even though the patients in the series are young. In this study, age itself, smoking and diabetes mellitus did not have any association with the atherosclerotic changes. Most probably, in these cases the genetic predisposition for the atherosclerotic disease is so dominant that other acquired factors play a minor role and in fact are overruled by the hereditary factors. Atherosclerotic changes in the RA are more clearly correlated to carotid changes. This may be dependent on the
fact that the RA is exposed to heavier shear stress in the forearm and thus more prone to intimal trauma leading to the development of atherosclerotic plaques.

Coronary surgery has faced new challenges in the last few years. The requirements for better results have increased the need of preoperative examinations. The novel information of a correlation between forearm artery atherosclerosis and carotid artery stenosis can be utilised in the patient screening. If the patient is scheduled for CABG and the forearm arteries, especially the RA, are scanned with ultrasonography for grafting purposes and atherosclerotic changes are detected in the vessel wall, there is a high risk that the patient will also have similar changes in their carotid arteries. Further screening of the carotid arteries with ultrasonography should be considered. In many cases the changes even when found will not lead to any measures. On some occasions there may be significant stenosis that has to be taken into account when planning the operative strategy. As some of the significant changes in the carotid arteries can be asymptomatic and thus go undetected some patients may benefit from the new information and protective measures can be taken.

3. SYMPTOMS AFTER RA PROCUREMENT

The RA is often utilized in younger patients who are still of working age. Coronary surgery aims to restore and maintain their working capacity. Study IV included a follow-up which revealed that the RA harvest seldom affected patients’ daily functioning. Sensory and motoric symptoms are mild. Cold and exercise tolerance is significantly impaired after surgery but the impairment is slight, often only one step in a five-graded scale. In the light of current study, it is unlikely that the return to the former occupation is endangered by the RA harvest. This may became an issue for patients performing heavy manual labour especially if the work is performed outdoors. Therefore patients should be aware of such a possibility even if it is considered remote.
4. METHODOLOGICAL CONSIDERATIONS

The material in Studies I – III is comprehensive and the ultrasonographic and pletysmographic studies were performed dependably. The number of missing variables is insignificant. There was no need to exclude patients from the series due to inadequate data in Study I. The number of subjects was satisfactory and the results give adequate support to the conclusions reached.

Study II would have benefited from a larger number of control patients as this would have given more support to the results, but the bilateral scanning of the arms was limited to the initial phase of the study. Later on the examinations were guided by clinical guidelines which at the time seldom required bilateral scanning.

Study III has similar limitations. The number of patients which underwent scanning of the carotid arteries could be higher, even though these patients were scanned at the beginning of the series. The full procedure with bilateral ultrasonography of the arm arteries, pletysmography of the fingers and ultrasonography of the carotid, vertebral and subclavian arteries is costly and laborious. It was considered to be too heavy on practical grounds only and the study was performed alongside clinical routine. Even so the results of Study III are convincing.

The number of patients emerges even in Study IV as a limiting factor. The missing data indicates deficiencies in the collection of the material. Comprehensive material would have increased the value of the study. In the initial phase the pressure measurement proved difficult and a proper method was found only after several experiments. A pilot study would have solved some of the issues mentioned. As such, the results give only limited support to the conclusions reached.
SUMMARY AND CONCLUSIONS

The RA is a usable graft in CABG and should be preferred over SVG in younger patients. Due to its location and function preoperative screening is essential to avoid ischaemic complications of the hand. Traditionally the AT has been used in this respect but it has been challenged for being too subjective. However, even the best objective studies have their shortcomings and a conclusive method is yet to be found. The atherosclerotic involvement of the supra-aortic arteries and their off-springs has a prominent role in coronary surgery and the different sites of the atherosclerotic predilection have a reciprocal relationship.

The following conclusions can be drawn from the present study:

1. The Allen test has a good specificity rate and fairly good sensitivity rate. It can be used as a screening tool when the RAs are screened for grafting purposes in CABG. When the AT is negative it is safe to harvest the RA. In diabetics and patients with PVD preoperative ultrasonography is to be considered to detect significant pathology in the vessel wall. A positive AT is not synonymous with a non-harvestable RA. A further examination with ultrasonography or pletysmography is recommended.

2. When a contraindication for the RA harvest in the non-dominant hand is evident in the ultrasonographic or pletysmographic examination, the risk that there is contraindication in the dominant hand is clearly increased.
3. Forearm artery atherosclerosis is a clear indicator of carotid artery atherosclerosis in a young patient population with CAD. This information can be used in patient screening. When atherosclerosis of the forearm arteries is evident in the ultrasonographic examination, prior coronary surgery screening of the carotid arteries should be considered.

4. Intraoperative pressure measurement may be useful in situations when the AT is positive and no other objective screening methods are available. If the stump pressure in the RA to be harvested is more than 50% of the contralateral RA pressure it seems safe to harvest the RA.
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REFERENCES


Is the Allen test reliable enough?

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Abstract

Objective: The Allen test is a widely used screening method of hand circulation. Our aim was to study whether the Allen test alone gives sufficient information for harvesting the radial artery in coronary artery bypass grafting. Methods: One hundred and forty-five patients scheduled for coronary artery bypass grafting underwent the Allen test, upper arm Doppler ultrasonography and digital plethysmography. In ultrasonography both anatomical and circulatory measurements were performed. The Allen test was then compared with more objective tests and sensitivity; specificity and diagnostic accuracy were calculated. Results: Most of the patients had a negative Allen test, but 23% were positive (abnormal). Ultrasound scanning revealed anatomical anomalies in 10 patients and circulatory deficits in 17 patients. Thirteen patients had both circulatory and anatomical abnormalities. Sensitivity of the Allen test was 73.2% and specificity 97.1% based on our findings. There were no abnormalities in the recovery of the arms with harvested radial grafts. Conclusions: The Allen test is a good and valid screening test for the circulation of the hand. If the Allen test is negative it is safe to harvest the radial artery. If it is positive further examinations are needed to ensure safe harvesting of the radial artery.

