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CORONARY ANGIOGRAPHY

Correlation Between Magnetic Resonance Angiography (MRA) and Quantitative Coronary Angiography (QCA) in Ectatic Coronary Vessels

Sophie I. Mavrogeni,[1,*] Athanassios Manginas,[1] Emmanouil Papadakis,[1] Stefanos Foussas,[1] Marouso Douskou,[2] Panagiotis Baras,[3] Ioannis Seimenis,[3] and Dennis V. Cokkinos[1]

[1]Onassis Cardiac Surgery Center, Athens, Greece
[2]Bioiatriki MRI Unit, Athens, Greece
[3]Philips Hellas Medical Systems, Athens, Greece

ABSTRACT

Coronary artery ectasia (CAE) is defined as a dilatation of an arterial segment to a diameter at least 1.5 times that of the adjacent normal artery. The correct follow-up of ectatic vessels is hampered by the need for repeat angiograms. In this work we compared quantitative coronary angiography (QCA) measurements of the diameter of the proximal most ectatic part of coronary vessels, with corresponding measurements obtained by magnetic resonance angiography (MRA) using both gradient echo and turbo spin echo imaging sequences. Fifteen patients (14 male), aged 45–65 years, with known CAE were prospectively studied. Two electrocardiogram (ECG)-triggered pulse sequences were implemented for coronary magnetic resonance angiography. The first was a three-dimensional (3D), segmented, k-space gradient–echo sequence, employing a T2-weighted preparation prepulse and a frequency-selective, fat-saturation prepulse to enhance ''white blood'' (WB) contrast of the coronary arteries. The second sequence was an M2D dual Inversion Recovery (IR) Turbo Spin-Echo with a linear *k*-space acquisition scheme, providing ''black-blood'' (BB) contrast of the coronaries. All scans were carried out with the patient free breathing using a 2D, real-time Navigator beam, for respiratory motion tracking and gating. All patients underwent QCA, and the diameter of the proximal most ectatic part of each vessel was measured and compared with ''white-blood'' and ''black-blood'' MRA measurements. The average length of continuously visualized LM, LAD, LCx, and RCA by MRA was 2.5 ± 0.3, 5.8 ± 0.8, 3.9 ± 1.0, and 7.2 ± 1.2 cm, respectively. There were no statistically significant differences between diameter measurements of the proximal most ectatic part of each vessel, obtained with WB and BB sequences. There was a close correlation between MRA and QCA

*Correspondence: Sophie Mavrogeni, M.D., F.E.S.C., 50 Esperou St., 175-61 P. Faliro, Athens, Greece; Fax: +30-210-98-82-797; E-mail: soma@aias.gr.

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measurements ($r = 0.87$, $p < 0.001$). Bland–Altman analysis showed no systematic differences between the examined methods, over the whole range of vessel diameters measured. Coronary MRA is in close correlation with QCA for CAE detection. Magnetic resonance angiography, being noninvasive, may prove of significant value for the efficient follow-up of these patients.

Key Words: Coronary ectasia; Coronary angiography; Magnetic resonance angiography.

INTRODUCTION

Coronary artery ectasia (CAE) or aneurysmal coronary artery disease is defined as dilatation of an arterial segment to a diameter at least 1.5 times that of the adjacent normal coronary artery (Falsetti and Carroll, 1976; Seabra-Gomes et al., 1974; Swanton et al., 1978). It is found in up to 5% of angiographic and from 0.22% to 1.4% of autopsy series (Hartnell et al., 1985; Markis et al., 1976; Oliveros et al., 1974; Swaye et al., 1983). It can be diffuse, affecting the entire length of a coronary artery, but it can also be discrete or localized. When the dilatation involves the entire vessel, the word ''ectasia'' instead of aneurysmal disease is used. Coronary artery ectasia or aneurysm is attributed to atherosclerosis in 50% of cases, whereas 20% to 30% have been considered to be congenital in origin. The great majority of these patients have coexistent coronary artery disease. Only 10% to 20% of CAE cases have been described in association with inflammatory or connective tissue diseases (Befeler et al., 1977; Falsetti and Carroll, 1976). The presence of aneurysmal segments produces sluggish or turbulent blood flow, with increased incidence of typical, exercise-induced angina pectoris and myocardial infarction, regardless of the severity of coexisting stenotic coronary disease. This is due to repeated dissemination of microemboli to segments distal to ectasia or due to thrombotic occlusion of the dilated vessel (Al-Harthi et al., 1991; La Mendola et al., 1990; Rab et al., 1990). Slow blood flow in the coronary artery, demonstrated by our group, may also be a causative factor (Papadakis et al., 2001). Patients with pure ectasia (15% of the total population with CAE) have a more benign course, but 39% of them still present signs of previous myocardial infarction (Demopoulos et al., 1997). There is a higher incidence of adverse events in this population compared to individuals with normal coronaries (Markis et al., 1976). The best treatment has not been clearly established.

