# Use of multidetector computed tomography angiography of upper limb circulation in patients undergoing coronary artery bypass grafting surgery

Hasan B Altinsoy, Ozkan Alatas[1], Hidayet Kayancicek[2], Erhan Hafiz[3], Omer F Dogan[4]

Departments of Radiology, [1]Cardiovascular Surgery, Elazig Education and Research Hospital, [2]Department of Cardiology, Medicalpark University Elazığ Hospital, Elazıg, [3]Department of Cardiovascular Surgery, Gaziantep University School of Medicine, Gaziantep, [4]Adana Numune Education and Research Hospital, Adana, Cukurova, Turkey

**Correspondence:** Prof. Omer F. Dogan, Adana Numune Education and Research Hospital, Suleyman Demirel Bullivard, Adana, Cukurova, Turkey. E-mail: ofdogan@hacettepe.edu.tr

## Abstract

**Objective:** This study aimed to evaluate the bilateral forehand circulation using a 64-channel multidetector computed tomography (MDCT) as a noninvasive method to define criteria for an upper extremity arterial anatomy and pathology prior to the use of arterial conduits. **Materials and Methods:** Fifty-five patients with coronary artery disease who underwent total arterial coronary artery bypass grafting (CABG) were randomly selected for this prospective study. MDCT angiography was performed for 110 examinations of forearm and hand arterial anatomy. Prior to MDCT, Allen tests were performed in all patients with a normal result, except four. Thirteen patients had diabetes mellitus (DM), 8 had peripheral artery occlusive disease, and 19 had a history of smoking. **Results:** All arteries, including axillary, ulnar artery (UA) and radial artery (RA), were clearly visualized in all patients. Upper extremity anatomical and pathological results were examined in 16 patients (29.1%). Severely calcified RA and/or UA were found in 6 patients who had a moderate renal failure. Nearly total occlusion of the RA was detected in another two patients. Focal intimal RA calcification was recorded in 1 female and 3 male patients. Ten patients who had severe calcification or intimal sclerosis of the upper extremity arteries had DM. The remaining patients had normal forehand arterial circulation. A persistent median artery with the absence of radial and ulnar arteries and a high bifurcation of RA from the brachial artery was detected as an anatomic variation in seven patients (12.7%). **Conclusions:** The major advantages of MDCT angiography are its non-invasiveness and the ability to detect calcific subadventitial plaques, which are difficult to diagnose using conventional angiography. MDCT may be used as a safe and non-invasive method to assess RA and UA prior to harvesting the upper limb artery. Preoperative imaging of forehand arteries is a means to avoid unnecessary forearm exploration or the use of an unsuitable arterial conduit in CABG operations, especially in patients with DM and moderate renal impairment.

**Key words:** Duplex ultrasonography; hand circulation; multislice computed tomography angiography

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## Introduction

A previous study showed that the upper extremity arteries have a higher incidence of intimal hyperplasia and calcification.[1] The radial, or infrequently, the ulnar artery may be preferred for an arterial conduit in total arterial coronary artery bypass grafting (CABG) operations.[2,3] Calcification or intimal hyperplasia of the radial artey (RA) is the main risk factor for long-term graft patency. Studies of the prevalence of pre-existing diseases in this vessel have used Doppler ultrasound[4-6] or histological analysis.[1] Multislice computed tomographic (MSCT) angiography has emerged as a noninvasive diagnostic modality that is an alternative to conventional angiography.[7] Ofer *et al*. demonstrated that CT angiography yielded a sensitivity of 90.9% and a specificity of 92.4%.[7] Previous studies compared the sensitivity and specificity of CT angiography with those of conventional angiography for diagnosing lower extremity arterial stenoses and found that they vary from 90% to 98% and 92% to 97%, respectively.[8,9] These previous studies did not explore the use of CT angiography for detecting the pathology of upper extremity arteries.[7-9] Therefore, a 64-channel multidetector computed tomography (MDCT) angiography was used in the present study to examine the entire length of the RA for calcification, forearm arterial anatomy, and hand circulation after Allen and modified Allen test.

