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Detection of coronary artery stenoses using breath-hold magnetic resonance coronary angiography. Comparison with conventional x-ray angiography

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Abstract. – ***Purpose:*** **To detect coronary artery stenoses, we compare breath-hold magnetic resonance coronary angiography (MRCA) to conventional coronary angiography (CA).**

Materials and Methods: **Sixty-five patients with suspected coronary artery disease underwent MRCA and CA within one week. MRCA examination was performed by using the two-dimensional (2D) breath-hold technique with a fast spoil gradient-echo sequence/spiral. Each imaging sequence was obtained within one breath-hold in expiration (14 seconds of apnoea). The assessment of coronary artery stenoses on magnetic resonance (MR) angiograms was independently performed by two blinded readers and compared to conventional CA images.**

Results: **Three hundred and ninety segments were evaluated by the two imaging techniques. MRCA correctly detected 76 of 88 (86%) stenoses, and recognized 242 of 302 (80%) not affected segments. The Pearson correlation coefficient between MRCA and CA in assessing coronary narrowings was very high: r = 0.85. Despite this the mean difference was 4.5 with a standard error of estimate of 0.21, indicating that MRCA slightly overestimates the degree of stenoses.**

Conclusions: **Our study showed that 2D breath-hold MRCA is an accurate technique in displaying and quantifying the most significant stenoses in the proximal and middle segments of the coronary arteries.**

Key Words:

Magnetic resonance coronary angiography, Coronary artery stenoses, Conventional coronary angiography.

Introduction

The first images of the coronary arteries with the magnetic resonance (MR) techniques were obtained in 1987, using a conventional spin-echo technique[1]. The magnetic resonance coronary angiography (MRCA) was applied as a non invasive technique in the examination of coronary artery disease[2-6] since the early 1990s, but the conventional coronary angiography (CA) is still the invasive method used to detect significant intraluminal narrowings, even if it may cause rare but dangerous vassal, cardiac and cerebral complications[5,7]. The existing highly accurate non invasive assessment of small vessels in various regions of the body by MR angiography suggested the use of this technique as a reliable diagnostic tool in imaging coronary arteries[8-9], although there were technical difficulties related to cardiac and respiratory motion, small diameter, tortuous and non-linear course of the coronary arteries[10]. In previous studies, MRCA was used to detect anomalous coronary arteries, coronary artery aneurisms or bypass graft patency[11-13]. The good quality of the images in those initial MRCA studies encouraged a more extensive clinical application in coronary anatomy and pathophysiology. In the study of ischemic disease MR may provide diagnostic clues not only on coronary lesions, but also on flow velocity and tissue characterization of the atherosclerotic plaques "in vivo"[14]. This would make MRCA a powerful tool to screen patients at risk for future acute coronary syndromes.

The MRCA acquisition techniques can be distinguished into three generations. The first used single-slice 2D breath-hold sequences[3,15]. The second one allowed 3D data sets during free breathing in multiple-slice acquisitions, using a respiratory belt[16-17] or the navigator technique with triggering or gating on the diaphragm motion[18-20]. Many disadvantages were overcome. The effects of cardiac and respiratory motion were abolished by 3D free-breath navigator-echo[18]. The third generation acquired volume data sets within single or multiple breath-holds, using multislice 2D[2,21] or 3D sequences[16,22-23]. The poor signal suppression of epicardial fat and myocardium or the low contrast-to-noise ratio were minimized by new intravascular contrast agents[24]. On the other hand, there were some limitations to depict the coronary artery tree, due to a low signal in the distal segment of the arteries and to a still long examination time. However, new techniques decrease the examination time and allow the imaging of the entire coronary artery tree.

The aim of our study was to compare the multislice 2D breath-hold MRCA to CA in detecting and quantifying hemodinamically significant coronary artery stenoses in patients with ischemic heart disease.

Materials and Methods

Subjects

Sixty-five consecutive patients (48 men and 17 women) with clinically suspected ischemic heart disease underwent to MRCA and CA within one week. The mean age was 59.9 years (range 36 to 78 years). Patients with contraindications to MR examination (cardiac pacemakers, ferromagnetic implants), or with unstable angina, arrhythmias or claustrophobia were excluded. The conventional invasive CA was performed by different investigators unaware of MRCA data. A written informed consent was given by each patient.

