IMAGE QUALITY IN EXTENDED ARC FILTERED DIGITAL TOMOSYNTHESIS

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Abstract

Purpose: To study image quality in Filtered Digital Tomosynthesis (FDTS) tomograms as a function of their reconstruction arc, using isocentrically acquired, fluoroscopic projection data.

Material and Methods: Both Digital Tomosynthesis (DTS) and Cone Beam CT (CBCT) reconstruction algorithms are based on backprojection and use cone beam projection data as input. Under limited angle conditions, CBCT is reduced to FDTS, where only a subset of projection data used for reconstruction. The effect of the reconstruction arc on the spatial resolution, slice thickness, contrast sensitivity, shape distortion and artifacts, was also experimentally studied. The investigation was performed using both simulated and actual fluoroscopic images.

Results and Conclusion: Image quality in terms of spatial resolution, slice thickness, shape distortion and artifacts, improved with increasing reconstruction arc and was optimized at 180°, while contrast continued to improve as the arc was increased to 360°. However DTS was assessed to be the technique of choice when reconstruction arcs of less than 40 degrees are used. Consequently, FDTS may be successfully implemented in applications involving extended arc reconstructions, in the range between 40° delimiting the DTS domain and 360° corresponding to CBCT.

Key words: tomosynthesis digital; imaging; volume; angiography.
Cone Beam CT (CBCT) has been used with radiotherapy simulators, to produce therapeutic-quality images, as those obtained using the systems’ CT option, which satisfy the data specification for 3D treatment planning software (2). CBCT exploits cone beam projection data acquired over a complete arc by using a planar detector such as an image intensifier (3). There are, however, situations where collecting projection data over 360° is not feasible; in such cases, limited angle reconstruction methods may be used.

DTS is a method of limited angle reconstruction of tomographic images, produced at variable heights, on the basis of a set of angular projections (5). The DTS reconstruction algorithms simulate classical tomography by either translating and adding the projection images (8) or by deploying the backprojection method, to transfer and deposit data at the intersection of each ray with the plane of reconstruction (6). In all approaches, a limitation in the size of sampling arc arises from the restricted movement of the tube-detector assembly. DTS tomograms are invariably affected by tomographic noise, i.e. blurred images of structural detail, lying outside the plane of interest, and superimposed over the focused image of the fulcrum plane. Several contributions have focused on enhancing the quality of these images by a variety of methods involving post-processing of tomograms (1, 9), or by pre-processing of projections (7, 11). Filtered Digital Tomosynthesis (FDTS) involves the application of filtering to the projection data, followed by backprojection (11).

This article comprises a study of image quality for FDTS reconstructed tomograms using data collected with isocentric fluoroscopic units, such as the radiotherapy simulator or the angiographic units. The effect of the reconstruction arc on spatial resolution, slice thickness, contrast sensitivity, shape distortion and artifacts, was experimentally investigated.

**Material and Methods**

Both DTS and CBCT reconstruction algorithms are based on backprojection and use cone beam projection data as input. Under limited angle conditions, CBCT
is reduced to FDTS, with only a subset of projection data used for reconstruction.

The overall effect of filtering of projection images as well as the variation of a basic set of image quality parameters as a function of the reconstruction arc was investigated using simulated projection data and geometries of the radiotherapy simulator. Simulated projections were generated with the use of a software data generator for radiographic imaging investigations (12). Additionally, a subjective visual assessment of image quality under different reconstruction arcs, using DTS and FDTS was performed on tomograms obtained using actual angiographic projection data from a contrast-enhanced sheep lung. The phantom was imaged with the Philips DVI, Digital Angiographic unit, operated at a source to isocenter distance equal to 67.5 cm and a source to image intensifier distance equal to 92.5 cm. The imaging chain had a limiting resolution of 12 lp/cm. Projection images were acquired every $2^0$ over a $120^0$ arc using a DTS prototype system (10). All projections were filtered along each row with a standard ramp filter and a Hamming window.

The following image characteristics were studied:

(i) **Spatial resolution**

Spatial resolution was measured using a simulated bar pattern phantom with line pairs varying in size from 1 to 20 lp/cm. The object was considered to have a thickness of 1 mm and to be inclined at $45^0$ with respect to the source detector rotation plane. The oblique orientation of the bars was chosen in order to provide visual information on the system’s ability to filter out noise at various distances from the coronal plane of the phantom (13). The source to isocenter distance was set to 100 cm and the source to image intensifier distance to 130 cm. The imaging chain was considered to have a limiting resolution of 20 lp/cm. Projection images were generated at every $2^0$ over a $360^0$ arc. Both DTS and FDTS tomograms were reconstructed at various reconstruction arcs. Spatial resolution was assessed by means of the Square Wave Response Function (SWRF), determined over the complete range of spatial frequencies.
(ii) Slice Thickness
Slice thickness was measured using the same set of data described above. Measurements were performed for each spatial frequency by means of the Full Width at Half Maximum (FWHM) of the intensity profiles taken along the transverse axis of the corresponding pair of bars (4).

