Effect of Reconstruction Parameters on Cardiac CT Angiography Image Quality

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Abstract

Cardiac CT exams are being investigated as a means to diagnose and evaluate coronary artery disease. The quality of these studies is determined by many factors including timing of contrast delivery, patient cooperation during breath hold, CT acquisition parameters including radiation dose, and scan reconstruction parameters such as slice thickness and reconstruction filters.

The purpose of this investigation was to determine the impact of reconstruction parameters on spatial resolution and image quality as defined both by signal-to-noise ratio measurements and human judgement. Both phantom and clinical datasets were investigated.

Our findings indicate that slice thickness and the choice of reconstruction filter have significant impact on noise and image quality perception. Further investigation into the effects of clinical interpretation of coronary lesions is needed.

1. Introduction

New advancements in computed tomography (CT) technology enable high-resolution cardiac CT angiography exams with sub-millimeter isotropic resolution. These ECG-tagged cardiac examinations with retrospectively gated reconstruction require low pitch factors and slow table speeds (4-8 mm/s). CT image quality is a function of many different factors, including scan protocol, injection protocol, and reconstruction protocol. As shown in Figure 1, the ability to discern and quantify coronary lesions is critical for the use of this modality in clinical assessment. While various protocols have been suggested for cardiac CT data acquisition and image generation, optimal reconstruction parameters are not well established. Therefore, this study was performed to investigate the impact of reconstruction parameters on spatial resolution and image quality of the system.

In-plane spatial resolution is an expression of the user's ability to resolve small spatial details. Resolution is normally reported in line pairs per centimeter (lp/cm). Typically values range from 5 to 21 lp/cm at 2% modulation. The lp/cm is derived from the modulation transfer function (MTF) of the system. The MTF is calculated from the real portion of the Fourier Transform of the point-spread function. The MTF describes the ability of the system (in this case the CT scanner) to transfer the spatial information of an object to an image. System geometric considerations (such as focal spot size, detector width and sampling), pixel size and the convolution kernel (reconstruction filter) all impact the MTF and spatial resolution. MTF is normally plotted as frequency (lp/cm) vs. MTF (%) and normally reported as $MTF_{50\%}$, $MTF_{10\%}$, $MTF_{2\%}$, $MTF_{0\%}$ (cut-off). $MTF_{2\%}$ approximates the human visual system's ability to resolve objects.

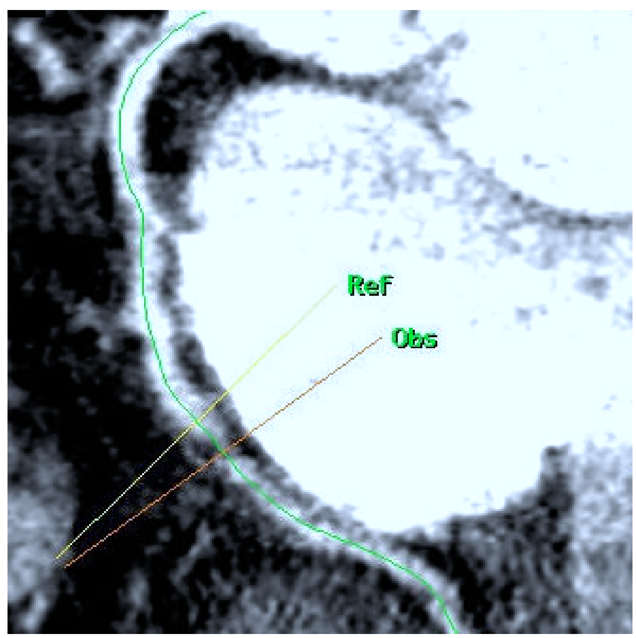

Figure 1. Example of a curved multiplaner reconstruction of the right coronary artery indicating reference (Ref) and obstruction (Obs) regions.

2. Methods

2.1. Data acquisition

To address noise and spatial resolution, a standard 0.25 mm bead phantom was scanned using a 16-slice CT scanner (Mx8000IDT, Philips Medical Systems) with the normal coronary scanning protocol [140kV, 400mAs, 0.42s gantry rotation, 0.2 pitch, heart rate of 60 bpm, detector collimation of 16x0.75mm, slice thickness (ST) of 0.8mm, slice increment (SI) of 0.4 mm, matrix size of 512].

Five patient studies also acquired using the normal coronary scanning protocol on the CT scanner were utilized to assess the effect of reconstruction parameters on image quality.