MRCA Technique

All patients were examined in supine position with a 1.5 Tesla cardiac-dedicated scanner (G.E. Genesis Signa Gemsow). Data acquisition was triggered by the electrocardiogram and each imaging sequence was performed within one breath-hold in expiration (12-18 seconds of apnoea, mean: 14 seconds). The first step was to determine the position of the heart, using scout images. An oblique coronal image (where the atrio-ventricular groove with the proximal and distal segments of the right coronary artery – RCA – were shown) was required to image the entire course of the RCA. A sagittal scan (where the roots of the left coronary artery – LCA – and the RCA were shown) was than obtained for assessing the left anterior descending coronary artery (LAD) and a coronal localizer slice about the root of the aorta (where the left main coronary artery – LM – was imaged) was needed to acquire a scan plane which included the LM, the proximal left circumflex coronary artery (LCx) and the proximal LAD. The next step was to obtain several slices with the images of the maximum length of the coronary arteries, by using a "fast spoil gradient-echo sequence/spiral" (TR = 800-860; TE = 5,4; FOV = 24×24 cm).

Using this technique it was possible to display quickly 16 or more sections in many phases of the cardiac cycle, because of the short TE used in imaging the blood, rapidly moving, that produces a high intensity and bright signal. The "spiral" gradient-echo sequence allowed a good spatial resolution in a reasonable short time, providing immediate feed-back to the imaging operator.

Conventional Coronary Angiography Technique

The coronary X-ray angiography was done by the transfemoral approach (Judkins technique). The angiograms, documented in cinefilm, were examined and evaluated separately by two cardiologist who were not the MRCA investigators. Stenoses exceeding 50% of the luminal diameter were considered significant. In case of disagreement, a joint reading was needed.

Data Evaluation

The following segments were evaluated: LM (segment 5 according to the system of the American Heart Association)[25], the proximal and middle segments of LAD (segments 6 and 7 and the first half of segment 8, respectively), of LCX (segments 11 and 13) and of RCA (segments 1 and 2). The following classification was used for visual assessment: significant stenoses or occlusion, absence of significant stenoses or occlusion, impossibility to evaluate. According to previous studies[19-26] side branches and distal segments were not included in the evaluation and a segmental reduction or signal loss in the MRCA image was considered to represent a coronary artery stenoses or occlusion.

Statistical Analysis

The assessment of coronary artery stenoses on the MR angiograms was independently performed by two experienced investigators, blinded to the findings of the CA examinations.

The length of the depicted coronary arteries was measured and was expressed as mean ± SD. The sensitivity, the specificity, the positive predicted value (PPV) and the negative predicted value (NPV) were calculated by standard methods.

The mean values of MRCA and CA coronary narrowings assessed by the two observers were considered for the analysis. The interobserver variability was evaluated by the method described by Bland and Altman[27].

The Pearson correlation coefficient and the linear regression analysis were used to compare MRCA-versus CA-detected coronary stenoses, by including all segments and by analysing separately proximal and middle tracts.

Furthermore, agreement between the data obtained by means of the two techniques was assessed by the method of Bland and Altman. The plot of differences against their mean also allows to investigate any possible relationship between the measurement error and the true value. A "p" value less than 0.01 was considered significant.

Results

No patient experienced adverse events related to the MRCA technique. The average time of the examination, including the patient setting, was 25 ± 5 minutes.

Coronary Vessel Length

The length of the coronary arteries was evaluated per reader, per examined patients. The mean interobserver lengths were: 66.2 ± 5.5 mm for the combined LM and LAD coronary arteries; 25.3 ± 10.1 mm for the LCx; 109.7 ± 25.2 mm for the RCA.

Coronary Artery Stenoses

Out of the 65 patients studied, 52 had one or more coronary stenoses. Eighty eight hemodinamically significant stenoses were assessed by using the conventional CA: 48 out of 88 stenoses were localized in the proximal segments of the LAD, LCx, RCA or LM, 40 in the middle segments. Five patient had left main disease. MRCA adequately assessed 390 coronary artery segments and correctly detected 76 out of 88 (86%) significant coronary artery stenoses, while excluded coronary disease in 242 out of 302 (80%) not affected segments (Figures 1 and 2).