Coronary artery ectasia should not be confused with Kawasaki disease (KD), which is an acute vasculitis of unknown etiology usually occurring in children younger than 5 years of age. Kawasaki disease is more prevalent in Orientals than in Caucasians. Despite the treatment for acute illness with aspirin and γ-globulin, many children develop coronary aneurysms that frequently result in coronary artery stenosis or obstruction. Kawasaki disease is the most common cause of pediatric ischemic heart disease in the world (Demopoulos et al., 1997).

The correct follow-up of ectatic vessels is hampered by the need for repeated angiograms. Magnetic resonance angiography has been recently used for the noninvasive evaluation of the proximal part of the coronaries (Kim et al., 2001) and makes possible the visualization of the major epicardial coronary arteries in most of the subjects.

In this study, we compared measurements of the diameter of the proximal most ectatic part of the coronary vessels obtained by quantitative coronary angiography (QCA), with those measured by magnetic resonance angiography (MRA) in patients with CAE, using both white-blood and black-blood contrast of the examined vessels. Acquisition of the MR data was achieved with the patients breathing freely through the use of a prospective, two-dimensional Navigator technique, thus adding to the patient friendliness of the MR method. Results allowed the assessment of the potential role of coronary MRA as a tool for the noninvasive follow-up of CAE patients.

This study is a first approach to compare the severity of CAE using QCA and MRA. In this population there were no obstructive lesions in the ectatic vessels studied. Therefore, the extent of minimum/maximum stenosis or degree of eccentricity was not addressed.

PATIENTS AND METHODS

A. Patient Population

Fifteen patients (14 males), aged 53 ± 6 (range: 45–65) years, were included in the study. All were referred for diagnostic coronary angiography for the evaluation of chest pain. Patients were ineligible for enrollment if they had a known contraindication for magnetic resonance imaging (MRI). The great majority of patients had dyslipidemia, smoking history, and coexisting coronary artery disease.

All patients underwent coronary cine angiography, which confirmed coronary artery ectasia. Following QCA, coronary MRA was performed. The mean interval between the two examinations was 2 days (range: 1–4). Imaging times for QCA and MRA were comparable. Both QCA and MRA were completed without complications, while no clinical events were manifested between the two examinations. The imaging protocols were accomplished without the use of nitrates, since nitrates may induce coronary ischemia in CAE (Papadakis et al., 2001).

B. Quantitative Coronary Angiography

Conventional, contrast-enhanced coronary angiography was performed using a transfemoral arterial approach. Quantitative information was provided by an experienced investigator, who was blinded to the MRA results. The selected end-diastolic frames were magnified, digitized, and analyzed off-line with the QCA imaging system (CMS, MEDIS, Leiden, The Netherlands). Automatic contour detection was performed with the geometric edge-differentiation technique according to a previously validated method (Hausleitet et al., 1996). The proximal most ectatic segment of the major coronary arteries was preselected for diameter measurement, while the guiding catheter served as a calibration factor.