## Material and Methods

The study protocol was approved by the local ethics committee. The informed consent was signed by the patients prior to the study. Fifty-five patients with multivessel coronary artery disease were included in this study in the preoperative period. A total of 110 extremities were investigated. The patient characteristics are summarized in Table 1. The clinical characteristics and risk factors such as history of smoking, diabetes etc. for arterial pathology in 55 patients have been summarized in Table 1. Preoperative medication has also been summarized in Table 1. The exclusion criteria of the study were as follows: prior radial artery (RA) cannulation, chronic kidney disease and previous RA trauma. The age of the patients ranged from 27 to 70 years (mean 53.7 ± 8.3 years; SD ± 6.56 years). Thirteen patients were females. MDCT angiography was performed in all patients who had normal Allen and modified Allen test results, except 4 patients who had a persistent median artery as an unusual arterial anomaly. The patient risk factors for RA calcification were as follows: 10 patients had diabetes mellitus (DM), 7 patients had aortoiliac or femoral occlusive disease and 11 had a history of smoking and hypercholesterolemia. A total of 31 patients had hypercholesterolemia. DM, hypertension, peripheral vascular disease and hypercholesterolemia were the risk factors of RA and/or UA calcification or intimal disease. The remaining two patients had no risk factors for upper extremity calcification or intimal hyperplasia other than coronary artery disease.

**Table 1: Preoperative patients' characteristics and medication of the both groups**

| | |
|---|---|
| Age (y) (Range) | 27-70 |
| Mean (±SD) | 53.7±8.3 |
| Sex | |
| Male | 42 (76.3%) |
| Female | 13 (23.7%) |
| Smoking history | |
| Never smoked | 11 (20%) |
| Previous | 25 (45.4%) |
| Current | 19 (34.5%) |
| Diabetes | |
| None | 45 (81.8%) |
| Diet control | 2 (3.6%) |
| Oral hypoglycemic drugs | 2 (17.8%) |
| Insulin dependent | 6 (10.9%) |
| Hypertension | 28 (50.9%) |
| Peripheral vascular disease | 8 (14.5%) |
| Hypercholesterolemia | 31 (56.3%) |
| Mild renal dysfunction | 4 (7.2%) |
| Medication | |
| Calcium receptor inhibitor | 46 (83.6%) |
| Beta Blocker | 33 (60%) |
| Antiaggregant (s) | 55 (100%) |
| Nitrate | 49 (89%) |

### Computed tomography angiography

The 64-channel MDCT angiography was performed in all patients who had negative Allen test results. All CT angiography studies were completed in less than 3 min. Multidetector CT angiography studies were performed using a 64-channel multidetector CT (Volume Zoom scanner; Siemens Medical Systems, NJ, USA) after administering 120 mL of nonionic iodinated intravenous contrast (150–200 mg/mL) at a rate of 2–4 mL/s via an 18-gauge angiocath using a power injector. Technical parameters were as follows: detector collimation 1 mm; slice thickness 1.25 mm; reconstruction index 1 mm; pitch 1.75; gantry rotation time 0.5 s; table speed 28 mm/s. Axial images were transferred to a workstation, and three-dimensional images were obtained using volume rendering and maximum intensity projections. The entire length of the RA was examined for calcification, soft plaques and stenosis. Hyperdense foci in the arterial wall were recorded as local calcification; occlusion was defined as a distal cut-off or the inability to visualize the distal part of the artery. Bilateral radial arteries and proximal hand circulation were clearly visualized in all patients successfully. The technical success rate of forearm CT angiography was 100%.

### Statistical analysis

Three clinical risk factors for upper extremity (dystrophic calcification of the digital arteries and medial focal or diffuse hyperplasia) were included as independent variables using logistic regression analyses. A forward stepwise

procedure was used to identify a model. Exact logistic regression was used to fit the model to the data. Positive arterial calcification and any arterial abnormality (focal or diffuse calcification) detected using MDCT were included as dependent variables. *P* values and 95% confidence intervals were reported for key results.