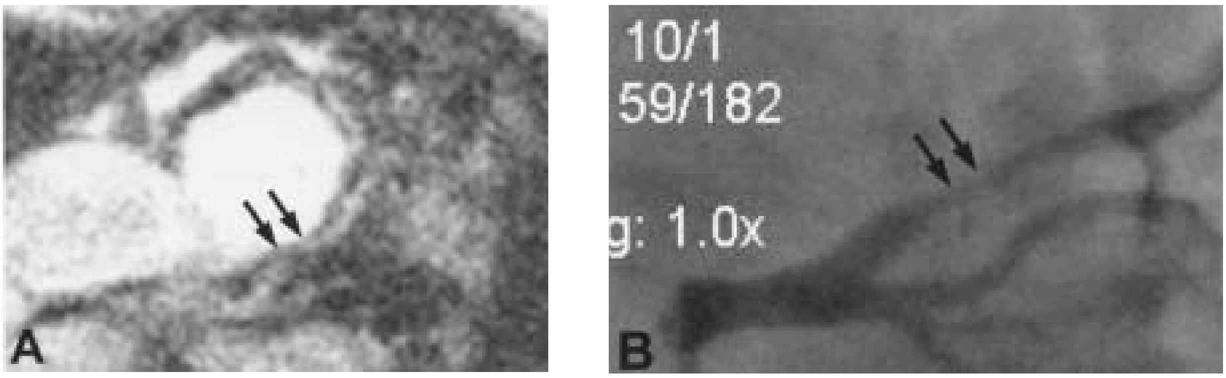

Figure 1. A, Magnetic resonance coronary angiography of a 65 year-old female patient, showing a significant stenosis of the left anterior descending coronary artery (arrows). ***B,*** The corresponding stenosis of the left anterior descending coronary artery as displayed by conventional angiography.

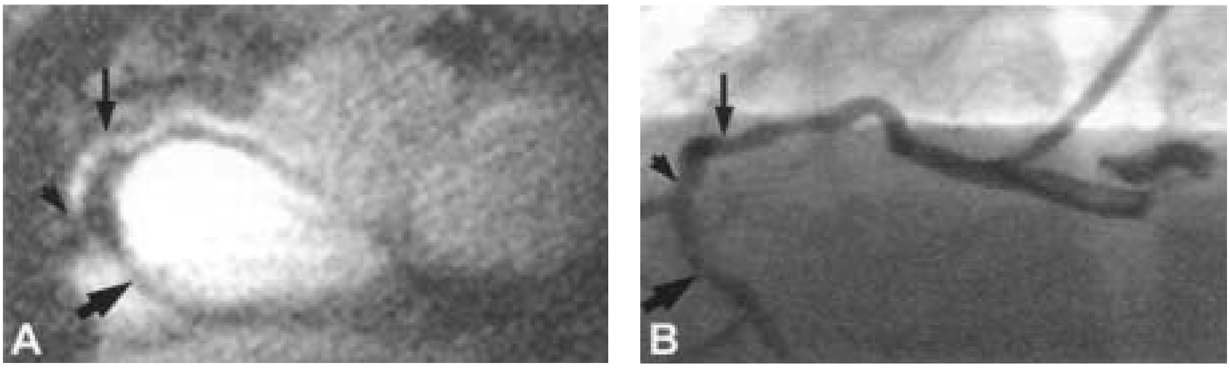

Figure 2. A, Magnetic resonance coronary angiography of a 58 year-old male patient showing three stenoses on different segments of the right coronary artery (arrows). ***B,*** Conventional coronary angiogram shows the corresponding stenoses.