2.2. Data analysis

Studies (phantom and clinical scans) were reconstructed with a combination of four different reconstruction filters (CA,CB,CC,CD) and three different slice thickness (0.8,1.0,2.0 mm). Each reconstruction was analyzed identically using a dedicated workstation (MxView, Philips Medical Systems).

Image noise was evaluated by measuring the standard deviation (Houndsfield units) in a large uniform region of interests (ROI) within the phantom. The impulse response and resulting spatial resolution from the MTF curves were determined from the centrally located bead.

Clinically, noise measurements were performed in the ascending and descending aorta at the level of the ostium of the left main coronary artery on axial CT slices. Qualitative interpretation of axial and volume rendered images were also performed using side-by-side comparisons by two cardiologists.

3. Results

3.1. Phantom data analysis

Phantom scans were used to describe the change in noise with various combinations of the slice thickness and reconstruction filter used during reconstruction. Figure 2 shows the impact of different filters (CA, CB, CC, CD) and slice thickness (0.8, 1.0 and 2.0 mm) on the noise. The noise increased significantly with sharpness of filtering. Modulation transfer functions (MTF) of the system for the four cardiac reconstruction filters are shown in Figure 3.

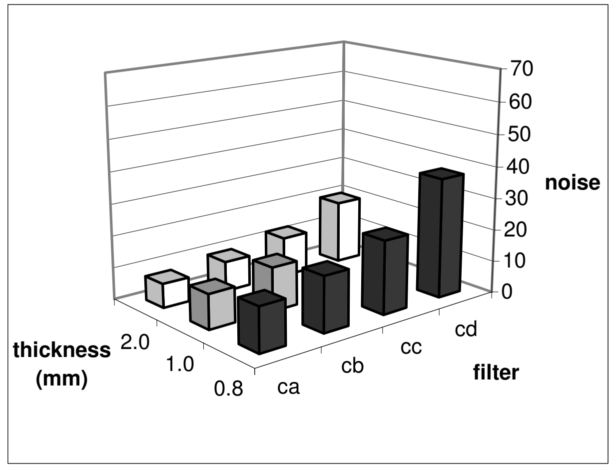

Figure 2. Noise measurements from the cardiac phantom showing the variations with increasing slice thickness and spatial smoothing.

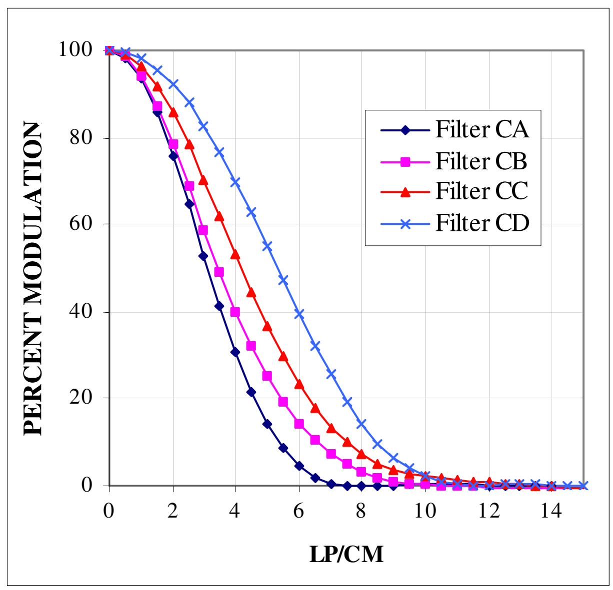

Figure 3. Modulation transfer function (MTF) of the system for the four cardiac reconstruction filters.

From these results, we can draw several conclusions. First, the use of a sharper reconstruction filter yields a higher spatial resolution. As the filters CA, CB, CC, and CD are arranged from smoothest to sharpest the spatial resolution follows suit (6.5, 8.5, 10, 10.5 $MTF_{2\%}$, respectively). Secondly, there is a trade-off for the improved spatial resolution is image noise. As the spatial resolution increases, the image noise does as well. The effects of these trade-offs on clinical images are described next.

3.2. Human data analysis

Clinical scans were also used to describe the change in image noise and perceived image quality with various combinations of slice thicknesses and reconstruction filters. Figure 4 demonstrates the impact of different filters (CA, CB, CC, CD) and slice thickness (0.8, 1.0 and 2.0 mm) on the noise. These results are consistent with the trends observed in phantom analysis. Figures 5 and 6 show examples of the axial slices and volume rendered images obtained with different reconstruction filters and a constant slice thickness of 0.8 mm.

