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ORIGINAL RESEARCH—SINONASAL DISORDERS

Flat panel cone beam computed tomography of the sinuses

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ABSTRACT

OBJECTIVE: This study aims to compare the image quality and potential diagnostic accuracy of paranasal sinus CT scans generated by flat panel cone beam CT at three specific data acquisition times.

STUDY DESIGN: Prospective, single blinded analysis.

SUBJECTS AND METHODS: Eleven patients without previous radiologic evaluation were selected based on history and findings suspicious for chronic sinusitis. Each patient was scanned at three different acquisition times: 10, 20, and 40 seconds. A panel of neuroradiologists and otolaryngologists, blinded to the scan acquisition time, individually reviewed images and rated overall image quality and visualization of specific anatomic sites. Image noise values were also calculated. Techniques were compared with a Wilcoxon matched-pairs signed ranks test.

RESULTS: Compared to the 10-second acquisition time, the 40- and 20-second acquisition time techniques had significantly better image quality ($P < 0.05$) and image noise ($P < 0.05$). No difference in image quality and image noise existed between the 20- and 40-second techniques. No difference in visualization of specific anatomic structures existed between any of the time techniques.

CONCLUSION: The quality of flat panel CT imaging of the sinuses directly relates to scan time and thus radiation dose.

Options for imaging of the paranasal sinuses include plain radiography, computerized tomography (CT), and magnetic resonance imaging (MRI). The current standard in CT imaging of the paranasal sinuses is multislice helical CT, which allows for submillimeter volumetric imaging that allows for accurate coronal and sagittal reconstructions. One disadvantage of these scanners is the relatively higher radiation doses when compared with older single-slice scanners.[1]

In 1998, Mozzo et al[2] introduced the first cone beam technique developed for maxillofacial imaging. This new generation of CT scans, known as flat panel (or cone beam) CT, allows for greater spatial resolution at lower radiation doses than the more widely used conventional multidetector CT scanners. Flat panel CT uses a matrix array of detector elements, rather than the conventional "ring" or "fan beam" array of detectors found in more conventional CT scanners. Each individual detector element in the matrix array is smaller (0.3 mm) than that in conventional arrays, which allows for greater spatial resolution that is also isotropic, ie, giving equal resolution in all three imaging planes (x, y, and z-axis). This allows for equal resolution of reconstructed images whether they are in sagittal, coronal, or axial views, or any combination of oblique reconstructions.

The physics of the two-dimensional matrix array enables a more efficient use of the emitted radiation from the x-ray tube for image generation and thus allows the entire image set to be generated from a lower total radiation dose to the patient. For example, conventional multidetector CT scans of the sinus expose the patient to 0.96 to 2.00 mSv of radiation, which makes the radiation exposure associated with a CT scan of the sinuses equivalent to approximately 100 chest x-rays.[3] An adult sinus scan with a cone beam CT can decrease this dose to 0.04 to 0.17 mSv.[4,5] The lower radiation dose achievable with the flat panel cone beam CT technology is desirable to avoid unnecessary radiation of radiosensitive organs such as the eye lens and the thyroid gland. Since the introduction of this technology, several companies have developed compact flat panel CT scanners. These scanners are being used in office and intra-operative settings.[6,7]

The goal of this study is to compare the image quality of sinus CT scans performed with flat panel technology at different data acquisition times. In addition, as scan time is inversely related to image noise (higher noise with lower scan times), the amount of noise will be compared between the different scan times. This study does not compare image quality of flat panel CT scans to that of conventional multidetector CT scans. Previous studies have shown that a considerable reduction of radiation dose can be achieved

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without significant loss of image quality. However, these studies have relied on ex vivo dissected human skull specimens or radiologic phantoms.[8-11] Our study will expand on this previous work with an assessment of the quality of scans performed on human subjects.