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Keywords: Radial artery; Coronary artery bypass grafting; Ultrasonography; Allen test

1. Introduction

Radial artery as a conduit for coronary artery bypass grafting (CABG) was introduced by Carpentier et al. [1]. It was abandoned relatively soon after because of problems in early patency [2]. A new interest in the radial artery in coronary surgery came with the concept of total arterial revascularisation. The radial artery is the second major artery to the hand and in order to avoid ischaemic complications it is important to reliably assess the circulation before harvesting it. Traditionally this has been done with the Allen test which was described by Edgar V. Allen in 1929 [3]. The Allen test, albeit being cheap and simple, has been criticised for being too unreliable and subjective, even to a degree that it should be abandoned in favour of more objective tests [4].

The circulation of the hand is supported by two main arteries, ulnar artery and radial artery. Some individuals have even a third, or median, artery supporting the hand. These arteries form several collaterals in the hand which makes the harvest of the radial artery possible without compromising the circulation [5]. Sufficient circulation to the hand can be endangered in situations with lack of palmar collaterals, absent or insufficient ulnar artery or sclerotic changes within the supra-aortic, brachial or antebrachial vessels if the radial artery is sacrificed. For reasons mentioned above 7.5—27.1% of the radial arteries are not suitable for harvesting [6,7].

Our aim was to study whether the Allen test alone is a reliable screening method before harvest of the radial artery regarding sensitivity, specificity and diagnostic accuracy.

2. Material and methods

Between October 2000 and April 2005, 145 patients were enrolled in this study. Subjects were considered for CABG with a possible use of radial artery as a graft. Emergency cases and patients older than 60 years were excluded. Mean age was 52.0 years (SD 5.7). Male gender was predominant (130 vs 15) and most of the patients were right handed (136 vs 9). Patients underwent the Allen test, Doppler ultrasonography and digital plethysmography. All tests were performed by the same examining physician in the laboratory of clinical physiology. The non-dominant arm was studied and if there were contraindications for the harvest of radial artery, the dominant arm was also tested. Only non-dominant arms were included in this study. Patients were advised not to
smoke or consume caffeine 3 h prior to the examination. Dipyridamole was prohibited on the day of examination.

The Allen test was performed by asking the subject to clench his fist for 1 min while both radial and ulnar arteries were compressed with the examiner’s fingers. The wrist was held at the level of the heart and extension was avoided. The ulnar artery was then released and the time that elapsed between the release and the recovery of normal pallor of the thumb and thenar area was recorded. Cut-off point was determined at 6 s. A positive test was reported when there was abnormality in the capillary filling of the fingers in 6 s.

Biplane ultrasonography was performed to assess calcification, sclerosis of the media and anomalies. The inner diameters of the radial and ulnar arteries were measured both distally and proximally. A transducer with emission frequency between 5 and 10 MHz was used, based on best visibility (Aloka, Pro Sound 5500). The harvest of the radial artery was contraindicated when diffuse intimal or medial calcification was present, when inner diameter of the radial artery was less than 2 mm or an anomaly, such as high bifurcation of the brachial artery or hypoplasia of the radial or ulnar artery, was seen. Circulatory measurements with Doppler ultrasonography included peak systolic velocity (PSV) and end diastolic velocity (EDV) of both radial and ulnar artery. A resistance index was calculated (PSV-EDV/PSV) and end diastolic velocity (EDV) of both radial and ulnar artery. A resistance index was calculated (PSV-EDV/PSV). These measurements were repeated on the ulnar artery while the radial artery was compressed. During radial compression the distal part of the radial artery was controlled for reverse flow. An absence of reverse flow in the distal part of the radial artery was less than 2 mm or an anomaly, such as high bifurcation level, e.g. within the proximal third of the artery was contraindicated when diffuse intimal or medial calcification was present, when inner diameter of the radial artery was less than 2 mm or an anomaly, such as high bifurcation of the brachial artery or hypoplasia of the radial or ulnar artery, was seen. Circulatory measurements with Doppler ultrasonography included peak systolic velocity (PSV) and end diastolic velocity (EDV) of both radial and ulnar artery. A resistance index was calculated (PSV-EDV/PSV). These measurements were repeated on the ulnar artery while the radial artery was compressed. During radial compression the distal part of the radial artery was controlled for reverse flow. An absence of reverse flow in the radial artery and an increase of ulnar PSV less than 20% were interpreted as abnormal findings and were considered as contraindications for radial artery harvest [6,7].

Digital plethysmography (Finapress) was performed on every digit both at rest and during radial compression. A 40% decrease in systolic pressure in any digit was considered abnormal and was a contraindication for harvest [6].

Statistical analysis was performed by using SPSS 15.0 software.

3. Results

Seventy-seven percent of patients had a negative Allen test (111/144), while 23% were positive (i.e. abnormal). On one patient the Allen test was not performed, but other measurements were carried out. Proximal inner diameter of the radial artery was 3.06 ± 0.63 mm (range 1.2–5.3) and distal inner diameter was 2.6 ± 0.46 mm (0.9–3.06). Ulnar artery was proximally 3.25 ± 0.72 mm (1.3–5.8) and distally 2.39 ± 0.49 mm (1.0–3.5), respectively. In six patients (4.1%) the inner diameter of the radial artery was less than 2 mm. There were more ulnar arteries with small calibres as 27 patients (18.6%) had smaller vessel than 2 mm. The brachial bifurcation level, e.g. within the proximal third of the antebrachium, was normal in 96.6% of the patients (140/145).