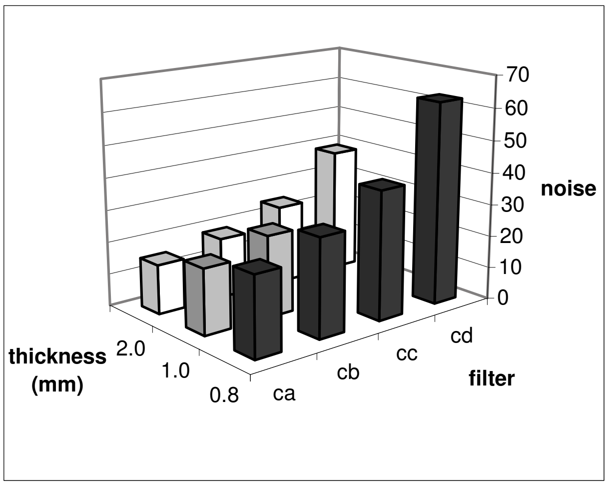

Figure 4. Noise measurements from the clinical cardiac cases showing variations with increasing slice thickness and spatial smoothing.

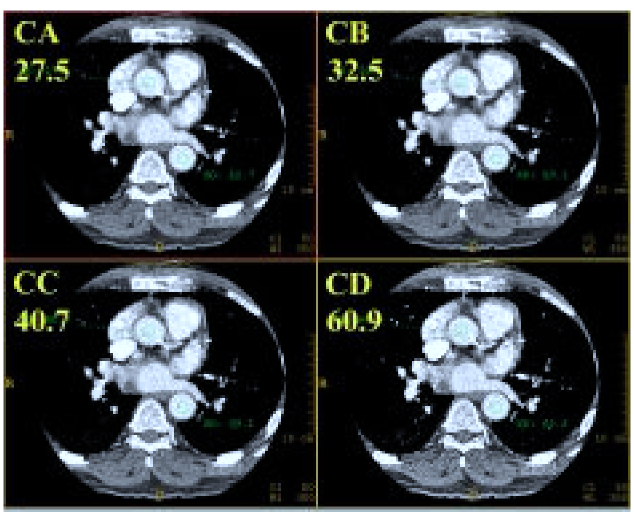

Figure 5. Noise measurements for the four reconstruction filters used during reconstruction of 0.8 mm axial slices from one clinical study.

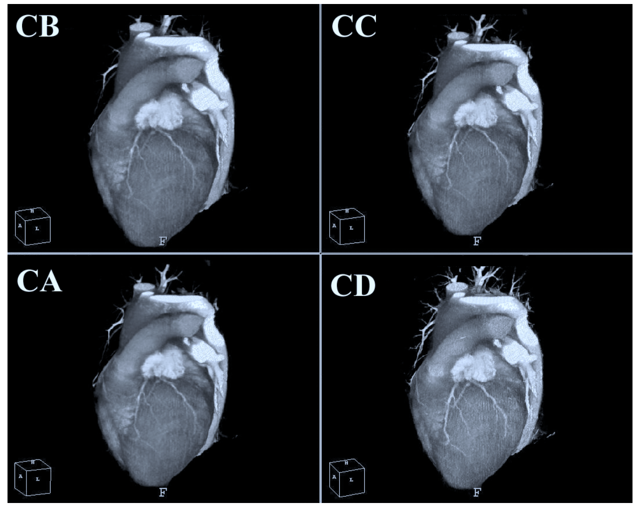

Figure 6. Volume rendered images of the coronary arteries using a slice thickness of 0.8 mm and the four cardiac filters as indicated.

Clinical assessment of the effect of reconstruction parameters on image quality was made by cardiologists in an evaluation of random side-by-side images. The cardiologists reported whether one of the images had greater image quality or if the images had equivalent image quality. The rating for axial images with CA and CB filters was higher than for the sharper filters, indicating the importance of reducing image noise for improving diagnostic quality. Interestingly, greater slice thickness (1 and 2.0 mm) with less filtering was rated slightly better than 0.8 mm reconstruction with CA or CB. This may be an indication that datasets with isotropic resolution and a reasonable noise level are clinically preferable to datasets with solely the highest resolution.