METHODS

After approval from the New York University School of Medicine Institutional Review Board, 11 patients with symptoms of chronic rhinosinusitis (CRS) were enrolled in this prospective study, and informed consent was obtained for flat panel CT of the paranasal sinuses at three different scan times. The MiniCAT flat panel cone beam CT scanner (Xoran Technologies, Ann Arbor, MI) was used with standard adult protocol parameters. Three scans were performed on each of the 11 patients: 40-second scan: effective radiation dose 0.17 mSv; 20-second scan: effective radiation dose 0.08 mSv; 10-second scan: effective radiation dose 0.04 mSv. The CT scans were de-identified, had protocol time removed, and a random number was assigned to each CT scan in compliance with Health Insurance Portability and Accountability Act (HIPAA) standards. Each scan was subsequently reviewed by a neuroradiologist (EW) and two otolaryngologists (JJ, RL). Eleven sets of each of the three scan times were performed for a total of 33 scans. Image quality and composite visualization scores were provided independently by each reviewer for all 33 scans.

Visualization was defined as the ability to determine contour and absence/presence of disease. Overall image quality was scored on a 5-point ordinal scale (1 = nondiagnostic to 5 = excellent). The composite visualization score was computed as a sum of binary scores for each of 13 structures: anterior skull base, medial orbital walls, nasal cavity, each maxillary sinus, each ethmoid sinus, each frontal sinus, each sphenoid sinus, and each osteomeatal unit. The binary score for each structure was given as 1 = limited visualization or 2 = excellent visualization. For each scan, a single image noise score was determined for each of the scans. A function on the CT viewing program calculates image noise. This value was achieved by windowing a standardized region of interest analysis for each scan.

Statistical Analysis

The image quality and composite visualization scores for each acquisition time were represented for each subject as average overreaders. Acquisition techniques were then compared in terms of these mean scores and with respect to image noise with a Wilcoxon matched-pairs signed ranks test. The nonparametric Wilcoxon test was applied to the mean image quality and visualization scores because these scores are on an ordinal rather than ratio (ie, continuous numeric) scale of measurement. This same test was used for the continuous measure of noise for consistency and because the more conventional *t* test was not considered appropriate given the small sample size (n = 11 subjects) and the concomitant sensitivity of the *t* test to the underlying normal distribution assumption. All reported *P* values are exact two-sided significance levels and were declared statistically significant when less than 0.05.

RESULTS

The mean image quality rating scores for the scans were 3.30 for the 10-second scan, 4.21 for the 20-second scan, and 4.55 for the 40-second scan. The mean visualization scores for the scans were 24.73 for the 10-second scan, 24.88 for the 20-second scan, and 24.55 for the 40-second scan. The mean image noise scores were 60.53 for the 10-second scan, 38.87 for the 20-second scan, and 35.26 for the 40-second scan.

Table 1 shows the analysis when the three techniques are compared with each other. Compared with the 10-second acquisition time, the 40- and 20-second acquisition time techniques had significantly better image quality ($P < 0.05$) and image noise ($P < 0.05$). No difference in image quality

Table 1
Comparative analysis

	Image quality			Visualization			Image noise		
Techniques compared	Mean	SD	*P* value	Mean	SD	*P* value	Mean	SD	*P* value
10 sec vs 20 sec	−0.91	0.45	**0.0020**	−0.15	1.54	0.2930	31.10	23.83	**0.0010**
10 sec vs 40 sec	−1.24	0.78	**0.0029**	0.27	2.36	0.9863	38.11	31.34	**0.0049**
20 sec vs 40 sec	−0.33	0.65	0.1719	0.42	2.82	0.5723	7.01	17.51	0.3652

The mean and standard deviation (SD) of the within-subject difference between each pair of techniques is given in terms of each endpoint. The mean and SD reported for the comparison of a given pair of techniques is for the within-subject difference in the relevant endpoint, computed as the value observed for the shorter acquisition time minus the value acquired using the longer acquisition time. Thus, a negative mean difference implies that the shorted time was associated with lower values of the endpoint. Each *P* value is from the Wilcoxon test to compare the relevant pair of techniques by testing whether the mean difference between these techniques is different from zero. Results significant at the 5 percent level are highlighted in *bold*.

