Assessment of maxillary sinus opacity and natural ostia with digital tomosynthesis radiography

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Purpose

Functional endoscopic sinus surgery (FESS) is a minimally invasive technique of treating sinus disease which enlarges the natural ostia and passageways of the paranasal sinuses, thus preserving the normal pathway of mucociliary clearance [1]. The development and utilization of this technique is dependent upon the high resolution imaging of the sinuses. Thin-slice, helical scans with multi-detector computed tomography (MDCT) provides excellent multi-planar reformation (MPR) images that are important to the successful performance of this treatment technique. In turn, the development and utilization of FESS for patients with sinusitis, the most common entity in this region, has increased the importance of MDCT. However, the radiation exposure delivered by the thin-slice, helical MDCT sinus examination, especially to the lens of the eye, a particularly radiosensitive organ, is an important issue that needs to be addressed.

Recently, radiography systems based on full-field, flat-panel cesium iodide, amorphous silicon detectors have become commercially available. These systems provide rapid access to the image for diagnosis, improved image quality relative to that of screen-film and storage phosphor systems, and potential for reduced radiation exposure and advanced applications. Digital tomosynthesis (DT) radiography is an exciting advanced application that removes overlying structures, enhances local tissue separation, and provides depth information about structures of interest by providing "digitally synthesized, or reconstructed, tomographic images". With conventional tomography, only a single section image could be acquired at a time, and, if multiple sections were desired, additional positioning time and patient dose were required. In contrast, DT allows easy and swift volume data acquisition of any designated region of the body with arbitrary patient posture; it also enables automatic, arbitrary and high-speed reconstruction of large-area, high-resolution, thin-slice, tomographic radiographic images. More specifically, multiple very-low-dose x-ray projection images are acquired over a range of different angles during a single, rapid, linear sweep of the x-ray tube with a stationary detector. The acquired projection image data are automatically reconstructed to form tomographic slices through the imaged object, each slice parallel to the detector plane. The high-resolution, thin-slice, images can be viewed at a review workstation or via PACS as DICOM images. Image acquisition is on the order of a few seconds with the total examination time from patient preparation to image reconstruction typically being accomplished within 2 minutes, similar to a conventional, non-tomosynthesis exam [2].

DT radiography has been reported to be advantageous in a variety of clinical fields [3-7]; it can also be applied for the evaluation of sinus diseases playing a middle role between conventional radiography and MDCT. We previously performed a phantom experiment showing that the use of DT radiography remarkably reduced radiation exposure to the eye lens to 1/300, compared to MDCT for routine sinus examination [8]. This result is explained by the following facts: DT radiography is routinely performed using posterior-
anterior (PA) projections with a limited sweep angle for sinus examination and thus does not expose the eye lens to direct radiation; instead, the majority of the incident x-ray fluence is attenuated by the overlying tissues, mainly the skull, before direct exposure to the eye lens on DT radiography. This accessible, low-cost, and very-low-dose DT radiography technique may be clinically useful as an initial imaging alternative to MDCT for diagnosing sinusitis and evaluating the natural ostia in patients with suspicion of sinusitis who may undergo FESS. Specifically, for the patients who are not indicated for FESS based on the finding of DT sinus radiography, MDCT sinus examination can be effectively spared. Fortunately, there is inherent high-contrast between the structures of interest, such as air, bone, and soft tissue in the sinus region, and sinusitis is not a condition where extreme image quality is critical for the definitive diagnosis. However, to our knowledge, the clinical feasibility of DT radiography for this clinical indication has thus far not been investigated and reported.

The purpose of the present study was to perform a pilot study and investigate the clinical feasibility of DT sinus radiography for detecting abnormal opacity and identifying obstruction of the natural ostia in the maxillary sinuses in patients with suspicion of sinusitis, using MDCT as the reference standard.
Methods and Materials

Study Population

Between April 2009 and March 2010, 21 consecutive patients with suspicion of sinusitis (10 men, 11 women; aged 22 to 84 years, mean, 56.0 ± 19.5 years) underwent sinus examination with both 16- or 64-detector CT and DT. Three of these patients with suspicion of acute maxillary sinusitis who underwent both modalities within 2 days (mean, 1.3 ± 0.6 days; 1-2 days) or 18 with suspicion of chronic sinusitis who showed similar findings with both modalities within 3 months (mean, 17.8 ± 26.9 days; 0-90 days) were retrospectively included in the present study. All gave written informed consent. No patient had undergone any sinus operations according to their medical records, and actually disclosed post-operative change on those examinations.

