MULTISLICE SPIRAL COMPUTED TOMOGRAPHY IN CARDIAC IMAGING

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ABSTRACT

Objective: Multislice computed tomography is an emerging technology with the potential for non-invasive coronary investigation. The aim of this study was to evaluate the feasibility and limitations of multislice computed tomography in the detection of coronary artery disease.

Patients and Methods: Multislice computed tomography was performed in symptomatic patients with atypical chest pain and in asymptomatic patients. Each patient underwent prospective electrocardiograph triggered investigation without contrast medium for screening and quantification of coronary calcifications, and retrospective electrocardiography gated multislice computed tomography angiography for visualisation of coronary artery lumen changes.

Results: Superior image quality of both axial and 3-dimensional images was achieved with multislice computed tomography in patients with slower heart rates and those in regular sinus rhythm. Greatly improved image quality in obese patients, allowed for reliable quantification of coronary calcifications. With multislice computed tomography angiography, good image quality was achieved in patients with a heart rate of less than 70 beats per minute.

Conclusion: Multislice computed tomography appears of benefit in the non-invasive assessment of coronary artery disease, despite its use being currently limited by the exposure time of 250 ms to patients with a slower heart rate.

Key Words: Computed tomography, angiography, Coronary vessels, Electrocardiography

INTRODUCTION

Coronary artery disease (CAD) is a major health problem and a frequent cause of mortality in developed countries. The need to detect coronary atherosclerosis early in its clinical course is well recognised.1 Selective coronary angiography (SCA), an invasive procedure, remains the diagnostic standard for establishing the presence, site and severity of CAD. However, the nature and predictability of plaque behaviour cannot be determined by SCA. In addition, SCA cannot be used as a screening test as it is an invasive procedure, involving certain risks.2 Given the associated patient risk and costs of SCA, an alternative method for determining CAD would be very useful and could lead to a reduction in diagnostic coronary catheterisation procedures.3,4

Several imaging techniques have been utilised to image CAD non-invasively, including transthoracic and transoesophageal echocardiography,5-6 fluoroscopy,7 and magnetic resonance imaging (MRI).8,9 None of these techniques have achieved reliable results in a clinical setting due to limitations in spatial, temporal, or contrast resolution. Electron beam computed tomography (EBCT) has also been used in the diagnosis of CAD, primarily as a means of quantifying coronary calcification,10-12 and detecting coronary artery stenoses or occlusion. However, high costs and limited availability to date have precluded widespread use of this approach.13-15

Multislice computed tomography (MSCT) represents a recent advance of the widely used and cost-effective helical CT scanning technique. With four slices scanned
simultaneously and a half-second rotation time, MSCT provides new opportunities for cardiac imaging. Partial view acquisition and electrocardiograph-gated helical reconstruction are feasible with this new type of scanner, allowing image acquisition with an effective exposure time of 250 ms in the slow motion phase of the cardiac cycle. The aim of this study was to evaluate the feasibility and limitations of MSCT use in the detection of CAD.

PATIENTS AND METHODS

Patient Population

One hundred consecutive patients (78 men, 22 women) were referred for quantification of coronary calcifications and detection of coronary artery stenoses between July 1999 and May 2000. Patients recruited into the study included symptomatic patients with atypical chest pain (n = 54), where MSCT was used as a primary investigation tool to assess the risk of CAD, and asymptomatic patients (n = 46), where MSCT was used to evaluate individual risk of developing CAD. Exclusion criteria for investigations were renal insufficiency (creatinine levels >1.5 mg/dL), previous coronary bypass surgery, or an unstable clinical condition. The study was approved by the Board of Ethics, Klinikum Grosshadern, and the National Federal Office for Radiation Protection. All subjects gave informed consent following detailed explanation of the procedure. Participants ranged in age from 27 to 87 years (mean age, 63 ± 15 years), and had a mean heart rate of 72 ± 16 beats per minute.

Coronary Screening

A multislice CT scanner (Somatom Plus 4 Volume-Zoom, Siemens, Forchheim, Germany) with dedicated cardiac reconstruction software, was employed. Sequential scanning of calcium screening commenced, using simultaneous acquisition of four 2.5 mm collimated slices at a table feed of 3.6 mm/sec, 500 ms rotation time, 140 kV, 100 mAs, and 250 ms exposure time. Prospective electrocardiograph (ECG) triggering at 450 ms prior to the next R wave (Figure 1), allowed investigation of the entire heart within a 20 to 30 second period, while the patient held his or her breath.