C. Magnetic Resonance Angiography

Coronary MRA was performed using a 1.5 T Philips Intera CV MR scanner (Philips Medical Systems, Best, The Netherlands). A commercial, five-element, cardiac phased array receiver coil was used for signal acquisition. All patients were examined with four electrocardiogram (ECG) electrodes (Fischer et al., 1999) on the anterior left hemithorax and during free breathing. To compensate for respiratory motion artifacts, a prospective, 2D, real-time navigator beam was properly placed on the patients' right hemidiaphragm for slice tracking and end-expiratory gating (Stuber et al., 1999a). The R wave of the ECG was used as a trigger for data acquisition, and all images were acquired in mid-diastole.

Two different imaging sequences were used to obtain images with white-blood and black-blood contrast of the coronaries. The white-blood sequence used (Botnar et al., 1999) was a 3D, segmented k-space, gradient–echo sequence [echo time (TE) = 2.1 ms, repetition time (TR) = 7.5 ms, flip angle = 30°, reconstructed slice thickness = 1.5 mm, in-plane image resolution = 0.7 mm × 1.0 mm] employing a T2-weighted preparation prepulse and a frequency-selective, fat-saturation prepulse. For the right coronary artery, a double oblique volume was imaged with use of the coordinates prescribed by a three-point planscan tool (Stuber et al., 1999b). For the left coronary artery system, a transverse volume was scanned centered on the origin of the left main coronary artery. The black-blood sequence used (Stuber et al., 2001) was an M2D, dual Inversion Recovery (IR) Turbo Spin Echo sequence (TE = 28 ms, echo train length = 25, TR = 2 cardiac cycles, slice thickness = 3 mm, slice overlap = 1.5 mm, in-plane image resolution = 0.7 mm × 1.0 mm), with a linear *k*-space acquisition scheme. One set of overlapping 2D sections was acquired for the right coronary artery and one set for the left coronary system. Anatomical positioning for each set was identical to that of the corresponding volume scanned with the white-blood sequence. This was ensured through a system software parameter, which enables locking of the geometrical parameters (angulations and offsets) of a sequence to the values used in the last executed sequence. Therefore, the white-blood sequence for the right coronary artery was first run, followed by the corresponding black-blood sequence. The white-blood volume for the left coronary system was then scanned and the same volume was finally acquired with the black-blood sequence.

Source images obtained with the two sequences were used to derive multiplanar reconstructions (MPR) along the vessel path and maximum (minimum for black-blood angiograms) intensity projections (MIPs) on an image processing workstation. Source and postprocessed images were evaluated by an experienced observer (blinded to the QCA results) aiming at identifying the ectatic parts (long-axis views). Evaluation of associated coronary stenoses was beyond the scope of this study, since it has been thoroughly covered by other authors (Kim et al., 2001). Moreover, no stenotic lesions were detected in the ectatic vessels examined. The diameter of the proximal most ectatic segment of each vessel was measured as the Full Width Half Maximum of a signal intensity profile located perpendicular to the vessel long axis. This method has been proven to provide reliable results in Time-of-Flight angiography measurements, in contrast to techniques relying on vessel visual inspection (Hoogeveen et al., 1998). Multiple measurements were made, either at different points across the ectatic segment or in adjacent source images depicting the same ectatic part, in order to ensure that the maximum diameter was determined.

The intraobserver variability for minimal coronary lumen diameter was 0.19 mm for the catheter studies (Papadakis et al., 2001) and 0.22 mm for the MRI

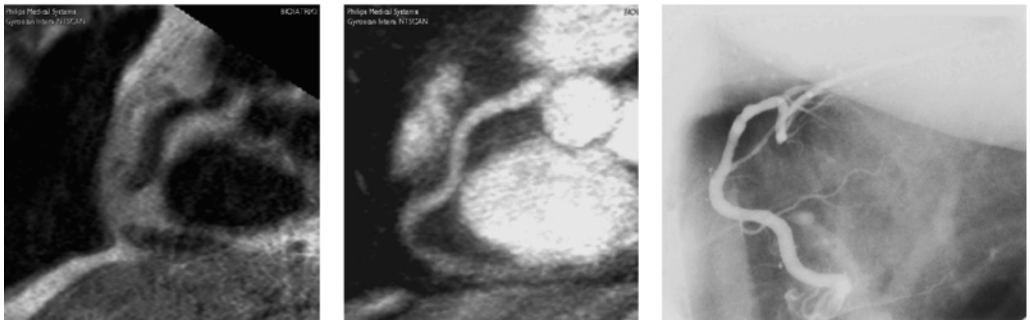

Figure 1. Coronary magnetic resonance angiograms employing black-blood (left) or white-blood (middle) contrast and a corresponding quantitative angiogram (right) from a patient with ectatic RCA (max. diameter of the ectatic part 5.2 mm).