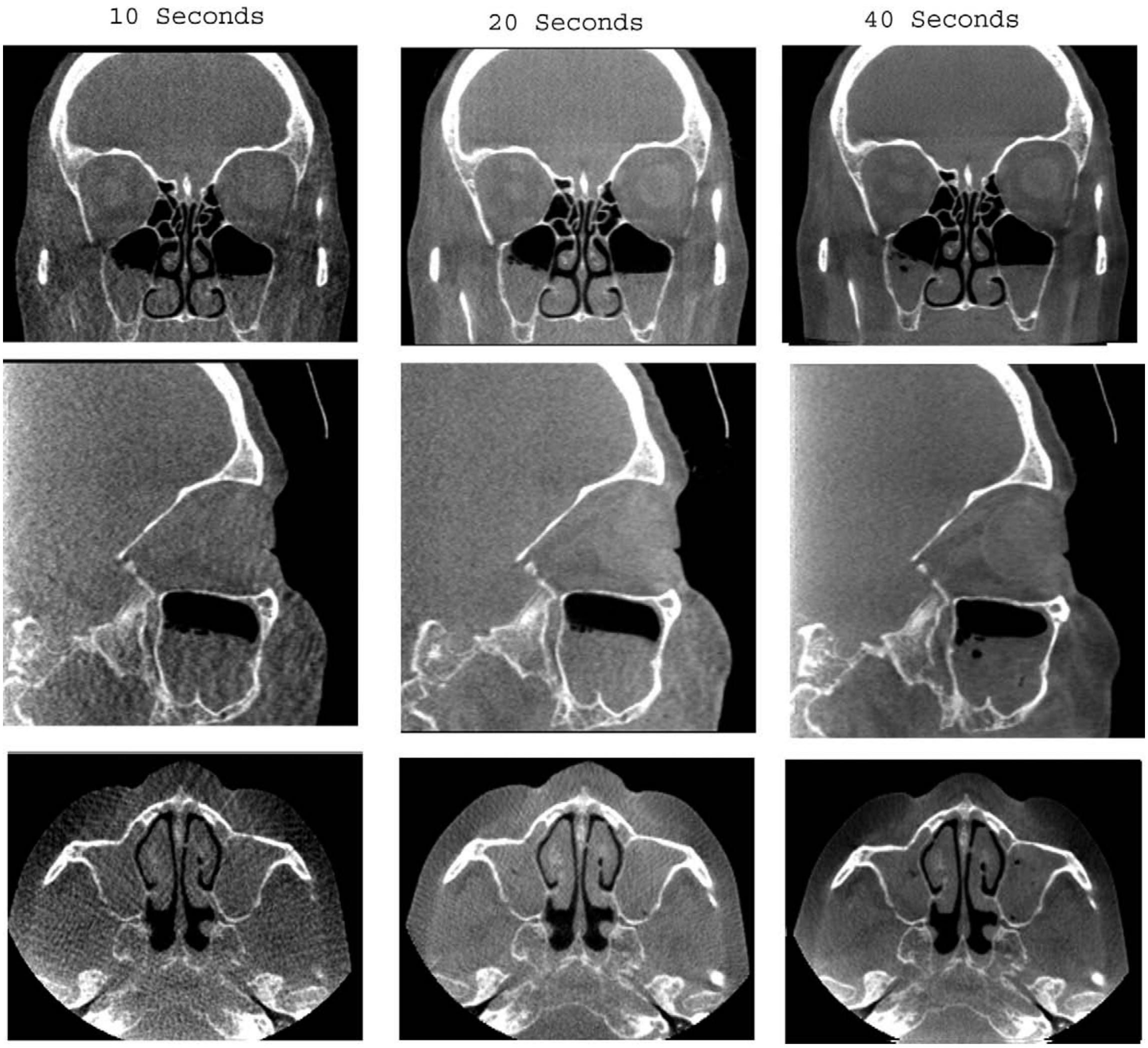

Figure 1 Coronal, sagittal, and axial CT images obtained with the low (10 sec), medium (20 sec), and high (40 sec) dose protocols.