Coronary CT Angiography

Prior to MSCT angiography, a test bolus of 20 cc with a flow rate of 3 cc/sec was given, and repeated scanning (every 2 seconds) of the ascending aorta at the level of the main pulmonary artery was completed. Scan delay was then determined as the interval from the start of the injection to peak enhancement in the ascending aorta, plus three seconds. Coronary vessel enhancement was achieved with 140 cc of non-ionic contrast material (Ultravist 300°; Schering, Berlin, Germany), with a flow rate of 2.5 to 3 cc/sec. After the predetermined delay time, helical scanning was commenced using simultaneous acquisition of four 1 mm collimated slices at a table speed of 3.6 mm/sec and a rotation time of 500 ms. During the helical scan, the ECG trace was digitally recorded. Helical scanning ranged from 1 cm below the carina, to the base of the heart, covering 12 cm in 30 to 34 seconds.

Helical raw data and the digital ECG trace were used to retrospectively reconstruct axial images with a temporal resolution of 250 ms per slice, on a dedicated workstation (InSight, NeoImagery Technologies, City of Industry, California, USA). Slices at the different z-positions were reconstructed at the end of diastole, immediately prior to the P wave (Figure 2) and 400-550 ms prior to the next R wave. The field of view was adjusted to encompass the heart only. The effective slice thickness and reconstruction increments were 1.25 mm
and 0.5 mm, respectively, resulting in 210 to 240 axial slices for the entire volume.

**RESULTS**
The imaging protocol was well tolerated by all patients. All subjects were able to hold their breath for the required duration. Total room time required for each study was 20 minutes or less. No contrast reactions or complications occurred. Selective coronary angiography was performed in 32 patients within 8 ± 12 days of the MSCT angiographic study, using a transfemoral Judkins approach. Visualisation of stenoses on MSCT angiography was evaluated and compared with that achieved on SCA.

**Figure 3.** Coronary segments seen in axial multislice computed tomography images (a) and application of the volume rendering technique to the same data set, demonstrating the course of the coronary segments (b). Nomenclature is as specified by the American Heart Association18: 1-4: segments of the right coronary artery; 5: left main stem; 6-10: segments of the left anterior descending artery; 11 and 12: segments of the ramus circumflexus; RNS: ramus nodi sinuatrialis; RVD: ramus ventricularis dexter; RMD: ramus marginalis dexter; CS: coronary sinus; RPLD: ramus posterolateralis dexter; RPLS: ramus posterolateralis sinister; RAVS: ramus atrioventricularis sinister.
Contrast Enhancement and Contrast-to-Noise Ratio
The blood attenuation in the aortic root (46 ± 13 Hounsfield Unit [HU]) was similar to that of the left ventricle (45 ± 12 HU) on the non-enhanced MSCT images. Attenuation in the aortic root and in the coronary arteries increased significantly after contrast administration (p < 0.001, paired t test). Aortic root attenuation increased to 256 ± 22 HU (range, 232 to 283 HU). Larger branch vessels from the major coronary arteries were often identified (Figures 3a and 3b). Attenuation in all the major coronary arteries increased to exceed 200 HU, while intraventricular attenuation increased to a greater degree (mean, 275 ± 21 HU).

The average contrast-to-noise ratio (CNR) of the MSCT data was 9.1. The CNR was highest (11.0 ± 1.8) in the proximal right coronary artery and lowest (6.0 ± 2.1) in the distal ramus circumflexus. The CNR on the MSCT images decreased systematically from proximal to distal, within each coronary artery.

Image Quality
Superior quality of both axial and 3-dimensional (3D) images could be achieved with MSCT in patients with slower heart rates or a regular sinus rhythm. Image quality was greatly improved in obese patients, allowing for reliable quantification of coronary calcifications. Figure 4 provides a representative comparison between MSCT and EBCT imaging in an obese patient, illustrating the superior image quality achieved with the MSCT technique. Using MSCT angiography, good image quality was achieved in all patients with a heart rate less than 70 beats per minute.

Coronary MSCT angiography has the potential to allow better visualisation of the extent of atherosclerosis than that obtained with non-enhanced CT screening. Figure 5 shows MSCT angiography imaging of a 67 year-old male patient, with coronary atherosclerosis demonstrated by plaques appearing in the coronary wall. In the authors’ experience with MSCT angiography, no correlation between calcified plaques and high grade stenosis has been noted.

DISCUSSION
A non-invasive, imaging technique requires high spatial resolution and high contrast-to-noise ratios to identify stenoses in coronary arteries. A sufficient injection of contrast material is also necessary to obtain a high contrast level. A further major challenge for coronary CT angiography is to control for significant cardiac motion artifacts. MSCT offers several advantages as an imaging approach in this regard — a thin section, short acquisition time, and the ability to use retrospective data processing.