MDCT Scan Technique

We used a 16-detector CT (LightSpeed 16; GE Healthcare, Milwaukee, WI) for 18 patients or a 64-detector CT scanner (LightSpeed VCT; GE Healthcare, Milwaukee, WI) for 3 patients with rotation time of 350 ms and collimation of 16 × 0.625 mm or 64 × 0.625 mm, respectively. All the patients were positioned supine on the bed at the iso-center of the gantry with the neck extended posteriorly for an x-ray projection tilted 10 degrees to Reid's base line (the line between the infraorbital margin and the upper margin of the external auditory meatus) in the z-direction. We performed a non-contrast helical scan from the top of frontal sinuses to just below the maxillary antra in z-direction using the following scan parameters: tube voltage, 120 kVp; tube current-time product, 197.2 ± 12.2 (144-200) mAs; helical pitch, 1.276 ± 0.262 (0.531-1.375); matrix, 512 × 512; and field of view 25 cm × 25 cm. According to the dose report for each scan on the CT scanner, the scan length was 11.8 ± 0.8 (10.5-14.0) cm; and the volume CT dose index, 34.2 ± 11.1 (30.4-69.6) mGy. We obtained axial slice images of 5 mm-thickness and 5 mm-interval and reconstructed MPR coronal images of 2.5 mm-thickness and 2.5 mm-interval with a soft tissue window display (window level, 40 HU; window width, 250 HU) using the "Standard" kernel, and obtained axial slice images of 1 mm-thickness and 2.5 mm-interval and reconstructed MPR coronal images of 1 mm-thickness and 2.5 mm-interval with a bone window display (window level, 500 HU; window width, 3000 HU) using the "Bone Plus" kernel.

DT Radiography Scan Technique

We used a full-field, flat-panel, digital X-ray detector radiography system (Definium 8000; GE Healthcare, Chalfont St. Giles, UK). This system includes a cesium iodide scintillator and an amorphous silicon photodiode-transistor array. The detector has an image size of 41 cm × 41 cm and a pixel dimension of 0.2 mm × 0.2 mm. The DT advanced
application (VolumeRAD; GE Healthcare, Chalfont St. Giles, UK) utilizes a generalized filtered back projection algorithm for tomosynthesis image reconstruction. We performed a DT radiography scan covering the frontal to maxillary sinus with multiple PA projection views of all of the patients in the upright position using the following scan parameters: tube voltage, 80 kVp; tube current-time product per projection, 1.2 ± 0.5 (0.6-2.9) mAs; sweep angle, 40 degrees; 60 projection views; caudo-cranial sweep direction; a source-to-image distance of 100 cm; and the dose-area product for each scan displayed on the radiography system, 15.7 ± 7.5 (6.3-35.4) dGy#cm² (field of view: 18 cm × 24 cm). We reconstructed DT coronal images with a slice interval of 2 mm and a sampling factor (the number of "virtual slices" averaged) of 1. A cine-view of DT coronal images of a patient with normal sinus in an upright position is shown in Figure 1 on page 6.

**Image Analysis**

Two readers who were blinded to patient information, in consensus, retrospectively assessed abnormal opacity and obstruction of the natural ostia in bilateral maxillary sinus using the aforementioned MDCT axial and MPR coronal images and DT coronal images on a 6-megapixel color medical imaging display system (Coronis Fusion 6MP DL; Barco, Kortrijk, Belgium) through a PACS system (INFINITT PACS; INFINITT Healthcare, Seoul, Korea). The MDCT and DT images were independently evaluated in a random order. We defined the obstruction of the natural ostia as the loss of air density in the pathway from the hiatus semilunaris to the maxillary ostium via the ethmoid infundibulum.

**Data Analysis**

Data were expressed as the mean ± standard deviation (SD). We compared the results regarding the detection of abnormal opacity and the identification of natural ostia obstruction in bilateral maxillary sinus between both modalities and calculated the diagnostic accuracy, including the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), and quantified diagnostic agreement using Cohen’s #-statistics with DT using MDCT as a reference.
Fig. 1: Figure 1. Cine loop of coronal digital tomosynthesis sinus radiographic images of a 30-year-old female patient with normal sinus on the upright position.

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Results

Abnormal opacity was identified in 35/42 sinuses (83%) by MDCT; natural ostia obstruction, 20/42 (48%). Abnormal opacity was identified in 35/42 sinuses (83%) by DT; natural ostia obstruction, 22/42 (52%).

For the detection of abnormal opacity by DT, the sensitivity was 97% (34/35); specificity, 86% (6/7); PPV, 97% (34/35); NPV, 86% (6/7) (Table 1); and kappa value, 0.83 (excellent).