The impact of image quality should be further assessed on the ability to make a diagnosis of coronary artery disease or quantify the extent and degree of a coronary stenosis. Figure 7 shows three curved multiplaner reconstructions (cMPR) of a bypass graft using various combinations of the slice thickness and reconstruction filter. The top and middle images show the difference in the cMPRs with a change in the reconstructed slice thickness (2.0 vs. 0.8 mm) while the middle and bottom cMPRs show the effect of the filter (CA vs. CD).

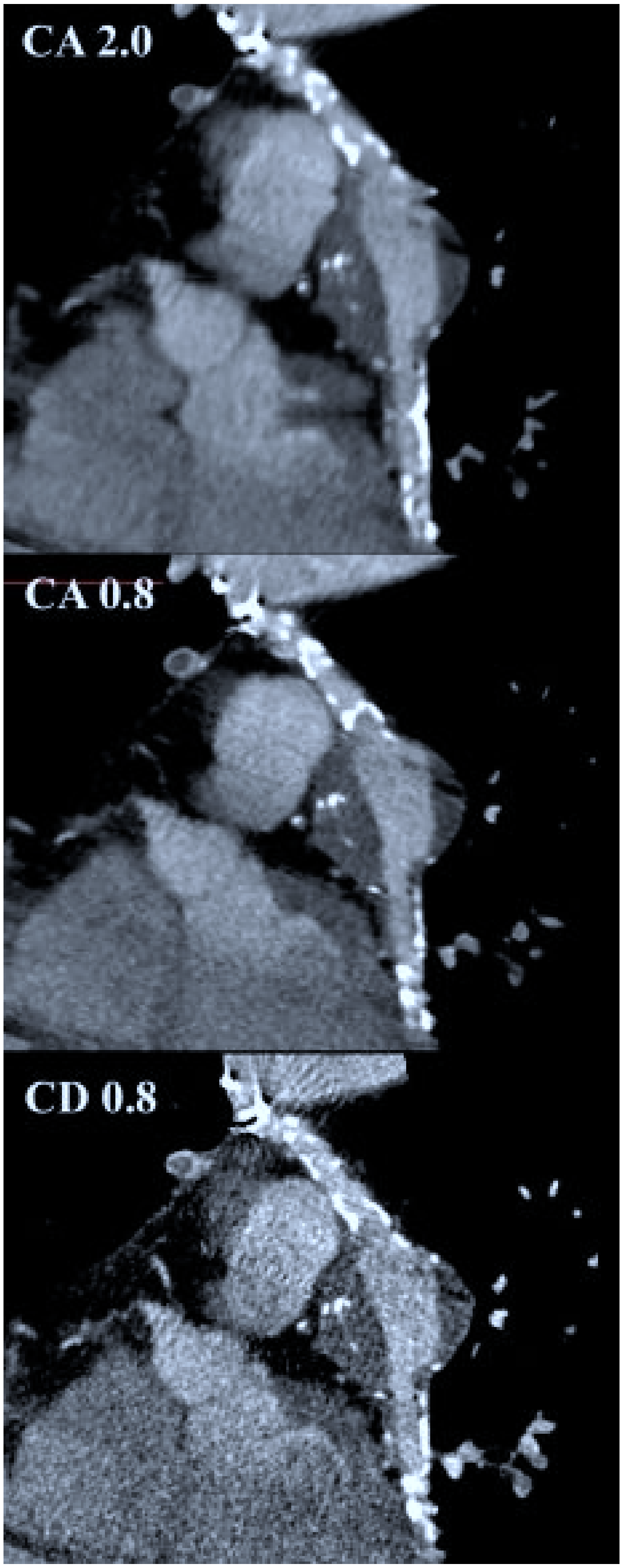

Figure 7. Curved multiplane reconstructions (cMPR) of a subject with a bypass graft aneurysm. Data reconstructed with 3 combinations of filters and slice thickness (top: CA, 2.0 mm; middle CA, 0.8 mm; bottom CD, 0.8 mm).

4. Conclusions

These findings indicate that the selection of a reconstruction filter and slice thickness for reconstruction have a significant impact on the noise and image quality perception. The effects of these parameters on the spatial resolution of the system are important as the coronary arteries are only 4 to 1 mm in diameter as the vessels follow a distal path. Reduction of image noise and attainment of isotropic resolution improve the diagnostic value of the images. Further investigation into the effects of clinical interpretation of coronary lesions must be examined.

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