Changes of flow velocity and resistance index in ulnar artery between rest and radial compression are summarised in Table 1. All changes in flow velocities were significant. In eight patients the increase of ulnar PSV was less than 20%. Reverse flow on distal radial artery during radial compression was present in 122 patients. Intimal calcification in radial artery was found in 12 patients and on ulnar artery in 13 patients. Sclerosis of the media was seen on seven patients’ radial artery and on six ulnar arteries.

Ultrasonography Doppler studies showed that 10 patients had anatomical anomalies, 17 patients had circulatory deficits and 13 patients had both anatomical and circulatory abnormal findings. Altogether 40 patients had ultrasonogram scanning, suggesting that the radial artery should be left untouched.

Digital plethysmography showed significant changes in digital pressures between rest and radial compression. These are summarised in Table 2. Thirty-three patients had a 40% decrease on digital pressure in thumb, 19 of these (13.1%) had zero pressure. Corresponding figures for the fifth finger are 25 and 15 (10.3%), respectively.

Based on the findings of the Allen test, Doppler ultrasonography and plethysmography we calculated that the Allen test has a sensitivity of 73.2% and a specificity of 97.1%. Positive Allen tests were compared against abnormal findings in Doppler ultrasonography (absence of reverse flow, lack of sufficient increase in ulnar PSV, intimal or medial calcification, anomaly) and plethysmography (decrease of digital pressure more than 40%). Positive predictive value is 90.9% and negative predictive value 90.1%, and therefore a diagnostic accuracy of 90.3%. When the Allen test is compared to zero digital pressure of the thumb we received positive predictive value of 57.6% and negative predictive value of 98.2%. This comparison also gives the highest sensitivity, 89.2%, among the different single-parameter analysis. We had no ischaemic complications in the arms of the patients with harvested radial artery during hospital stay.

4. Discussion

The use of the radial artery as a conduit for coronary bypass grafting is a routine procedure today. Ischaemic complications associated with the harvest of radial artery are rare but they have been reported [8]. On a single patient such...
a complication is disastrous and should be avoided. There has been a debate whether the Allen test is a sufficient screening method to exclude patients with possibly compromised hand circulation.

There are several reasons for insufficient ulnar hand circulation. The collaterals between the radial artery and the ulnar artery are several. Altogether there are four arches, two in the carpal area and two in the palmar area. The palmar arches, superficial and deep, are especially important. They have been studied in detail in several cadaver studies [5,9]. Although there is considerable variation between the reported results, it is important to notice that the superficial and deep arch support each other in majority of cases, and thus, create a safety marginal.

The Allen test is a clinical test and, as such, a subjective measure, which contains several possible biases. It tells us nothing about the vascular anatomy of the hand, only the functional circulatory status which is interpreted by the examiner, whose interpretation is based on experience that may vary considerably. A false-negative result may be due to inadequate compression of the radial artery and false-positive result may be due to extension of the wrist. Furthermore, there is no consensus regarding the cut-off point which may vary between 3 and 10 s. We chose to set the cut-off point to 6 s as a compromise between absolute sensitivity and specificity.

Jarvis et al. [4] studied 93 hands in 47 patients with Doppler ultrasonography and the Allen test to examine the overall reliability of the Allen test and determine the optimal cut-off point. They found that diagnostic accuracy was maximal at 5 s cut-off point, being 79.6%. Sensitivity and specificity were 75.8% and 81.7%, respectively. Sensitivity was at its peak level at 3 s (100%), but diagnostic accuracy was only 52% and specificity decreased to 27%. The authors concluded that the Allen test is unreliable and should be substituted with more objective tests.

Ruengsakulrach et al. [10] used a 10 s cut-off point and studied 71 patients with the Allen test, Doppler ultrasonography dynamic test and biplane for evaluation of the anatomy. Diagnostic accuracy was 97.2% when compared to ultrasonography regarding the flow in thumb artery. The absence of flow in thumb artery was considered as a contraindication for harvest of radial artery. Sensitivity and specificity were 100% and 97.1%, respectively. Other parameters, namely flow of the superficial palmar arch and flow of the ulnar artery, were not as reliable as the flow of thumb artery. The authors concluded that the Allen test is a valid screening method and that the use of ultrasound in conjunction with the Allen test permits safe harvest of the radial artery.

Earlier ultrasonography studies have shown that collateral circulation is insufficient in 10–23% of cases where radial artery is considered for harvesting [6]. Our own study showed that 27.7% (40/145) of patients had anatomical variations, pathologic changes or abnormal circulatory findings that would have made the harvest of radial artery questionable. Their radial arteries were left untouched.

There are multiple anatomical variations that unable the use of radial artery. A small diameter may carry problems in harvesting and in anastomosis technique. Also medial or intimal calcification can cause problems which may lead to a poorer patency or graft failure. Hypoplasia of ulnar artery is rare but does exist. In our material one patient had a hypoplastic and one had occluded ulnar artery. In 6.8% of cases there was anatomical contraindication for radial artery harvest.

Anatomy of the radial or ulnar artery per se is seldom a reason why radial artery is not suitable for harvesting. More often there is a circulatory deficit which can be measured as insufficient increase of ulnar flow, absence of reverse flow in radial stump or as a loss of blood pressure in digits. In our study 11.7% patients had a circulatory contraindication for radial artery harvest. Anatomical and circulatory changes often correlate which each other and 9% of our patients had both anatomical and circulatory contraindications.

Circulation to the hand is secured if there is adequate collateral circulation between radial and ulnar arteries and the ulnar artery is able to respond to the increased demand. If these two prerequisites are met there should be sufficient circulation to the hand to ensure safe harvest of the radial artery. Adequate collaterals are difficult to point out except with angiography, which is impractical. Ulnar response can be measured with Doppler scanning as we have done. The functional circulatory status after radial artery harvest can be measured as blood pressure in digits or as flow digital arteries. We chose to measure blood pressure as this is easily done with plethysmography. During radial compression pressure of the thumb decreased to zero in 13.1% of the patients, which suggests radial dominance. Earlier on, this has been reported in 26–28% of patients [11].