The agreement between the readers in evaluating MRCA-detected coronary stenoses was very high (r = 0.90). The interobserver variability values were: mean difference = 0.26; standard deviation = 17.5 with standard error of estimates = 0.30. The sensitivity, specificity, PPV and NPV of MRCA in evaluating coronary stenoses compared to CA are summarized in Table I. In particular, we found the higher values regarding the LM tract and the proximal and middle segments of LAD and RCA, the lower values were calculated regarding the Lcx, particularly for the middle tract. The Pearson correlation coefficient between the coronary narrowings detected in all segments, calculated by using the two techniques was high: r = 0.85, $p < 0.01$ (Figure 3). The linear regression equation was calculated as y = mx + b, by considering MRCA the dependent variable. It showed an intercept value of 6.0 and a slope value of 0.92. The mean difference was 4.5, indicating that MRCA slightly underestimates the degree of coronary stenoses. The standard error of estimates was 0.21. The 95% confidence interval for the bias was 41.3 to –32.3. The 95% confidence interval for upper and lower limits of agreement was 40.6 to 42.0 and –31.6 to –33.0, respectively. We observed a dispersion of data over the upper limits of agreement due to the lower concordance of the two technique in assessing coronary stenoses in the middle tract of epicardial vessels, mostly regarding LCx. Despite that, the observed limits of agreement were small enough to be confident (Figure 4).

Only considering the estimate of proximal lesions, we obtained a high correlation value: r = 0.86 ($p < 0.001$). The intercept value was 5.7 and the slope value was 0.91. Thus, MRCA tends to give a slight overestimation of the degree of coronary stenoses. We calculated a

Table I. Overall MRCA data in the evaluation of coronary stenoses, compared to CA.

Segments	*Sensitivity %*	*Specificity %*	*PPV %*	*NPV %*
LM	100	100	100	100
LAD prox	97	93	86	97
LAD med	89	91	81	95
LAD	92	92	72	96
LCx prox	75	67	50	86
LCx med	63	65	20	92
LCx	71	65	36	89
RCA prox	100	93	90	100
RCA med	92	92	75	98
RCA	95	92	72	99
Overall	86	83	60	95

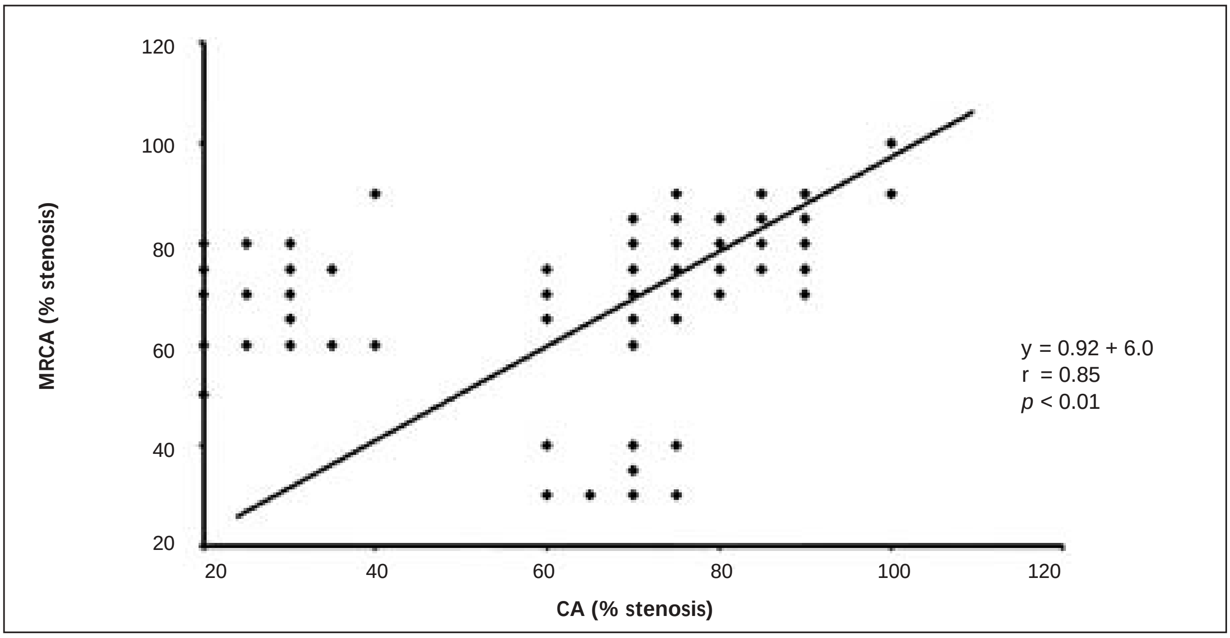

Figure 3. Correlation between magnetic resonance coronary angiography (MRCA) and conventional coronary angiography (CA) in evaluating the degree of stenoses.