study. Taking into account the relatively low intraobserver variability, the minimum detectable difference using MRA in coronary vessel diameter is determined by the spatial resolution of the method and it cannot be less than half the used pixel size.

D. Statistical Analysis

All measurements were expressed as mean ± standard deviation. Statistical significance of the differences between the examined methods was investigated with the paired Student's *t*-test. Correlation between QCA and MRA data was sought with Pearson's correlation coefficient. Statistical significance was considered for $p < 0.05$. A Bland–Altman analysis was also used to assess the agreement between QCA and MRA methods.

RESULTS

The MRA vessel diameter measurements were obtained from all patients participating in this study, since good image quality was achieved for all ectatic segments examined. Total MR imaging time did not exceed 1 hour for any of the patients. Navigator efficiency was in the range of 35–55 %. Examples of a coronary magnetic resonance angiogram and a corresponding quantitative coronary angiogram in a patient with ectatic RCA are shown in Fig. 1.

The average length of continuously visualized LM, LAD, LCx, and RCA by MRA was 2.5 ± 0.3, 5.8 ± 0.8, 3.9 ± 1.0, and 7.2 ± 1.2 cm, respectively. Diameter measurements of the proximal most ectatic segments of each vessel, obtained by black-blood MRA, were similar to those acquired with white-blood MRA (MRA-BB: LM 5.38 ± 1.40, LAD 5.18 ± 0.90, LCx 6.21 ± 2.38, RCA 5.52 ± 0.94 mm vs. MRA-WB: LM 5.33 ± 1.30, LAD 5.02 ± 0.70, LCx 6.15 ± 2.33, RCA 5.44 ± 0.77 mm, respectively). Corresponding QCA measurements were: LM (n = 2) 5.61 ± 1.73, LAD (n = 6) 5.16 ± 0.81, LCx (n = 2) 5.70 ± 2.21, RCA (n = 10) 5.23 ± 0.94 mm. Results are summarized in Table 1.

Comparison between measurements obtained with the two MRA sequences and QCA, using a paired Student's *t*-test, showed no statistically significant differences. A statistically significant correlation was observed between white-blood MRA and QCA diameter measurements (Pearson coefficient $r = 0.87$, $p < 0.001$) (Fig. 2). The agreement between MRA and QCA was also investigated through Bland–Altman analysis, and the results are graphically illustrated in Fig. 3. No systematic differences were observed for the two methods, over the whole range of vessel diameter values encountered in this study. The mean difference between them was 0.09 ± 0.53 (95% CI: −0.19 to 0.39) mm.

Table 1. Diameter (mm) of the proximal most ectatic part of coronary arteries in patients with CAE.

	LM	LAD	LCx	RCA
QCA	5.61 ± 1.73	5.16 ± 0.81	5.70 ± 2.21	5.23 ± 0.94
MRA-WB	5.33 ± 1.30	5.02 ± 0.70	6.15 ± 2.33	5.44 ± 0.77
MRA-BB	5.38 ± 1.40	5.18 ± 0.90	6.21 ± 2.38	5.52 ± 0.94

Abbreviations: QCA, quantitative coronary angiography; MRA, magnetic resonance angiography; WB, white-blood sequence; BB, black-blood sequence.