We compared the Allen test with Doppler ultrasonography and plethysmography and found that the negative Allen test correlates well with sufficient circulation in the hand after radial artery harvest. Specificity rate was 97.1% at 6 s cut-off point. Sensitivity was 73.1%; therefore it is possible that the radial artery is harvestable even if the Allen test is positive. If the Allen test is positive or there is suspicion of pathologic changes in arterial wall of radial artery, as it can in diabetes or in arteriosclerotic disease we recommend plethysmography and Doppler ultrasound scanning preoperatively.

Contraindications as outlined in the section 2 are summarised in Table 3. We regard them as valid contraindications; however, none of them is absolute. In our study we found that zero pressure in thumb during radial artery compression is a marker of significantly reduced circulation of the hand and as such an absolute contraindication for radial artery harvest.

<table>
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<th>Doppler ultrasonography</th>
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<tr>
<td>Morphological</td>
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<tr>
<td>Inner diameter &lt; 2 mm</td>
</tr>
<tr>
<td>Diffuse intimal or medial calcification</td>
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<tr>
<td>Anatomical anomaly</td>
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<td>Circulatory</td>
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<tr>
<td>Absence of reverse flow in radial artery during RAC</td>
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<td>&lt;20% increase of ulnar PSV during RAC</td>
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<th>Plethysmography</th>
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<td>&gt;40% decrease in digital pressure during RAC</td>
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RAC, radial artery compression.
If the Allen test is positive we recommend preoperative plethysmography and Doppler ultrasonography scanning. Plethysmography, especially of the thumb, should be performed primarily. Correspondingly we recommend these tests if we suspect pathologic changes such as those mentioned above in the arterial wall of radial artery to avoid unnecessary explorations of the radial artery.

We conclude that the Allen test is a good and valid screening test for the circulation of the hand. If the Allen test is negative it is safe to harvest the radial artery. If it is positive further examinations are needed to ensure safe harvesting of the radial artery.

References


Non-harvestable radial artery. A bilateral problem?
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Non-harvestable radial artery. A bilateral problem?

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Abstract

Since radial artery is preferably harvested from a non-dominant hand, our aim was to study whether there are contraindications for radial artery harvest in the dominant hand if the radial artery of the other hand is not suitable for harvesting. Thirty-three patients scheduled to coronary artery bypass grafting with contraindication for radial artery harvest in the non-dominant hand underwent Allen test, upper arm Doppler ultrasonography and digital plethysmography. In ultrasonography, both anatomical and circulatory measurements were performed. Both hands were then compared to each other. Furthermore, twelve control patients without contraindication for radial artery harvest in the non-dominant hand were examined. All 33 patients had contraindication for radial artery harvest in the non-dominant hand. Twenty-four (73%) had contraindication in the dominant hand as well. In terms of morphology, there was no statistically significant difference between the hands but circulatory parameters as a group suggested contraindication. Among controls, four patients (33%) had contraindication in the dominant hand. In the case of a non-harvestable radial artery in a hand there is clearly an increased risk for contraindication for radial artery harvest also in the other hand.

Keywords: Radial artery; Coronary artery bypass grafting; Ultrasonography

1. Introduction

Radial artery is widely utilized as a conduit for coronary artery bypass grafting nowadays. It offers many advantages. It is easy to harvest and handle and its patency rates seem superior to venous grafts [1]. When planning total arterial revascularisation it is considered as a conduit of third choice. Optimal preoperative assessment has been studied in detail earlier [2]. Following guidelines drawn by these studies selection of suitable grafts can be done in a safe manner. Traditionally the non-dominant hand is the first choice for harvest in order to avoid neurological and ischemic complications in the dominant hand. Unfortunately there is contraindication for the harvest of radial artery in 10–27.7% of the cases [3, 4]. The evaluation of the dominant arm becomes necessary, when there are contradictory findings preventing the harvest of radial artery in the non-dominant arm or there is need for two radial artery grafts.

There are several functional reasons preventing the harvest of the radial artery. The artery itself may be too small or it may have intimal or medial calcifications. The circulation of the hand may be dependent on radial artery due to insufficient anastomotic connections between the radial artery and ulnar artery or the ulnar artery may be hypoplastic or absent.

The aim of this study is to find out how the status of the non-dominant arm correlates with the dominant arm and whether the issues leading to non-harvestable radial artery are limited only to the one side of the patient.

2. Material and methods

Between October 2000 and April 2005, 145 patients who were planned for coronary artery bypass grafting (CABG), with a possible use of the radial artery as a conduit, were examined with Doppler ultrasonography and digital plethysmography. Patients older than 60 years and emergency cases were excluded. Forty patients had a contraindication for radial artery harvest in non-dominant arm. Thirty-three patients out of 40 had their dominant arm examined as well. These 33 patients were included in this study as a study group. Seven patients were left unexamined due to practical reasons such as lack of laboratory time. The majority of patients were right-handed (30 vs. 3) males (29 vs. 4). Mean age was 53.2 years (S.D. 5.0). Additionally, there were 12 patients with both arms examined without contraindication for radial artery harvest in the non-dominant hand. These 12 patients were included as a control group. Patient demographics and risk factors are summarised in Table 1.

Morphological findings were assessed with biplane ultrasonography. Inner diameter of both major arteries was measured both distally and proximally. Sclerosis of the media and intimal calcifications were observed as well as...
anatomical anomalies. Circulatory measurements included peak systolic velocity (PSV) and end diastolic velocity (ESV) on both radial and ulnar artery. PSV was recorded again on the ulnar artery while the radial artery was occluded by compression. Furthermore, the distal part of the radial artery was controlled for reverse flow while the proximal part was compressed. Emission frequency of the transducer was between 5 and 10 MHz, based on best visibility (Aloka, Pro Sound 5500).