(iii) Contrast sensitivity
A second electronic phantom was designed for contrast sensitivity investigations, consisting of an ellipsoid containing six equally sized spheres (R=0.5 cm), equidistantly spaced and with their centers along the long diameter of the middle coronal slice of the phantom. The spheres were of varying densities ranging from 0 to 2.00 g/cm$^3$ providing background contrast variations of 2%, 5%, 10%, 20%, 30% and 100%. Contrast sensitivity, defined as the difference in signal strength between the structure of interest and the background was studied as a function of the reconstruction arc. For each sphere, the arc needed to establish a minimum 2% contrast relative to the background, was determined.

(iv) Shape distortion and artifacts
Artifacts and shape distortions are present in limited angle reconstructions. In order to assess them, a spherical phantom was used, composed of a high density material, placed inside a homogeneous medium of unit density. The phantom was imaged with its center positioned on the isocenter. Central axial tomograms, coinciding with the sampling plane, were reconstructed for different reconstruction arcs and the ratios of the FWHM of the diameter profiles along the horizontal and vertical directions were used for assessment of shape distortions.

Results
Fig. 1 shows the SWRF plots using both the DTS and FDTS tomograms. The slice thickness variation with the size of reconstruction arc for both DTS and FDTS are presented in Fig. 2. Studies for a high (5 lp/cm) and a low (1 lp/cm) spatial frequency are shown on the same graph. Contrast sensitivity for a range
of background contrast conditions is given in the table. Shape distortion dependency on the reconstruction arc is shown in Fig. 3. The effect of increasing reconstruction arc on images of anatomic content is shown in Fig. 4, for reconstructed tomograms of the contrast-injected sheep-lung phantom. Three parallel coronal planes at 5 mm spacing distance were reconstructed with DTS and FDTS using reconstruction arcs of $40^\circ$ and $120^\circ$, respectively.

**Discussion**

The extent of the reconstruction arc has a significant impact on spatial resolution (Fig.1). In the higher frequency range the two techniques provide comparable results for arcs smaller than $120^\circ$. However, for larger reconstruction arcs, FDTS demonstrates a clear advantage. On the other hand, DTS may be considered the technique of choice when reconstruction arcs in the range of $40^\circ$ or less are used. An increase in the arc results in tomograms of finer slice thickness (Fig.2). As shown by the table, high contrast structures, such as vascular structures or markers used in radiotherapy, may be detected under limited angle conditions, while low contrast structures will appear only on extended arc reconstructions. In fact, our results show that, a full $360^\circ$ reconstruction i.e., CBCT, is necessary to detect a 2% contrast variation to the background. The shape distortions present in limited arc reconstructions, introduce problems (axial elongations) when defining contours of otherwise discernable structures. Again, as seen in Fig. 3, reconstruction arcs of $180^\circ$ or larger are required to eliminate such shape distortions. The same conclusion can be drawn from the slice thickness results, shown in Fig. 2, not surprisingly, since both concepts are related to the filtering of out-of-plane information. Consequently, image quality in terms of, high contrast spatial resolution, slice thickness, shape distortion and artifacts, improves with the reconstruction arc and is optimized at $180^\circ$, while contrast continues to improve when the arc is increasing towards $360^\circ$.

**Conclusions**
Based on the above observations, it may be stated that the sampling range between $40^\circ$ and $360^\circ$, delimited by DTS and CBCT respectively, is the domain where FDTS can be applied to the advantage of applications where sampling over an extended arc is possible. FDTS with an extended arc may even successfully substitute CBCT in applications, where densitometric information is not required.
References


### List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>DTS</td>
<td>Digital Tomosynthesis</td>
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<tr>
<td>FDTS</td>
<td>Filtered Digital Tomosynthesis</td>
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<tr>
<td>CBCT</td>
<td>Cone Beam CT</td>
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<td>FWHM</td>
<td>Full Width at Half Maximum</td>
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<td>SWRF</td>
<td>Square Wave Response Function</td>
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FIGURE CAPTIONS

Fig. 1. SWRF plots for different reconstruction arcs, for (a) DTS and (b) FDTS reconstructed images. Simulated projection data for a bar pattern phantom have been used.

Fig. 2. Slice thickness variation in DTS and FDTS with the size of reconstruction arc. The effect has been studied for a high (5 lp/cm) and a low (1 lp/cm) spatial frequency.

Fig. 3. Shape distortion and artifacts: the center axial section of the sphere has been reconstructed and the ratio of the FWHM of the diameter profiles along the horizontal and the vertical directions was plotted as a function of the reconstruction arc. An axial tomogram reconstructed using an arc of 60° is shown in the insert.

Fig. 4. A tomographic sequence of three transversal planes distanced at 0.5 cm through the angiographic phantom reconstructed using DTS and FDTS at 40° and 120° reconstruction arcs.

Table. Minimum reconstruction arc required to establish a 2% contrast detectability for different background contrast.
(a)

(b)
<table>
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<th>Object</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
<td>Object Contrast</td>
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<td>5%</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>100%</td>
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<tr>
<td>Min Arc for contrast detectability</td>
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<td>$144^0$</td>
<td>$70^0$</td>
<td>$36^0$</td>
<td>$20^0$</td>
<td>$0^0$</td>
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