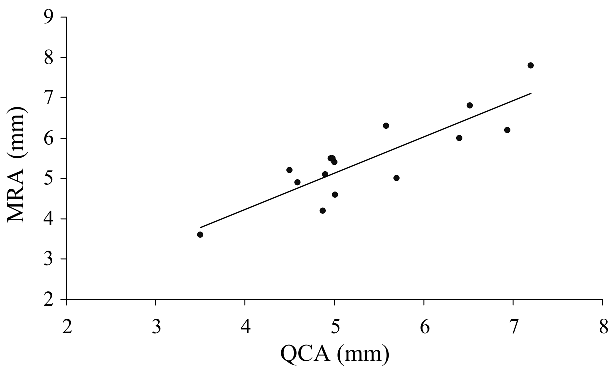

Figure 2. A statistically significant correlation (Pearson coefficient r = 0.87, $p < 0.001$) was observed between white-blood MRA and QCA results, in patients with coronary artery ectasia. (*View this art in color at www.dekker.com.*)

DISCUSSION

In this study comparing coronary magnetic resonance angiography with x-ray coronary angiography for the evaluation of the proximal most ectatic part of the coronaries of patients with CAE, we found that there is good agreement between the two techniques.

Coronary artery ectasia can be expected to be present in about 5% of prospective coronary angiograms. The majority of these patients have also coexistent, obstructive coronary artery disease. The course of these patients is very similar to those with comparable severity of coronary artery disease. Thrombus formation or spasm are predisposing factors to acute myocardial infarction and cardiac death (Befeler et al., 1977; Swanton et al., 1978) with an incidence of about 11% over 2 years. Microembolization with consecutive disturbance of coronary perfusion may also contribute to ventricular arrhythmias and even sudden cardiac death. The occlusion of major coronary vessels may result in acute ventricular dysfunction (Al-Harthi et al., 1991; Rath et al., 1985). On the other hand, a spontaneous rupture of an aneurysmatic coronary artery, although it is rare, represents a serious complication (Swaye et al., 1983). Moreover, CAE size may change over time, and this is positively correlated with myocardial ischemia (Cokkinos et al., 1999).

Since the morphology of CAE is heterogeneous, specific treatment should be individualized. The use of platelet inhibitor as a prophylaxis against ischemic syndromes due to fibrin thrombus formation and microemboli is indispensable in all forms of CAE (Swaye et al., 1983). Nitroglycerine administration has no therapeutic benefit in CAE and it may also lower the ischemic threshold. Consequently, the administration of nitrates in CAE should be avoided. However, beta-blocker administration could be of value due to their negative chronotropic effect and reduction of myocardial oxygen consumption in the absence of vasodilatation (Jackson et al., 1977). Fibrinolytic as well as interventional recanalization of the vessel is also a therapeutic approach in thrombotic occluded CAE (Rab et al., 1990).

Such patients cannot be considered fit to fly unless subjected to complete myocardial revascularization by aortocoronary grafting, bypassing the involved segments. In patients with isolated ectasia, flying is also not permitted, if there is a history of previous myocardial infarction, angina, or abnormal ECG. Supervision of these patients should be annual, and usually, stress test or scintigraphy are used for routine check-up (Cokkinos et al., 1999). Repeated direct visualization of coronaries is rather impossible, due to the invasive nature of the conventional x-ray angiography.

The three-dimensional, noncontrast enhanced, free-breathing coronary magnetic resonance angiography facilitates visualization of the vast majority of the proximal and middle segments of the left main, left anterior descending, and right coronary arteries (Kim et al., 2001). In our study we included the proximal most ectatic segments because they are the ones visualized best. Coronary magnetic resonance angiography has already been of clinical value for the assessment of anomalous coronary artery disease, and it is in some cases superior to x-ray coronary angiography in delineating the course of anomalous vessel, but it is still considered an investigational technique for the assessment of stenotic native vessel (Task Force of the European Society of Cardiology, Association of European Pediatric Cardiologists, 1998). However, it is proposed as a valuable tool for patients who present with severe left ventricular systolic