Digital blood pressures were measured with pletysmography (Finapress) both at rest and during radial artery compression. Contraindications for radial artery harvest based on these examinations are presented in Table 2.

As each non-dominant hand had its own matched control, namely the dominant hand, the statistical significance was analysed by using McNemars test for paired proportions. Comparisons between study group and control group were analysed with Student’s t-test. Analyses were performed using SPSS 15.0 software.

3. Results

All patients in the study group had a contraindication for radial artery harvest in their non-dominant arm. Twelve patients had circulatory parameters that prevented the radial artery harvest; in 11 patients the radial artery wall morphology suggested sclerosis or small diameter and 10 patients had both circulatory and morphological contraindications in their non-dominant arm.

Proximal inner diameter of the radial artery in the non-dominant arm was 3.02±0.90 mm (range 1.2–5.3) and distal inner diameter was 2.4±0.65 mm (range 0.9–3.4). Corresponding figures for the dominant arm were 2.97±0.69 mm (range 0.9–3.9) and 2.39±0.60 mm (range 0.9–3.8). The radial artery was smaller than 2 mm in seven patients on the non-dominant arm and in six patients on the dominant arm. Intimal or medial calcifications were present in 13 patients’ non-dominant radial artery whereas they were present in 11 patients’ dominant arm. Two patients had an anatomical anomaly in the non-dominant arm. The other patient had a high brachial bifurcation level, only 3–4 cm distal to axillary artery and the other patient had a hypoplastic ulnar artery. There was only one anomaly on the dominant arm with a high level of brachial bifurcation.

Seventeen patients failed to present reverse flow in the non-dominant distal radial artery during radial artery compression. In the dominant side there were 10 cases of absent reverse flow. In general, the ulnar arteries responded well to radial artery compression. Mean increase in ulnar PSV was 79.7±50.8% in the non-dominant side and 62.1±48.9% in dominant side. Less than 20% increase in ulnar PSV was seen in two non-dominant arms and in three dominant arms. Pletysmographic examination identified 23 patients with contraindication for radial artery harvest in the non-dominant arm and 16 patients with corresponding situation in the dominant arm.

Proximal inner diameter of the radial artery in the non-dominant arm among control group was 2.92±0.52 mm (range 2.3–3.7) and distal inner diameter was 2.58±0.51 mm (range 2–3.4). Corresponding figures for the dominant arm among controls were 2.85±0.57 mm (range 2.1–3.8) and 2.44±0.39 mm (range 2–2.9). Three patients in the control group had sclerotic changes in the wall of the radial artery in the dominant hand. Two patients had significant drop in blood pressure in pletysmography during radial artery compression. There was no statistically significant difference in vessel size between the groups.

Altogether 24 patients (73%) in the study group had a contraindication for radial artery harvest in their dominant arm. Statistical analysis revealed that there were no significant differences in morphological contraindications. Amongst circulatory contraindication there was dispersion and combining the contraindications there was statistical significance. Results of statistical analysis between the non-dominant and dominant hand among the study group are summarized in Table 3. In the control group there were four patients (33%) with contraindication for radial artery harvest in the dominant hand. Risk of having a non-harvestable radial artery in the dominant hand is doubled when there is a contraindication for radial artery harvest in the non-dominant hand. Risk ratio was calculated to 2.18 (95% confidence interval 1.14–4.14).

---

Table 1
Summary of patient demographics and risk factors

<table>
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<tr>
<th>Study group</th>
<th>Control group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td>Age</td>
<td>53.2 years (S.D. 5.0)</td>
<td>50.5 years (S.D. 5.19)</td>
</tr>
<tr>
<td>Male</td>
<td>29 (88%)</td>
<td>11 (92%)</td>
</tr>
<tr>
<td>Dominant right hand</td>
<td>30 (91%)</td>
<td>10 (83%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>7 (21%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Smoking</td>
<td>17 (52%)</td>
<td>4 (33%)</td>
</tr>
<tr>
<td>Hypertonia</td>
<td>15 (45%)</td>
<td>6 (50%)</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>28 (85%)</td>
<td>10 (83%)</td>
</tr>
</tbody>
</table>

Table 2
Contraindications for radial artery harvest

- Doppler ultrasonography
- Morphological
- Inner diameter <2 mm
- Diffuse intimal or medial calcification
- Anatomical anomaly
- Circulatory
- Absence of reverse flow in radial artery during RAC
- <20% increase of ulnar PSV during RAC
- Pletysmography
- >40% decrease in digital pressure during RAC

Radial artery compression (RAC).
Table 3
Summary of statistical analysis

<table>
<thead>
<tr>
<th>Contraindication</th>
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<th>2</th>
<th>P-value</th>
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</thead>
<tbody>
<tr>
<td>Morphological</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner distal diameter &lt; 2 mm</td>
<td>67</td>
<td>8</td>
<td>1.000</td>
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<tr>
<td>Inner proximal diameter &lt; 2mm</td>
<td>25</td>
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<td>0.250</td>
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<tr>
<td>Intimal calcification</td>
<td>26</td>
<td>3</td>
<td>1.000</td>
</tr>
<tr>
<td>Sclerosis of the media</td>
<td>71</td>
<td>4</td>
<td>1.000</td>
</tr>
<tr>
<td>Anomaly</td>
<td>0</td>
<td>3</td>
<td>1.000</td>
</tr>
<tr>
<td>Morphological combined</td>
<td>70</td>
<td>15</td>
<td>0.289</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Circulatory</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of reverse flow</td>
<td>29</td>
<td>7</td>
<td>0.289</td>
</tr>
<tr>
<td>&lt;20% increase of ulnar PSV</td>
<td>0</td>
<td>16</td>
<td>0.688</td>
</tr>
<tr>
<td>&gt;40% decrease in pressure (dig I)</td>
<td>59</td>
<td>22</td>
<td>0.065</td>
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<tr>
<td>&gt;40% decrease in pressure (dig II)</td>
<td>47</td>
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<td>&gt;40% decrease in pressure (dig III)</td>
<td>63</td>
<td>0</td>
<td>0.031</td>
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<tr>
<td>&gt;40% decrease in pressure (dig IV)</td>
<td>90</td>
<td>0</td>
<td>1.000</td>
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<tr>
<td>&gt;40% decrease in pressure (dig V)</td>
<td>62</td>
<td>13</td>
<td>0.453</td>
</tr>
<tr>
<td>Circulatory combined</td>
<td>70</td>
<td>17</td>
<td>0.039</td>
</tr>
</tbody>
</table>