## Results

In 39 patients (78 extremities), normal upper limb arteries were detected [Figure 1]. Focal calcification leading to mild stenosis, occlusion or narrowing and diffuse calcification of the distal upper limb arteries were detected by CT angiography in 12 of the 55 patients [Figure 2A and B]. Nine patients were males and three were females aged older than 55 years. Four patients had DM (three males and one female). Severe arterial calcification and intimal occlusive disease were detected in six patients [Figure 3A and B]. Four patients had mild renal dysfunction [estimated glomerular filtration rate (eGFR) ≤60–89 mL/min/1.73 $m^2$]. Two patients had severe calcification in the ulnar artery [Figure 4A]. The collaterals separated from the radial and ulnar arteries were also severely calcific in these patients [Figure 4A]. These patients also had aortofemoral occlusive disease. Seven patients had a variation of the forearm arterial anatomy. High bifurcation of RA from the brachial artery was noted in 3 male patients [Figure 4B]. The other four patients had persistent median artery with absent UA [Figure 5]. The hypoplastic median artery was found in 1 patient.

**Figure 1:** Normal anatomical upper extremity arterial circulation. There is no evidence for arterial calcification or intimal hyperplasia or occlusive disease from proximal to distal end of the arteries including digital branches

The RA was not used as a conduit in 16 coronary artery bypass grafting (CABG) patients because it had calcification or anatomic anomalies. RA calcification or narrowing of the artery due to intimal or medial calcification was detected using MDCT in 29.1% of the arteries. Focal plaques or diffuse calcinosis was found in 10 patients. The overall incidence of anatomic or pathological abnormality of forehand circulation was 27.1%. Eight arteries with stenoses were detected. The forward stepwise logistic procedure selected a model with the clinical risk factors of age, sex, and peripheral artery disease for arterial stiffness alone. The logistic regression model involving two factors was fitted to the data by means of an exact procedure (peripheral artery disease, $P = 0.02$; glomerular filtration rate, $P = 0.04$). The stepwise logistic regression procedure identified peripheral vascular disease and high blood creatinine levels concomitant with DM as the main risk factors for any MDCT-detected arterial calcification or plaque. With the use of these two variables, a logistic regression was fitted to the data by means of an exact procedure; the results are shown in Table 2.

## Discussion

This study presented the results of upper extremity arterial examinations using MDCT angiography as a noninvasive method in coronary artery disease patients who underwent total arterial CABG operation. After examination of 110

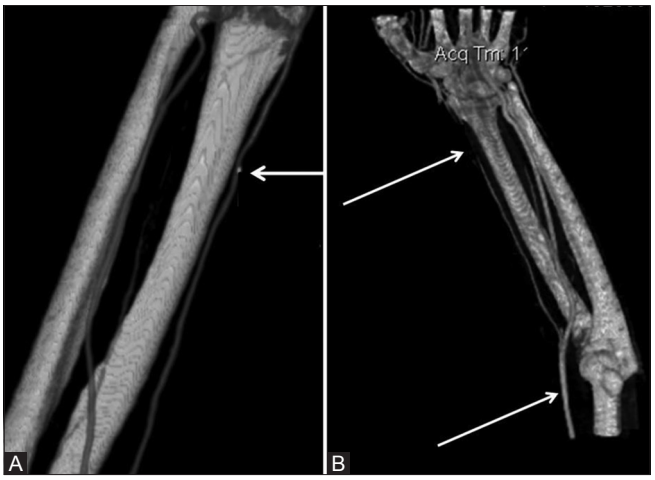


**Figure 2 (A and B):** (A) Forearm computed tomographic angiography, the anterior projection shows eccentric focal calcification (white arrow) at the distal radial artery, causing mild stenosis. (B) Computed tomographic angiography demonstrates clearly using an anterior projection there is a severe narrowing of the distal radial artery (distal white arrows). The axillary artery is normal (upper white arrow)