Table 1. Detection of Abnormal Opacity

<table>
<thead>
<tr>
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<th>MDCT Positive</th>
<th>MDCT Negative</th>
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<tbody>
<tr>
<td>DT</td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>6</td>
</tr>
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</table>

DT, digital tomosynthesis; MDCT, multi-detector CT.

For the identification of natural ostia obstruction by DT, the sensitivity was 90% (18/20); specificity, 82% (18/22); PPV, 82% (18/22); NPV, 90% (18/20) (Table 2); and kappa value, 0.71 (good).

Table 2. Identification of Natural Ostia Obstruction

<table>
<thead>
<tr>
<th></th>
<th>MDCT Positive</th>
<th>MDCT Negative</th>
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<tbody>
<tr>
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<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

DT, digital tomosynthesis; MDCT, multi-detector CT.

DT and MDCT MPR coronal images of the sinus in a patient with chronic sinusitis and natural ostium obstruction in the right maxillary sinus are shown in Figure 2 (Figure 2A on page 8, Figure 2B on page 8, and Figure 2C on page 9) on the upright and supine positions, respectively. Like MDCT, DT allowed detailed assessment regarding the detection of abnormal opacity and the identification of natural ostia obstruction in the maxillary sinuses.
Fig. 0: Figure 2(A). Digital tomosynthesis (A and B) and 64-detector CT multi-planar reformation coronal images (C) of the sinus in a 50-year-old male patient with chronic sinusitis and natural ostium obstruction in the right maxillary sinus on the upright and supine positions, respectively. The left maxillary sinus is clear, and the left natural ostium, the pathway from the hiatus semilunaris to the maxillary ostium via the ethmoid infundibulum, shows a complete patency with both modalities. In contrast, the right maxillary sinus is occupied by the large amount of abnormal opacity, and the right natural ostium is totally obstructed with both modalities. Tomosynthesis allows detailed assessment regarding the detection of abnormal opacity and the identification of natural ostia obstruction in bilateral maxillary sinus.

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**Fig. 0:** Figure 2(B). Digital tomosynthesis (A and B) and 64-detector CT multi-planar reformation coronal images (C) of the sinus in a 50-year-old male patient with chronic sinusitis and natural ostium obstruction in the right maxillary sinus on the upright and supine positions, respectively. The left maxillary sinus is clear, and the left natural ostium, the pathway from the hiatus semilunaris to the maxillary ostium via the ethmoid infundibulum, shows a complete patency with both modalities. In contrast, the right maxillary sinus is occupied by the large amount of abnormal opacity, and the right natural ostium is totally obstructed with both modalities. Tomosynthesis allows detailed assessment regarding the detection of abnormal opacity and the identification of natural ostia obstruction in bilateral maxillary sinus.

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**Fig. 0:** Figure 2(C). Digital tomosynthesis (A and B) and 64-detector CT multi-planar reformation coronal images (C) of the sinus in a 50-year-old male patient with chronic sinusitis and natural ostium obstruction in the right maxillary sinus on the upright and supine positions, respectively. The left maxillary sinus is clear, and the left natural ostium, the pathway from the hiatus semilunaris to the maxillary ostium via the ethmoid infundibulum, shows a complete patency with both modalities. In contrast, the right maxillary sinus is occupied by the large amount of abnormal opacity, and the right natural ostium is totally obstructed with both modalities. Tomosynthesis allows detailed assessment regarding the detection of abnormal opacity and the identification of natural ostia obstruction in bilateral maxillary sinus.

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Conclusion

DT sinus radiography is clinically feasible in patients with suspicion of sinusitis since it allows excellent detection of abnormal opacities and good identification of obstruction of the natural ostia in the maxillary sinus. The in-plane resolution of DT radiography (0.2 mm) was superior to that of MDCT (approximately 0.5 mm), but the resolution of both modalities was sufficiently high for the assessments examined in this study. In contrast, the depth-resolution of DT radiography (2 mm) was inferior to that of MDCT (1 mm), and the contrast resolution of DT radiography was generally poorer than that of MDCT. We think that the reduced depth and contrast resolutions of DT might not be high enough to assess all subtle findings or fine structures in the sinuses that may be visible with MDCT. This may explain why identification of obstruction of the natural ostia was less accurate than the detection of abnormal opacities with DT radiography. However, these results indicate that very-low-dose DT imaging of the sinus may play a significant role in the clinical care of patients presenting with suspicion of sinusitis that may be candidates for FESS, as an imaging modality of the first step.
References


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