1, % of patients with bilateral contraindication; 2, % of patients with contraindication in dominant hand only.

4. Discussion

Cardiac surgeons are frequently faced with a problem of positive (i.e. abnormal) Allen test in the non-dominant arm of a patient whose radial artery is planned for harvest. In many cases further examinations with Doppler ultrasound and pletysmography reveal a harvestable graft with appropriate dimensions and sufficient compensatory flow in ulnar artery despite the positive Allen test. Some diseases, like diabetes or atherosclerosis, affect the wall of the vessel and thus compromise the graft. These patients can have negative (i.e. normal) Allen test but non-harvestable radial artery nonetheless. Therefore, in cases where the Allen test is positive (i.e. abnormal) or there is suspicion of vessel wall pathology, Doppler ultrasound and digital pletysmography performed preoperatively is a good screening method which decreases unnecessary explorations of the radial artery during the operation.

To our knowledge, there are only few studies investigating the intra-individual variation of radial arteries. Abu-Omar et al. [5] performed the Allen test for 287 consecutive patients and found 43 patients with positive (i.e. abnormal) Allen test. These patients underwent Doppler ultrasonography. Out of 43, five had abnormal findings in Doppler ultrasonography and went for further scanning of the contralateral arm. Two patients had contraindications for harvest of the radial artery on both arms. This study was confined only to morphological scanning. No data on circulatory parameters were reported.

Dogan et al. [6] have reported their results on the assessment of anatomy of radial artery with computed tomography angiography. Sixteen patients scheduled for CABG were examined and both arms were scanned in all patients. Six patients had contraindications for radial artery harvest, three had calcification on their radial artery and another three had anatomic anomalies. Both arms were scanned but it is not reported which of the arms had contraindications.

Doscher and colleagues [7] studied 200 arms on 100 patients with Doppler ultrasound. Dimensions and flow of the major arteries were measured. They found that hand dominance had no significance in determining the vessel size or flow. There was significant difference between gender both in size and flow.

Morphological contraindications such as small diameter of the radial artery, intimal or medial calcification or anatomic anomaly are dependent either on patient’s anatomy or certain pathologic condition. Size of the artery is related to the body size and is therefore fairly symmetric. Anomalies vary but their number is too low in our material to draw conclusions. Intimal or medial calcifications reflect a systemic disease affecting the wall of the vessel. Both radial arteries are equally exposed to such disease.

Circulatory requirements for radial artery harvest are adequate collaterals between the radial and ulnar artery and sufficient response in ulnar artery flow to meet the increased demand after harvest. Digital blood pressure and reverse flow in distal radial artery during radial artery compression reflect the collateral flow. Collaterals between the two major vessels of the arm are formed by four arches, two in the carpal area and two in the palmar area [8]. There is considerable variation in these connections and partly this variation can be intraindividual. Fulfilment of the second requirement is expressed in increased ulnar PSV. These two requirements are somewhat intertwined: without adequate collaterals the ulnar bed remains unchanged and there will be no increased demand.

Earlier studies have shown that, after careful evaluation, 10–27.7% of the cases have non-harvestable radial arteries. In this study, we found that if the radial artery is, for some reason, non-harvestable in the non-dominant arm, risk that it is non-harvestable in the dominant arm is at least threefold. We anticipated that the morphological contraindications would be better correlated than the circulatory contraindications. If there is morphological contraindication for harvest of the radial artery in the non-dominant arm it is probable that that the condition is symmetrical and there is contraindication on the dominant arm as well. However, if the contraindication is circulatory there is the possibility that collateral circulation is different from side to side and the radial artery may well be harvestable on the dominant side.

We conclude that in the case of non-harvestable radial artery in the non-dominant hand there is clearly an increased risk for contraindication for radial artery harvest in the dominant hand. Analysis of single variables does not reveal a feasible landmark for the decision making whether other radial is available or not.

References


eComment: Is the inner diameter of radial artery reliable for its suitability as a graft?

Authors: Efstratios Apostolakis, Cardiothoracic Surgery Department of University Hospital of Patras, 22500 Rion Patras, Greece; Ioanna Koniari, Dimitrios Dougeni
doi:10.1510/icvts.2007.172569A

According to your study [1], one of the contraindications for radial artery harvesting is its small inner proximal and distal diameter, smaller than 2 mm (Tables 2 and 3 of the above study). This consideration is arbitrary and undocumented. The inner instantaneous diameter of the radial artery is the result of a dynamic and sensitive process, depending on the instantaneous vascular tone respectively. Especially for muscular type arteries such as radial, the vascular tone is very variable. On the contrary, large arteries modify their blood flow by increasing or reducing their internal diameter. Such a flow-dependent dilatation represents a fundamental mechanism that opposes the equivalent neurogenic and myogenic mechanisms that are activated during exercise vasoconstriction; in order to maintain shear stress within physiological levels [2].

Factors such as the environmental temperature, muscular exercise, post-ischemia hyperemia, levels of endogenous or exogenous catecholamines, agonists, and heart failure result from time to time in a continuous variability of the radial diameter and wall thickness/diameter ratio.