and image noise existed between the 40- and 20-second techniques. No difference in visualization of specific anatomic structures existed between any of the techniques. Figure 1 demonstrates the image quality difference between the three different acquisition times on the same patient.

DISCUSSION

This is the first study of human subjects with symptoms of CRS that compares the quality of CT images of the paranasal sinuses obtained with the use of a flat panel CT scanner using different imaging protocols. The ability to compare the CT visualization of the paranasal sinus anatomy of an individual patient with three different radiation doses provides a basis for determination of the optimal flat panel CT protocol that will minimize radiation exposure while providing adequate resolution and visualization of the sinus anatomy. Guided by the ALARA principle (As Low As Reasonably Achievable), the results of this study suggest that for diagnostic purposes and visualization of the specific anatomic structures evaluated, any of the three protocols may be adequate. However, adequacy must be determined by the otolaryngologist. There is superior image quality with the 40- and 20-second protocols compared with the 10-second technique.

For diagnosis of inflammatory sinusitis and gauging of treatment, data gained from the flat panel CT scans, in addition to clinical impression and endoscopy, suggest that such images provide useful radiologic documentation for the diagnosis of chronic rhinosinusitis. At this point, it is up to the individual operating surgeon to determine whether any of the flat panel techniques analyzed are suitable for surgery. With the increasing use of inoffice flat panel CT scanners, it will be incumbent on the otolaryngologist to determine the appropriate scan protocol for each patient. It is also up to the surgeon to determine whether images attained from any of the flat panel CT protocols would be optimal for surgery. If one were to use flat panel CT for preoperative planning in patients likely to undergo surgery and for use with an image guidance system, the surgeon must choose what he or she feels is the optimal protocol. For patients who undergo screening CT scans, and for post-treatment follow-up, a shorter (10-second scan) protocol may be enough. In certain clinical situations, flat panel CT can be a reasonable alternative to conventional multidetector CTs. Radiation exposure from the flat panel scan was less than 10 percent of that associated with the multidetector scanner. Notably, the radiation dose received by each test subject from three consecutive flat panel scans was still less than that of a single multidetector helical scan.

One major limitation of this study is that the small sample size (n = 11 subjects) provided the study with limited statistical power and limits the generality of the study conclusions. Therefore, additional data are needed to determine whether the lack of a significant difference between the 20- and 40-seconds acquisition times was an artifact of inadequate power and whether the significant findings will persist in a larger patient population.

CONCLUSION

Lower dose CT techniques achieved by flat panel cone beam CT may be an effective alternative to traditional multidetector CT scanners, with the advantage of decreased radiation dose and inoffice clinical availability. The quality of flat panel CT imaging of the sinuses is directly related to scan time and the radiation dose. Future studies may determine how flat panel CT quality compares with that of conventional multidetector CTs.

AUTHOR INFORMATION

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AUTHOR CONTRIBUTIONS

Richard A. Zoumalan, planning, data collection, analysis, writing, critical revision; **Richard A. Lebowitz,** planning, data analysis, writing, accruing of patients; **Edwin Wang,** planning, data collection and analysis, writing, critical revision; **Kathryn Yung,** planning, data collection and analysis, writing; **James S. Babb,** statistical analysis, analysis and interpretation of data; **Joseph B. Jacobs,** planning, data analysis, writing, accruing of patients, overall project management, final approval.

DISCLOSURES

Competing interests: Joseph B. Jacobs, GE Navigation consultant. This project was performed using a flat panel cone beam CT provided on loan from Xoran Technologies.

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