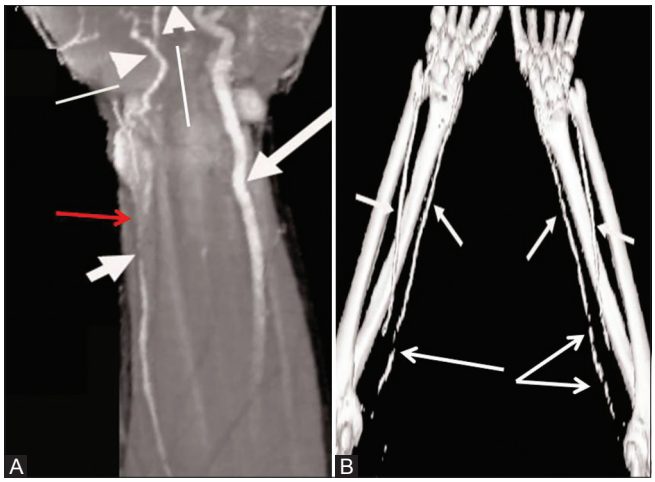


**Figure 3 (A and B):** (A) The anterior projection at the level of the hand reconstitution of the radial artery distal to occlusion (red arrow and short white arrows). Deep palmar arch (arrowheads) through the ulnar artery (long arrow on the right side) that explains the reason for normal Allen test in this patient; (B) Unenhanced computed tomography shows diffuse and dystrophic calcification of bilateral radial and ulnar arteries (arrows). Computed tomographic angiography shows patency of proximal ulnar and radial arteries, diffusely calcified segments cannot be evaluated

**Table 2: Results of exact logistic regression analysis of dependent variables for upper extremity arterial distrophic calcinosis and/or focal plaques**

| | *P* | Odds ratio | 95% CI |
|---|---|---|---|
| Peripheral vascular disease | 0.02 | 2.2 | 1.2-8 |
| LGF rate | 0.04 | 3.3 | 0.9-12 |
| DM | 0.08 | 3.0 | 0.7-11 |

CI: Confidence intervals, LGF: low glomerular filtration, DM: diabetes mellitus

extremities in 55 CABG patients, a different degree of arterial disease or unusual anatomic variations was clearly detected in 16 patients (29%) (32 extremities). Search of the English literature shows that the present study had the largest patient population. The use of MDCT angiography avoided unnecessary forearm exploration and the use of an unsuitable arterial conduit in CABG patients. In patients with peripheral artery disease, the presence of DM concomitant with a low glomerular filtration rate (eGFR ≤60–89 mL/min/1.73 $m^2$) predicted arterial dystrophic calcification as detected by MDCT.

Doppler ultrasonographic imaging and histopathologic examinations showed that the RA had a higher incidence of preexisting intimal hyperplasia, medial calcification, and atherosclerosis compared with the internal thoracic artery.[1] The results of previous investigations showed that the predictors of intimal disease of the RA were age, peripheral vascular disease and DM.[4-6] Indeed, focal or generalized calcification was found in 10 patients with DM. Four patients with DM also had a mild renal failure but did not need dialysis. The blood creatinine levels were lower than 1.8 in all patients (1.4–1.7 mg/dL).

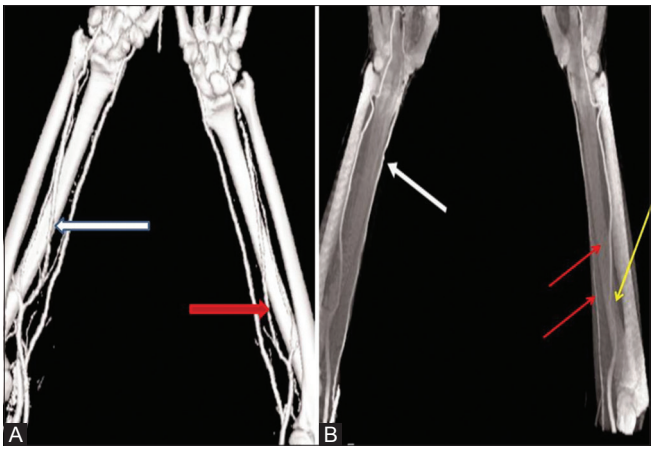


**Figure 4 (A and B):** (A) Computed tomographic angiography shows an anterior projection of diffuse calcific disease of the radial and the ulnar artery. The calcification of the branches from the radial and the ulnar arteries has been shown (red and white arrow). The radial arteries of the bilateral arms are patent but diffusely calcific; (B) Anterior projection of computed tomography shows high bifurcation of radial artery above the elbow joint. There is no bifurcation