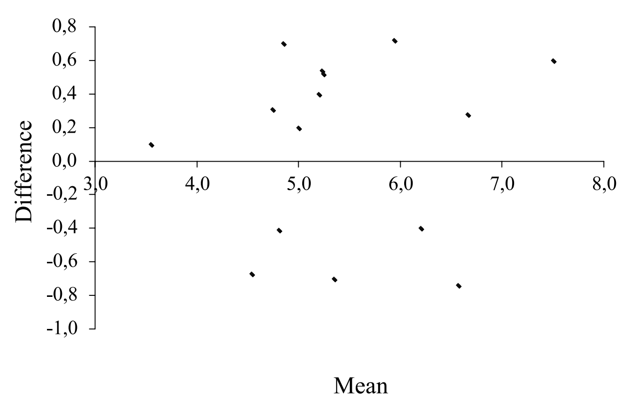

Figure 3. Bland–Altman analysis showed no systematic differences between white-blood MRA and QCA measurements, over the whole range of vessel diameters measured. (*View this art in color at www.dekker.com.*)

dysfunction, where the underlying disease is either severe multivessel coronary artery disease or nonischemic cardiomyopathy (Kim et al., 2001).

A detailed serial follow-up of patients with coronary ectasia would necessitate repeated angiograms. Although there are some studies about the role of MRA in Kawasaki disease (Greil et al., 2002) and ectatic RCA (Voigtlander et al., 1998), this is the first study where magnetic resonance angiography was compared with quantitative coronary angiography in patients with coronary ectasia. Again, it should be pointed out that Kawasaki disease (KD) is a different entity. In KD an aneurysm is formed first, which regresses spontaneously over the year, but in a few cases (<5%) develops into obstructive lesions after some years, resulting in ischemic heart disease regardless of the treatment. The lesions are usually concentrated at the proximal part of the coronary arteries and may rupture, thrombose, or develop stenotic lesions. Mortality rate due to pediatric myocardial infarction, induced by KD, is 22% after the first infarction (Demopoulos et al., 1997; Greil et al., 2002).

Although both white-blood and black-blood sequences gave similar results, the former was used for the comparison with QCA, since it is more widely available and has been used in most published studies until now. The excellent correlation between the two techniques gives the clinician a reliable, easily applicable tool for diagnosis and noninvasive evaluation of this high-risk population. Compared with computed tomography, magnetic resonance angiography has the advantage of requiring no exposure to ionizing radiation or injection of a contrast agent, and allowing patients to breathe freely throughout the duration of the examination. Imaging of all arteries studied by magnetic resonance angiography was of good quality in our 15 consecutive patients. No systematic differences between vessel diameter measurements obtained with magnetic resonance and quantitative coronary angiography were found. Coronary MRA may be expected to offer further valuable information, when complemented with coronary flow data, about the possibility of thrombotic occlusion of the aneurysmal vessels.

As a limitation of this study, it should be mentioned that the number of patients is rather small and serial data are not available. This study compared measurements obtained from a projectional technique (x-ray angiography) to those derived from an MR-imaged volume containing the examined vessel segments and this may produce some discrepancies between the two techniques. Furthermore, the accuracy of the MR-derived measurements may be hampered by a number of factors, such as the use of a nonisotropic voxel of considerable dimensions, flow-related artifacts, and intraluminal saturation effects. The limited resolution of the MRA techniques compared to that of the QCA may affect discrepancies between the two methods. Low resolution most often leads to underestimation of the vessel diameter, but the same tendency is also known for projectional techniques. Nevertheless, the in-plane MR image resolution used in this study (0.7 mm $\times$ 1.0 mm, which means at least 5 pixels per lumen diameter) is considered to be adequate for attaining accurate lumen diameters (Hoogeveen et al., 1998). The results of this study also indicate that detection of distal coronary ectasia may be limited.

Further research into this area would necessitate a larger study with more patients, possibly hosting both obstructive lesions and CAE. A follow-up study would also give valuable information, since any increase in CAE diameter or the appearance of stenotic lesions that did not preexist signal the evolution of the disease. The MRA results should also be complemented with flow and perfusion/viability studies in order to classify patients according to the severity of the disease.

In conclusion, coronary MRA, in close correlation with QCA, detects CAE of the visualized part of coronary arteries. This noninvasive method may prove of value for a more efficient follow up and serial evaluation of patients with coronary ectasia.

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