Scan acquisition during the slow motion phase of the heart allows the shortest possible scan time. To obtain images which are completely free of motion artifacts, a very short acquisition time would therefore be necessary. Unfortunately, to date acquisition times this short are impossible to obtain using MSCT (Figure 6). Although EBCT has a shorter acquisition time compared with MSCT, the dosage applied in EBCT is limited. This along with other reasons accounts for the greater noise level seen with EBCT imaging. Research shows that in helical CT reconstruction, the 180° linear interpolation algorithm is superior to the
360° linear interpolation algorithm for reducing motion artifacts in the ascending aorta. According to the 180° linear interpolation algorithm, also available in MSCT, the temporal resolution of a 500 ms helical MSCT scan is approximately 250 ms, with a proportionate decrease in motion artifact. Additionally, fast table movement in the helical mode tends to lead to pitch artifacts that increase cardiac motion artifacts and thereby reduce the accuracy of the score or stenosis measurement. In terms of the compromise between scan speed and motion artifact, the authors suggest the use of a pitch of approximately 1.5 for MSCT imaging.

Prospective ECG triggering is widely used but is inaccurate in the context of rapid changes in heart rate, or absolute arrhythmia. Irregularities during ECG recording will result in cardiac motion artifacts and in slice gaps or overlaps due to axial movement with every heart beat. As the heart rate changes during respiratory suspension, rapid adaptation of the ECG trigger to the heart rate is also essential. Retrospective ECG gating has advantages over prospective ECG triggering for patients with irregular heart rates due to fibrillation, and for those individuals with frequent changes in heart rate while holding their breath. In the current study, an interval of 400 to 550 ms prior to the next R wave was selected for retrospective ECG gated reconstruction of the MSCT raw data, to ensure image reconstruction prior to significant motion artifacts arising from systolic cardiac movement. ECG gating can also ensure scanning of the entire heart without gaps or overlap caused by axial movement of the heart during a cardiac cycle.

With regard to coronary screening, ECG-triggered multislice CT has a number of advantages over single slice CT and EBCT. Firstly, multislice acquisition allows improved calcium quantification and reproducibility as errors are largely eliminated. Due to the complex 3D motion of the heart, there is a high likelihood of missing calcifications or counting them twice with single slice sampling. Multislice imaging considerably reduces this probability. Moreover, EBCT is restricted to a fixed tube current setting. With multislice CT, the tube current setting can be adjusted for patient obesity to provide appropriately low image noise, allowing accurate calcium evaluation for all patients.
Scanner specifications require that prospectively triggered MSCT investigation of the heart must be performed with 4 times the 2.5 mm slice thickness. It has been shown that calcified plaques are more often detected in thinner slices due to decreased partial volume, however. While new technical developments are underway currently to reduce the slice thickness required, this impact of slice thickness on the results of calcium scoring should be kept in mind.

Retrospective ECG gating with MSCT requires a longer exposure time (250 ms) than prospectively ECG triggered electron beam CT (100 ms). However, a major advantage of retrospective ECG gating is that images can be reconstructed at any desired time point within the R wave to R wave interval. This advantage is most evident in patients with irregular heart rates due to atrial fibrillation although even in the normal heart, changes in heart rate frequently occur within a breath-hold. Disadvantages of retrospective ECG gating with MSCT include increased radiation compared with the prospective approach, and its deficient exposure time for patients with higher heart rates.

In the current study, the evaluation of coronary segments was based primarily on scrolling through the original axial slices. To achieve 3D post-processing within a reasonable timeframe (10 to 15 minutes), real time interactive 3D visualisation without manual segmentation was used exclusively to reach the diagnosis. Sliding thin slab maximum intensity projection was found to be particularly useful to follow the course of the coronary vessels, in order to create MSCT angiographic projection planes comparable to those derived from SCA. Shaded surface display (SSD) was not used in this study because of the time-consuming manual segmentation it demands to visualise the entire coronary tree.

One of the current limitations for the application of coronary MSCT angiography is its temporal resolution of 250 ms exposure time per slice. With this exposure time, diagnostic image quality can be achieved only in patients with a heart rate of less than 70 beats per minute. Higher heart rates can be reduced to allow sufficient diagnostic image quality by administering an oral beta blocker one hour prior to the CT investigation, after contraindications have been excluded (Figure 7). Shorter exposure times with MSCT may be realised in the future, with faster gantry rotation and alternative reconstruction algorithms.

CONCLUSION
Retrospective ECG gated MSCT provides high coronary image quality, despite cardiac motion, and the small size and tortuosity of the coronary arteries. Recent research has shown the potential of MSCT to image calcium and stenoses within the major coronary artery segments.

While further studies need to confirm these encouraging results, MSCT appears to have the potential to become a useful non-invasive test for the diagnosis of coronary artery disease in the future.
REFERENCES


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