Giannattasio et al. [3] demonstrated that congestive heart failure (CHF) is characterized by a reduction in the inner diameter of muscular arteries, which is proportionally related too the severity of the disease. In addition, Boutouyrie et al. [4] reported that the radial artery in hypertensive patients was not dilated but was with a thicker wall, compared to the normotensive population. Thus, the wall cross-sectional area and wall/lumen ratio were markedly increased in hypertensive patients, factors that indicated the normalization of circumferential wall stress.

In conclusion, in patients with coronary artery disease (CAD) and simultaneously left ventricular dysfunction, or with hypertension, the estimation of the inner diameter of the radial artery may lead to false rejection of radial artery suitability as a graft (“false – unsuitable”).

References


Authors: Theo Kofidis, Department of Cardio., Thoracic and Vascular Surgery, National University Hospital, 119074 Singapore; Felix Woitek
doi:10.1510/icvts.2007.172569B

We were reading the study performed by Kohonen et al. [1] with great interest and congratulate the authors for the additional research on radial arteries. The results give us some hints to predict radial artery availability for total arterial revascularization (TAR) once on side is not suitable.

But we want to raise the question: why not perform Doppler in every case, in spite of negative Allen test, for the case that the radial artery is small in caliber and would not be recommendable? Additionally, the Allen test has to be shown to be not always reliable for the assessment of collateral blood supply [2]. First, all patients should have a Doppler study done.

Second, in Caucasian populations elderly patients should be included since they are subject to controversy as to the age limit to perform TAR because of concerns about higher complication rates due to longer operation times, greater invasiveness of the procedure and the limited life expectancy of the cohort [3]. Some centers provide the opportunity for SV Doppler, which is equally crucial [4]. It has been shown that the diameter ratio (or discrepancy) of the graft vs. coronary target affects the long-term patency rate [5]. A Doppler study in every case should be employed to design the individual graft arrangement.

References


Non-harvestable radial artery. A bilateral problem?
Mika Kohonen, Ossi Teerenhovi, Tiina Terho, Jari Laurikka and Matti Tarkka
*Interact CardioVasc Thorac Surg* 2008;7:797-800; originally published online May 9, 2008;
DOI: 10.1510/icvts.2007.172569

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Interactive CardioVascular and Thoracic Surgery
Forearm vessel atherosclerosis. A harbinger of carotid disease?

Mika Kohonen a; Ossi Teerenhovi a; Tiina Terho a; Jari Laurikka a; Matti Tarkka a

a Heart Center, Tampere University Hospital, Finland

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ORIGINAL ARTICLE

Forearm vessel atherosclerosis. A harbinger of carotid disease?

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1Heart Center, Tampere University Hospital, Finland, and 2Department of Clinical Physiology, Tampere University Hospital, Finland.

Abstract

Objectives. Atherosclerosis is a systemic disease affecting several vessels of the body. Coronary artery patients requiring bypass surgery have increased prevalence of carotid artery atherosclerosis which is known to increase operative risk in coronary artery bypass surgery (CABG). Radial artery is often screened for grafting purposes preoperatively. Our aim was to find out whether atherosclerotic changes in forearm vessels are correlated and could reveal risk to carotid artery disease. Design. Eighty-five patients planned for elective CABG were examined with ultrasonography preoperatively. Biplane ultrasonographic scanning was performed on forearm arteries and both carotid arteries. Results. Eleven patients had pathologic changes in the wall of forearm vessels. Carotid artery disease was found on 19 patients. Forearm vessel pathology was found to have correlation to carotid artery disease. When forearm arteries show atherosclerotic pathology the risk of having carotid disease is at least five-fold, in subgroups even higher. Conclusions. Forearm arterial pathology is correlated to carotid artery disease. When forearm vessel pathology is evident in preoperative examination, scanning of the carotid vessels should be considered.

Key words: Radial artery, coronary artery bypass grafting, ultrasonography

Atherosclerosis is a systemic disease affecting often several vessels of the body. One well known site of predilection is coronary arteries and coronary artery disease (CAD) results in approximately 3 300 coronary artery bypass grafting operations (CABG) annually in Finland. Radial artery is frequently used as a bypass graft in these operations.

Atherosclerosis also affects carotid arteries. The correlation between CAD and carotid artery atherosclerosis is well established in earlier studies (1). The carotid vessels are closely related to other supra-aortic vessels which are in direct continuation to the vessels of the forearm. We have earlier studied the usefulness of radial artery as a bypass graft and evaluated the atherosclerotic changes in forearm arteries in subjects planned for CABG (2). To our knowledge there are only few studies indicating the relationship of atherosclerotic changes in the forearm arteries and carotid arteries (3,4).

Our aim with this study was to find whether pathologic changes in the wall of the forearm vessels are correlated to carotid atherosclerosis in patients with coronary artery disease.

Material and methods

Between October 2000 and April 2005, 85 patients planned for elective CAGB were enrolled to this study. Patients older than 60 years and emergency cases were excluded. Mean age of the patients was 52.2 (SD 4.7) years. Male gender was predominant (75 vs. 10). Thirty-five smokers were identified among patients and 20 of all were diabetics. Five of the diabetics were treated with insulin, 15 had oral anti-diabetic medication.

Patients underwent biplane ultrasonographic study of both carotid arteries. Radial and ulnar arteries of the non-dominant forearm were scanned with ultrasonography as well. Calcification of the
intima, sclerosis of the media and vascular anomalies were recorded on all vessels. Doppler ultrasonography was performed with a transducer with emission frequency between 5 and 10 MHz, based on best visibility (Aloka, Pro Sound 5500). Additionally, changes in carotid arteries were classified as follows: no sclerosis, sclerotic changes without stenosis, mild stenosis (1–15%), moderate stenosis (16–49%), significant stenosis (50–75%), severe stenosis (76–99%) and total occlusion.