mean difference of 3.9 with a standard error of estimate of 0.30. The 95% confidence interval for the bias was 40.2 to –32.4. The 95% confidence interval for upper and lower limits of agreement was 39.2 to 41.0 and –31.4 to –33.4, respectively. A correlation coefficient of 0.84 ($p < 0.001$) was calculated by comparing the degree of stenoses in the middle segments of coronary arteries. An intercept value of 6.3 and a slope value of 0.93 were determined. A higher estimation of degree of coronary narrowings was observed in evaluating middle

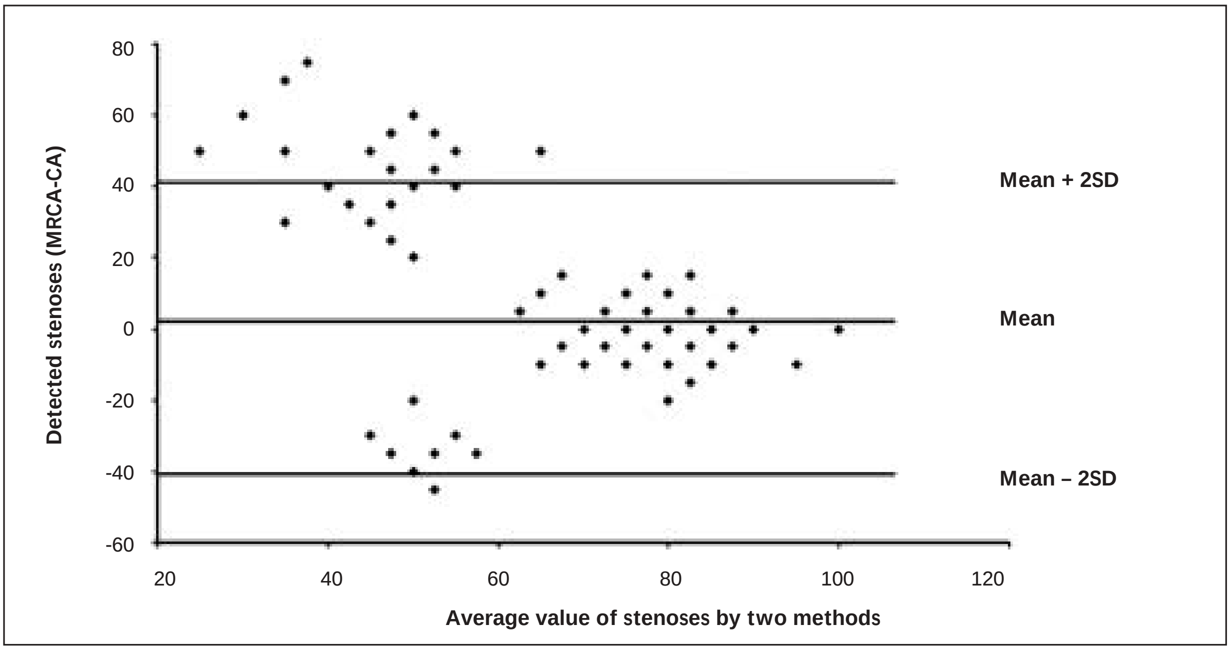

Figure 4. Differences between the percentage degree of stenoses against the mean of measurements by two methods.

segments. We calculated a mean difference of 5.0 and a standard error of estimate of 0.31. The 95% confidence interval for the bias was 42.2 to –32.2. The 95% confidence interval for upper and lower limits of agreement was 41.2 to 43.3 and –31.2 to –33.3, respectively.

Discussion

The emerging role of MRCA in detecting coronary stenoses in comparison with conventional CA has been recently reported in literature[17,28].

