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Reproducibility of multi-slice spiral computed tomography scans: An experimental study

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In multi-slice spiral computed tomography (CT) images interpolation artifacts are present. The relationship between the x-ray tube rotation angle and these artifacts is demonstrated. A head phantom was repeatedly scanned with a four-slice CT scanner at different pitch values. Two scans, made with identical scan parameters, nearly always have different x-ray tube starting angles. Consequently, artifacts appeared differently and residual artifacts appeared when subtractions were made. We conclude that only if the x-ray tube starting angle is equal for both scans or if a very low pitch is used, images are highly reproducible. © 2004 American Association of Physicists in Medicine. [DOI: 10.1118/1.1796131]

I. INTRODUCTION

In spiral computed tomography (CT) image reconstruction at any position the required projections are calculated by interpolating measurements at positions nearby. This procedure generally leads to interpolation artifacts.^{1,2} The relationship between the x-ray tube rotation angle and the interpolation artifacts is demonstrated. The artifacts appear differently in otherwise identical scans because the x-ray tube rotation angle is not reproducible. For several image processing techniques, like masking and subtraction,³ it is important that structures that do not change between the two CT scans are depicted identically. Lack of reproducibility may have negative effects on the quality of the processed images.

II. MATERIALS AND METHODS

A head phantom consisting of a human skull in a synthetic material was scanned with a multi-slice CT scanner with four detector channels (Mx8000 Quad, Philips, Best, The Netherlands). The x-ray tube angle at the start of a spiral CT scan is denoted by ψ_0 . This angle, which cannot be chosen by the user, varies from scan to scan. The difference in ψ_0 for a pair of scans is denoted by $\Delta\psi$. In order to obtain a collection of different values for ψ_0 , a series of 16 scans was made with all adjustable scan parameters kept constant. Series of scans were made for pitch 0.375, 0.625, 0.875, 1.25, and 1.75. For

all scans tube voltage 120 kV, collimation 4×1 mm, scan length 5.5 mm and tube charge 250 mAs were used. Reconstructions were made with a voxel size of 0.3×0.3

FIG. 1. Left column: Cross-sectional subtraction images of the skull phantom with $\Delta\psi \approx 0^\circ$ (window center: 0 HU, window width: 200 HU, FOV 154×154 mm²). Central column: same as left column except that $\Delta\psi \approx 90^\circ$. Right column: cross-sectional images of the small sphere (window center: 100 HU, window width: 150 HU, FOV 8×8 mm²). Numbers for each row in the figure represent the pitch value.

FIG. 2. Difference D between a pair of CT scans as a function of $\Delta\psi$ and pitch (see numbers in figures). (a) Scans of skull phantom. (b) Scans of small sphere.

$\times 0.5 \text{ mm}^3$. For each series subtractions were made of all 120 possible combinations of the 16 scans, representing a range of values $\Delta\psi$. The root mean square (rms) difference between two CT data sets, denoted by D , was used as a measure for the reproducibility.

Furthermore, a small tungsten carbide sphere (diameter, 0.28 mm; New England Miniature Ball Corp; Norfolk, VA), embedded in a synthetic material, was scanned to quantify the interpolation artifacts present in spiral CT. Reconstructions of these scans were made with a voxel size of $0.1 \times 0.1 \times 0.1 \text{ mm}^3$. Scans with other ψ_0 's were simulated by rotating the images around the z axis (with the z axis in the direction of table movement). The rms difference D for any value of $\Delta\psi$ was determined by subtracting the original and the rotated images.

III. RESULTS

In Fig. 1 cross-sectional subtraction images of the skull phantom and cross-sectional images of the sphere are shown for three pitch values. For $\Delta\psi \approx 0^\circ$ at all pitch values, and for $\Delta\psi \approx 90^\circ$ at pitch 0.375 the subtraction images showed virtually no differences between two scans. For $\Delta\psi \approx 90^\circ$ residual artifacts appeared at higher pitch values. The individual differences in an image pair were on the order of 200 HU, and sometimes twice as high. The CT scans of the sphere showed virtually no artifacts at pitch 0.375. At higher pitch values windmill artifacts appeared.

In Fig. 2(a) the rms difference D between two scans of the skull phantom is given as a function of $\Delta\psi$ and pitch. The maximum of D was found in a broad region around $\Delta\psi = 90^\circ$. The difference D increased if the pitch was increased, except for pitch 1.75. In Fig. 2(b) the difference D between the images of the sphere is shown. The relationship between D and $\Delta\psi$ is in reasonable agreement with the relationship found in the skull phantom, depicted in Fig. 2(a).

IV. DISCUSSION

It was found that the x-ray tube starting angle ψ_0 nearly always differs between two scans. The shape and orientation

of the interpolation artifacts depend on this starting angle, and therefore large residual artifacts may appear when subtractions are made.

The measurements of the small sphere allowed for a more quantitative determination of the relation between the error in the subtractions and the difference $\Delta\psi$. For example, the local minima of D at $\Delta\psi = 60^\circ$, 120° and 180° for pitch 1.75 appear to be a result of the angle of 60° between the hyperdense streaks in the corresponding image.

Reproducible spiral CT scans can be obtained in two different ways. First, one could aim at the same x-ray tube angle for both scans. The x-ray tube starting angle, however, is completely unpredictable on our scanner. This has been reported for at least one other scanner as well.⁴ Moreover, if two scans with the same x-ray tube starting angle could be made, even a very small displacement of the patient in the z direction would result in $\Delta\psi \neq 0$ for the two scans. Alternatively, a low pitch value can be used. For pitch 0.375 the difference between scans is very small and virtually constant for all differences in starting angles. Unfortunately, practical considerations such as limitations of total scan time often prohibit such a low pitch value. A possible solution is the use of a multi-slice CT scanner with more detector arrays (16–64). It is known that these scanners also produce windmill artifacts for larger pitch values.⁵ However, the pitch value can be decreased considerably for the same scan time. Therefore we expect that highly reproducible scans can be made with these scanners.

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¹G. Wang and M. W. Vannier, "Stair-step artifacts in three-dimensional helical CT: An experimental study," *Radiology* **191**, 79–83 (1994).

²J. Wilting and J. Timmer, "Artefacts in spiral-CT images and their relation to pitch and subject morphology," *Eur. Radiol.* **9**, 316–322 (1999).

³M. van Straten, H. W. Venema, G. J. Streekstra, J. A. Reekers, G. J. den Heeten, and C. A. Grimbergen, "Removal of arterial wall calcifications in CT angiography by local subtraction," *Med. Phys.* **30**, 761–770 (2003).

⁴H. Hu, "Multi-slice helical CT: Scan and reconstruction," *Med. Phys.* **26**, 5–18 (1999).

⁵E. Shefer, G. Shechter, A. Altman, and D. Braunstein, "Windmill artifacts in 16-slice CT (abstr)," *Radiological Society of North America scientific assembly and annual meeting program*, Oak Brook, IL (2003).