Conduit calcification and intimal hyperplasia are the important risk factors for long-term patency of coronary grafts. A few studies have examined the prevalence of preexisting disease in this vessel using Doppler US[4,6] or histologically.[1]

Carpentier *et al*. were the first to use the RA conduit in CABG patients in 1971. They reported an approximately 30% occlusion rate of this conduit. Therefore, the RA graft was not accepted as a perfect graft in CABG surgeries. Since the 1990s, the RA has become a popular conduit for coronary artery bypass surgery using pharmacological agents and "no-touch'' harvesting techniques to avoid conduit spasm.[10,11]

MDCT angiography has emerged as a noninvasive diagnostic modality that is an alternative to conventional angiography.[9] A high sensitivity and specificity of CT angiography compared with conventional angiography for lower extremity arterial investigations have been reported previously by Nicolosi *et al*. and Ofer *et al*.[5,7] The Allen and the modified Allen tests were performed in all patients except 4 patients who had a persistent median artery. While deciding the RA use in CABG operations, tests such as duplex ultrasonography and Allen and modified Allent tests have been increasingly used as an inexpensive and simple screening device for assessing the hand collateral circulation in most centers. The advantage of ultrasonography is that it can be used to examine the vessels, measure the flow velocity and assess the physiological adaptation of vessels by observing the direction of the blood flow after RA compression. However, one of the drawbacks of using this test is the lack of established standard criteria to differentiate normal and abnormal Doppler

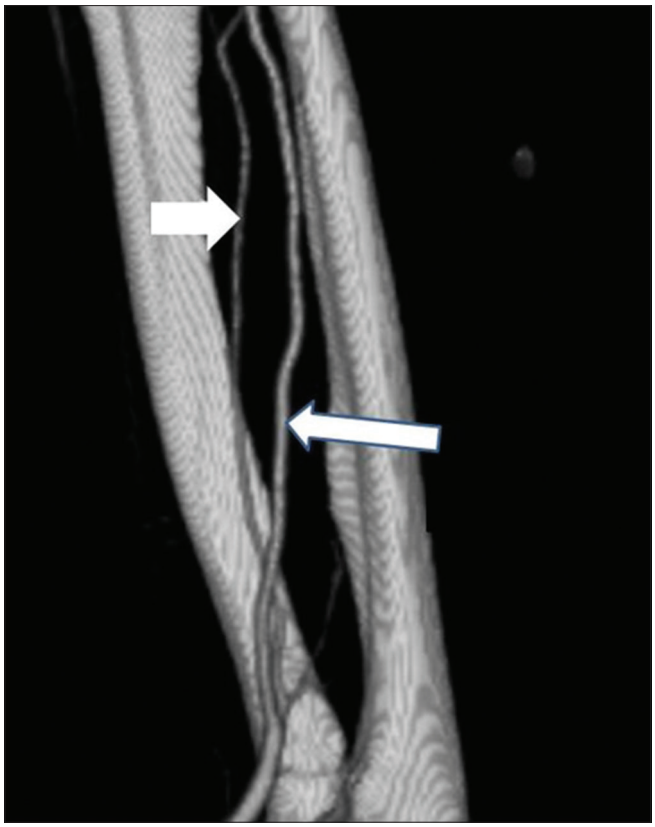

**Figure 5:** Anterior projection of computed tomography demonstrates a persistent median artery (long arrow). The radial and ulnar artery are absent. Interosseal artery (short arrow) separates from the persistent median artery

US results.[6] Moreover, ultrasonography is a subjective operator-dependent investigation. On the contrary, Allen test is a simple and cost-effective test. However, whether it is a valid screening test is still debatable. The present study determined that some patients had an RA occlusive disease (six patients had an RA-calcific disease including UA). However, it could not detect negative Allen test results in these patients. The modified Allen test is a subjective operator/patient-dependent test. Unexpected hand ischemia after RA intervention, including RA harvesting, has been reported.[12]

Previous studies demonstrated the MDCT results for the coronary anatomy and the major mediastinal vascular anatomy.[13,14] The present study showed the effectiveness of MDCT application in adult and pediatric patients for examining coronary arteries[13] and anomalies in the cardiovascular and mediastinal structures.[14]