In our study we used the MR multislice 2D breath-hold sequence (spiral) to depict epicardial coronary segments and to detect intraluminal narrowings. According to our data, this technique has been shown to compare favourably with conventional CA for the detection of significant stenoses.

Unlike previous 2D technique, that acquired a single slice per breath-hold, the multislice technique offers the option of acquiring multiple contiguous 2D slices in the same time frame, decreasing the difficulty of imaging the vessels and improving the skill of quantifying the severity of narrowing. Moreover, the multislice 2D technique provides higher intravascular signal intensity than 3D methods. On the other side, a 12 to 18 seconds breath-hold is required and this could be difficult for some patients, especially for those with severe cardiac or pulmonary dyspnoea.

We found a good sensitivity and specificity in detecting significant coronary stenoses and the resolution achieved by this technique allowed us to differentiate between non-significant and significant (> 50%) coronary stenoses, as provided by conventional CA, although MRCA gave us a slight overestimation of luminal narrowing.

Extensive segments of the epicardial coronary arteries were consistently imaged in the angiograms of the all enrolled patients, even if branch vessels with smaller diameters and distal coronary structures were not well displayed and so were excluded from the evaluation. In our study the reproducibility of MRCA in reading epicardial coronary lesions was very high, providing a consistency of image interpretation in all consecutive sessions.

The review of the literature showed some differences between our data, using the multislice 2D technique, and previous reports. Sandstede et al.[28] reported a sensitivity of 70% and a specificity of 90% for the detection of coronary stenoses. More recently, Watanabe et al.[29], by using in 12 patients a high-resolution selective three-dimensional technique, reported a sensitivity of 80% and a specificity of 85%. The present study the sensitivity was slight higher (86%) and the specificity was 83%, with increased values as compared to Nikolaou et al[19]. The good sensitivity and specificity of our study, similar to that reported by Watanabe et al.[29], could be explained considering that all the distal segments were excluded because of their reduced image quality. It could produce false positive results and the real stenoses could be hidden. Although the multislice acquisition allowed to image the entire course of the coronary tree, we limited the assessment of stenoses only to proximal and middle segments of the vessels to avoid the unacceptable increase of false positive result[19,26]. As reported in previous studies[2,5,16,20,29-36], the false positive results were mainly due to small vessel sizes because of partial volume effects of the neighbouring tissues. On the other side in the clinical setting, the imaging of distal segments and side branches may be useful in assessing the patency of revascularization procedures[33]. Poor image quality occurred if patients were unable to hold their breath until the end of the measurement leading to considerable image blurring. Moreover, the main drawback of MRCA was that several coronary segments were not evaluated for inadequate image quality, particularly of the LCx, which moves more rapidly in diastole than the LAD coronary artery. This might really contribute to the higher percentage of inadequate image quality and false positive results occurring in the imaging of this vessel.

We did not use contrast agents in our study because the bright-blood effect produced a good contrast-to-noise ratio within all the coronary artery tree. However, MRCA image contrast may be improved by the use of contrast agents. The usefulness of conventional extra cellular contrast agents has been demonstrated in breath-hold MRCA[26,37]. New intravascular contrast agents have been developed and some of them are currently undergoing Food and Drug Administration trials. These intravascular agents with a high relaxivity remain within the vessels longer than extra cellular ones and they are likely to benefit the breath-hold technique[38].

Conclusions

Although MRCA should not be considered applicable for the detection of all coronary artery stenoses, because spatial and temporal resolutions are still limited, its current clinical role could be crucial in ruling out the atherosclerotic involvement of major epicardial coronary arteries in patients at-risk for myocardial ischemia. The possibility to quantify flow within coronary arteries, as recently reported[31], combined with morphological and perfusion studies, will considerably increase the clinical usefulness of this non-invasive technique. Thus, MRCA would be more effective in detecting coronary artery diseases and so its clinical role will be more definite in the future years.

References

1) *Paulin S, von Schulthess GK, Fossel E, Krayenbuehl HP*. MR imaging of the aortic root and proximal coronary arteries. Am J Roentgenol 1987; 148: 665-670.