Correlation between atherosclerotic changes in carotid and forearm vessels was analysed using SPSS 15.0 software.

**Results**

Intimal calcified plaques were found on four patients in radial artery and on seven patients in ulnar artery. On three patients both forearm arteries were found to have intimal calcifications. Two patients had sclerotic changes in the medial layer of both forearm arteries. There were two patients with isolated ulnar sclerosis of the media and two patients with corresponding finding in radial artery. Vessel wall pathology was present on six patients in radial artery and on eight patients in ulnar artery. On three patients there was both radial and ulnar artery engagement. Altogether 11 patients (12.9%) had pathologic changes in the wall of forearm vessels.

Atherosclerotic changes in carotid arteries were found in 13 patients (15.3%) on the right side and in 19 patients (22.4%) on the left side. Thirteen patients (15.3%) had bilateral findings on their carotid arteries on the ultrasonographic scanning. Carotid disease was either bilateral or isolated to the left side. There were no patients with isolated right sided carotid disease. Ultrasonographic findings on patients with forearm and carotid artery pathology are summarised in Table I.

Smoking and diabetes had no statistically significant correlation neither to forearm vessel or carotid pathology. Results of risk factor analysis are summarised in Table II. Age did not have any correlation either. However, there was correlation between forearm vessel pathology and carotid atherosclerosis. When pathologic changes in forearm vessels were evident the risk of having carotid atherosclerosis was at least five fold. If these the changes were confined to radial artery only the correlation was even stronger. Statistical significance was found in both cases. Same is true even in isolated cases of ulnar involvement. Results of statistical analysis are summarised in Table III.

**Discussion**

Radial artery is often used as a bypass conduit in coronary artery surgery. It is screened preoperatively with various techniques, which have been investigated earlier in numerous studies. Based on our own results we recommend the use of ultrasonographic scanning in selected cases (2). Some authors even suggest that ultrasonographic examination should be mandatory (5). The higher prevalence of carotid atherosclerosis in patients with coronary artery disease is well known and the presence of carotid stenosis is known to increase the operative risk in coronary surgery. Many studies have been performed to identify patients with carotid disease preoperatively (6,7). In the cases where the forearm is examined with ultrasonography preoperatively and pathologic changes are found, atherosclerotic involvement of the carotid arteries would be very interesting to study.

Gaudino and colleagues involved 42 patients with coronary disease and 26 control patients in their study where they measured intima-media thickness (IMT) of the radial artery and common carotid artery with ultrasonography (3). Intima-media thickness is thought to be an early marker for atherosclerosis. They found no statistical correlation between the radial artery IMT and common carotid

<table>
<thead>
<tr>
<th>Nr</th>
<th>Radial artery</th>
<th>Ulnar artery</th>
<th>Carotid arteries</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Calcification</td>
<td>Calcification</td>
<td>Mild stenosis on left</td>
</tr>
<tr>
<td>2</td>
<td>Calcification</td>
<td>Calcification</td>
<td>Mild stenosis on both</td>
</tr>
<tr>
<td>3</td>
<td>Calcification + sclerosis</td>
<td>Calcification + sclerosis</td>
<td>Total occlusion on right, significant on left</td>
</tr>
<tr>
<td>4</td>
<td>Calcification + sclerosis</td>
<td>Calcification + sclerosis</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sclerosis</td>
<td>Sclerosis</td>
<td>Significant stenosis on both</td>
</tr>
<tr>
<td>6</td>
<td>Sclerosis</td>
<td>Sclerosis</td>
<td>Mild stenosis on both</td>
</tr>
<tr>
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<td>11</td>
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Mild stenosis 1–15%, significant 50–75%, total occlusion 100%.
Table II. Correlation of diabetes and smoking to vessel pathology.

<table>
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<tr>
<th></th>
<th>P-value</th>
<th>Odds ratio</th>
<th>95% CI</th>
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<tbody>
<tr>
<td>Smoking and carotid arteries</td>
<td>0.19</td>
<td>0.43</td>
<td>0.14-1.33</td>
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<tr>
<td>Smoking and forearm arteries</td>
<td>0.51</td>
<td>0.49</td>
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<td>0.28</td>
<td>2.07</td>
<td>0.53-7.97</td>
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CI: confidence interval.

Table III. Results of statistical analysis. Correlation between forearm vessel pathology and carotid artery pathology.

<table>
<thead>
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<th></th>
<th>P-value</th>
<th>Odds ratio</th>
<th>95% CI</th>
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</thead>
<tbody>
<tr>
<td>Radial artery disease</td>
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<td>8.5</td>
<td>1.42-51.0</td>
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<tr>
<td>Ulnar artery disease</td>
<td>0.012</td>
<td>7.5</td>
<td>1.60-35.1</td>
</tr>
<tr>
<td>Disease in both UA and RA</td>
<td>0.013</td>
<td>5.6</td>
<td>1.49-21.3</td>
</tr>
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</table>

CI: confidence interval.

we chose to treat the intimal and medial changes as one entity.

The incidence of radial artery pathology in our study was 7.1% which is considerably lower than in an earlier study. The overall incidence of forearm vessel pathology was 11%. Again, our patients are young and their disease has not advanced to a significant level. Therefore, it is interesting that even though our patients are relatively young with only moderate atherosclerotic involvement in forearm vessels this involvement is correlated to carotid artery disease and despite the small population size the correlation was statistically significant. Radial artery atherosclerotic involvement is a marker that predicts carotid artery disease. When found, pathological radial artery should necessitate at least an evaluation of carotid vessels. It remains to be seen if this correlation applies a series of elderly patients.

We conclude that atherosclerotic involvement of the forearm arteries is correlated to carotid artery disease even in a fairly young population of elective patients with coronary artery disease.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References