Dynamic ultrasonography (DUS) is used in many centers because it is the best noninvasive and inexpensive method to evaluate upper limb arteries.[4-6] Pola *et al*. established criteria for an abnormal DUS test result to determine which RAs could be harvested.[4] However, it is believed that difficulties in evaluating DUS findings and subjectivity of this technique can be overcome by state-of-the-art CT angiography studies. A study by Nicholosi *et al*. showed that 5.9% of patients had abnormal DUS test results.[5] These findings indicated that MDCT angiography might be used as another noninvasive radiological method prior to surgery in CABG patients to document the anatomy of the hand and forearm arterial tree for reliable RA harvesting in patients with a high risk of arterial calcification, for example those with DM or renal failure, although this method is not used routinely in the clinical setting.

MDCT angiography may be used as an alternative to Doppler US and the Allen test for clear documentation of anatomic and pathological abnormalities. Conventional angiography or digital subtraction angiography is the gold standard for evaluating arterial anatomy and pathologies. However, it has several disadvantages including long procedural time, need for sedation in some patients and arterial catheterization. Potential complications such as arterial occlusion and dissection, hematoma or pseudoaneurysm may be seen after the procedures. Therefore, a routine use of conventional angiography for RA evaluation is expensive and not practically feasible. Moreover, evaluating the upper extremity and the vessel wall for calcification is not possible using conventional angiography. The disadvantages of MDCT angiography include radiation exposure and iodine contrast-material administration. However, radiation dose, iodinated contrast load and procedural time are less for CT angiography compared with conventional angiography. In CT angiography, the contrast material is administered through a cubital vein; whereas, in conventional angiography, the contrast is administered through a catheter located in the arterial system. CT angiography is a cheaper, safer and noninvasive technique and provides detailed information about the anatomy of the vasculature and arterial pathologies. Moreover, it is quite difficult to evaluate changes in the arterial system with Doppler US.

Previous studies suggested that the surgical complications at harvest sites of hands occurred in 12%, and persistent symptoms were self-reported as follows: chronic pain 8%; numbness 34% and paresthesia/dysesthesia 12%. Overall, 39% of the patients reported persistent discomfort.[15] Therefore, detailed preoperative information is extremely important to avoid unnecessary forearm exploration for the harvesting of arterial conduits.[15,16]

Kaptanoglu and Baton showed that the succesful results of the variations of the upper extremity arterial system and superficial palmar arch using with computed tomography angiography to evaluate different variations in palmar circulation and forearm arteries prior to transradial or transulnar catheterization, hemodialysis or CABG, previously.[17] Ki and Choi have also researched vascular dominance in the forearm prior to invasive vascular procedures in arteries of the forearm using

3D-computed tomography angiography in 92 forearms.[18] They suggested that 3D tomography angiography showed valuable preoperative details of the forearm vessels for cases who requiring invasive vascular procedures on the forearm.[18] We first showed the use computed tomography angiography for upper limb extremities previously in our CABG patients prior to operation.[19] In our previous pilot study, the effectiveness of four channels CTA as a non-invasive and cheapest method has been described in our sixteen patients.[19]

## Conclusions

The present study showed that upper extremity arterial disease and anatomic anomalies are not rare. It was the largest case study to document the prevalence of upper extremity anatomy and pathology including focal or diffuse arterial stiffness as determined by MDCT and to identify the risk factors for arterial pathology. The findings suggested that the prevalence of bypass conduit calcification was not rare in CABG patients. Preoperative examination of upper limb arteries using MDCT may reduce unnecessary forearm exploration and postoperative complications prior to CABG. MDCT angiography can document anatomic and pathological details such as focal arterial calcinosis at the same time. Three-dimensional volume-rendered MDCT angiography provides clear images of the arteries for preoperative planning. Moreover, MDCT angiography may also be used for the preoperative evaluation of the upper extremity in CABG patients with risk factors for arterial stiffness, medial calcinosis, and anatomic malformations.

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**Conflicts of interest**
There are no conflicts of interest.

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