2) *Duerinckx AJ. Urman MK.* Two-dimensional coronary MR angiography: analysis of initial clinical results. Radiology 1994; 193: 731-738.

3) *Edelman RR, Manning W, Burstein D, Paulin S*. Coronary arteries: breath-hold MR angiography. Radiology 1991; 181: 641-643.

4) *Manning WJ, Li W, Boyle NG, Edelman RR*. Fat-suppressed breath-hold magnetic resonance coronary angiography. Circulation 1993; 87: 94-104.

5) *Manning WJ, Li W, Edelman RR.* A preliminary report comparing magnetic resonance coronary angiography with conventional angiography. N Engl J Med 1993; 328: 828-832.

6) *Pennell DJ, Keegan J, Firmin DN, Gatehouse PD, Underwood SR, Longmore DB.* Magnetic resonance imaging of coronary arteries: technique and preliminary results. Br Heart J 1993; 70: 315-326.

7) *Wyman RM, Safian RD, Portway V.* Current complications of diagnostic and Therapeutic cardiac catheterization. J Am Coll Cardiol 1988; 12: 1400-1406.

8) *Owens RS, Carpenter JP, Baum A, Perloff LJ, Cope C*. Magnetic resonance imaging of angiographically occult runoff vessels in peripheral arterial occlusive disease. N Engl J Med 1992; 326: 1577-1581.

9) *Polak JF, Bajakian RL, O'Leary DH, Anderson MR, Donaldson MC, Jolesz FA.* Detection of internal carotid artery stenosis: comparison of MR angiography, color doppler sonography, and arteriography. Radiology 1992; 182: 35-40.

10) *Van Der Wall EE, Vliegen HW, de Roos A, Bruschke AV*. Magnetic resonance imaging in coronary artery disease. Circulation 1995; 92: 2723-2739.

11) *Mc Connell MV, Ganz P, Selwyn AP, Li W, Edelman RR, Manning WJ.* Identification of anomalous coronary arteries and their anatomic course by magnetic resonance coronary angiography. Circulation 1995; 92: 3158-3162.

12) *Duerinckx AJ, Troutman B, Allada V, Kim D*. Coronary MR angiography in Kawasaki disease. Am J Roentgenol 1997; 168: 114-116.

13) *Gomes AS, Lois JF, Drinkwater DC Jr, Corday SR.* Coronary artery bypass grafts: visualization with MR imaging. Radiology 1987; 162: 175-179.

14) *Worthley SG, Helft G, Fuster V, et al.* High resolution ex vivo magnetic resonance imaging of in situ coronary and aortic atherosclerotic plaque in a porcine model. Atherosclerosis 2000; 150: 311-329.

15) *Wang Y, Rossman PJ, Grimm RC, Riederer SJ, Ehmann RL*. Navigator-echo based real-time respiratory gating and triggering for reduction of respiration effects in three-dimensional coronary MR angiography. Radiology 1996; 198: 55-60.

16) *Li D, Kaushikar S, Haacke EM, Woodard PK, Dhawale PJ, Kroeker RM*. Coronary arteries: three dimensional MR imaging with retrospective respiratory gating. Radiology 1996; 201: 857-863.

17) *Post JC, van Rossum AC, Hofman MBM, Valk J, Visser CA.* Three-dimensional respiratory-gated MR angiography of coronary arteries. comparison with conventional coronary angiography. Am J Roentgenol 1996; 166: 1399-1404.

18) *Wang Y, Rossman PJ, Grimm RC, Riederer SJ, Ehmann RL.* Navigator-echo based real-time respiratory gating and triggering for reduction of respiratory effects in three-dimensional coronary MR angiography. Radiology 1996; 198: 55-60.

19) *Nikolaou K, Huber A, Knez A, Scheidler J, Petsch R, Reiser M.* Navigator echo-based respiratory gating for three-dimensional MR coronary angiography. reduction of scan time using a slice interpolation technique. J Comp Ass Tom 2001; 25: 378-387.

20) *Ikonen AE, Manninen HI, Vainio P, et al*. Repeated 3D coronary MR angiography with navigator echo gating: technical quality and consistency of image interpretation. J Comp Ass Tom 2000; 24: 375-381.

21) *Duerinckx AJ, Atkinson DP, Mintorovitch J, Simonetti OP, Urman MK.* Two-dimensional coronary MRA: limitations and artefacts. Eur Radiol 1996; 6: 312-325.

22) *Van Ooijen PM, de Feyert PJ, Oudkerk M.* An introduction to three-dimensional cardiac imaging, rendering and processing. Cardiologie 1997; 4: 312-319.

23) *Van Geuns RJ, Wielopolski PA, de Bruin HG, et al.* MR coronary angiography with breath-hold targeted volumes: preliminary clinical results. Radiology 2000; 217: 270-277.

24) *Li D, Dolan RP, Walovitch RC, Lauffer RB.* Three-dimensional MRI of coronary arteries using an intravascular contrast agent. Magn Res Med 1998; 39: 1014-1018.

25) *A reporting system on patients evaluated for coronary artery disease: report of the Ad Hoc Committee for Grading of Coronary Artery Disease.* Circulation 1975; 51 (Suppl): 5-40.

26) *Regenfus M, Ropers D, Achenbach S, et al.* Noninvasive detection of coronary artery stenosis using contrast-enhanced three-dimensional breath-hold magnetic resonance coronary angiography. J Am Coll Cardiol 2000; 36: 44-50.

27) *Bland JM, Altman DG.* Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1(8476): 307-310.

28) *Sandstede J, Pabst T, Kenn W, Beer M, Neubauer S, Hahn D.* Three-dimensional MR coronary angiography in navigator-technique for primary diagnosis of coronary heart disease: a comparison with conventional coronary angiography. Ro Fo 1999; 170: 269-274.

29) *Watanabe Y, Nagayama M, Amoh Y, et al.* High-resolution selective three-dimensional magnetic resonance coronary angiography with navigator-echo technique: segment-by-segment evaluation of coronary artery stenosis. J Magn Reson Imaging 2002; 16: 238-245.

30) *Muller MF, Fleish M, Kroeker R, Chatterjee T, Meier B, Vock P.* Proximal coronary artery stenosis: three-dimensional MRI with fat saturation and navigator echo. J Magn Reson Imaging 1997; 7: 644-651.

31) *Hundley WG, Hamilton CA, Clarke GD, et al.* Visualization and functional assessment of proximal and middle left anterior descending coronary stenoses in humans with magnetic resonance imaging. Circulation 1999; 99: 3248-3254.

32) *Post JC, Van Rossum AC, Hofman MBM, de Cock CC, Valk J, Visser CA.* Clinical utility of two-dimensional magnetic resonance angiography in detecting coronary artery disease. Eur Heart J 1997; 18: 426-433.

33) *Kessler W, Achenbach S, Moshage W, et al.* Usefulness of respiratory gated magnetic resonance coronary angiography in assessing narrowings > 50% in diameter in native coronary arteries and in aortocoronary bypass conduits. Am J Cardiol 1997; 80: 989-993.

34) *Woodard PK, Li D, Haacke EM, et al.* Detection of coronary artery stenoses on source and projection images using three-dimensional MR angiography with retrospective respiratory gating: preliminary experience. Am J Roentgenol 1998; 170: 883-888.

35) *Sandstede JW, Pabst T, Beer M, et al.* Three-dimensional MR coronary angiography using the navigator technique compared with conventional coronary angiography. Am J Roentgenol 1999; 172: 135-139.

36) *Yang PC, Meyer CH, Terashima M, et al.* Spiral magnetic resonance coronary angiography with rapid real-time localization. J Am Coll Cardiol 2003; 41: 1134-1141.

37) *Ho VB, Foo TK, Arai AE, Wolff SD.* Gadolinium-enhanced, vessels-tracking, two-dimensional coronary MR angiography sin dose arterial-phase vs. delayed-phase imaging. J Magn Reson Imaging 2001; 13: 682-689.

38) *Knuesel PR, Nanz D, Wolfensberger U, et al.* Multislice breath-hold spiral magnetic resonance coronary angiography in patients with coronary artery disease: effect of intravascular contrast medium. J Magn Reson Imaging 2002; 16: 660-667.