Comparison of Simulated Cone Beam Computed Tomography to Conventional Helical Computed Tomography for Imaging of Rhinosinusitis

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Objectives/Hypothesis: Cone beam computed tomography (CBCT) has emerged as a low radiation dose alternative to traditional computed tomography (CT) to evaluate the paranasal sinuses. The purpose of our study was to determine how often clinically important findings would be missed if CBCT was used routinely for sinus imaging.

Study Design: Retrospective review.

Methods: We evaluated all maxillofacial CT scans performed for sinusitis over a 1-year period. The original multidetector CT (MDCT) images were reviewed retrospectively. A theoretical CBCT was then created from the original study utilizing only the bone algorithm images and separately reviewed. We calculated the proportion of abnormal findings that were identified on the MDCT but would have been missed by the theoretical CBCT; and reviewed the medical record to determine which potentially missed findings would have changed management. Radiation dose from the MDCT scanners was calculated and compared to published dose estimates for the paranasal sinuses on CBCT.

Results: Maxillofacial CTs from 361 consecutive patients were included, of which 12 (3.3%) demonstrated findings that would have been missed on the theoretical CBCT. Of those, four (1.1%) would have resulted in a change in management. Effective radiation dose for our scanners ranged from 0.67 mSv to 2.15 mSv, compared to a published estimated dose of 0.2 mSv for CBCT.

Conclusions: In the majority of patients undergoing simulated CBCT for evaluation of sinusitis, incidental findings of soft-tissue disease were rare. With appropriate selection of patients, CBCT can offer substantial radiation dose reduction and may provide a viable alternative to standard MDCT sinus imaging protocols.

Key Words: Cone beam computed tomography, multidetector computed tomography, sinusitis.

Level of Evidence: 4


INTRODUCTION

Cone beam computed tomography (CBCT), a relatively novel advance in computed tomography (CT) imaging, has emerged as a potential low-dose, cross-sectional alternative for evaluation of bony structures in the head and neck. CBCT was first adapted for clinical use in 1982, with initial interest primarily focused on applications such as angiography, in which high temporal and spatial resolution was desired and soft-tissue resolution could be sacrificed. Relatively low dosing requirements and the compact design of CBCT scanners led to intense interest and growth in the utilization of CBCT systems have become more prevalent, there has been increasing interest in potential CBCT applications in otolaryngology, specifically in the field of rhinology. Sinusitis is one of the most common chronic conditions in the United States and the fifth most common reason for an antibiotic to be prescribed. Up-front sinus CT has also been suggested as a more cost-effective alternative to empiric medical therapy or referral to the otolaryngologist in patients with presumed chronic rhinosinusitis (CRS), and CBCT may be a reasonable option for appropriately selected patients requiring further diagnostic testing. The high-quality bony definition afforded by CBCT have made this imaging modality particularly useful in intraoperative scanning of the paranasal sinuses and skull base surgery. Preliminary data suggest that intraoperative therapy guidance, and in surgical planning and intraoperative guidance for orthopedic, spinal, and abdominal procedures. These advantages offset CBCT's lack of diagnostic information about soft tissues in particular clinical situations. In 2001, the first CBCT scanner became commercially available for dentomaxillofacial imaging. This was rapidly adopted and used in evaluation of craniofacial fractures, orthodontics, endodontics, periodontics, and temporomandibular joint disease.

As CBCT systems have become more prevalent, there has been increasing interest in potential CBCT applications in otolaryngology, specifically in the field of rhinology. Sinusitis is one of the most common chronic conditions in the United States and the fifth most common reason for an antibiotic to be prescribed. Up-front sinus CT has also been suggested as a more cost-effective alternative to empiric medical therapy or referral to the otolaryngologist in patients with presumed chronic rhinosinusitis (CRS), and CBCT may be a reasonable option for appropriately selected patients requiring further diagnostic testing. The high-quality bony definition afforded by CBCT have made this imaging modality particularly useful in intraoperative scanning of the paranasal sinuses and skull base surgery. Preliminary data suggest that intraoperative...
CBCT may improve completeness of sinus surgery, assist in frontal sinus procedures, and allow for valuable assessment of skull base tumor resection. To date, however, there has been no evidence or studies evaluating the adequacy of CBCT in general diagnostic sinus imaging, mainly comprising the evaluation of acute and chronic sinus inflammatory disease.

Although CBCT has gained a growing foothold in evaluation of the paranasal sinuses, it is unknown whether the lack of soft-tissue contrast resolution would pose a significant limitation to preclude its widespread use in general diagnostic sinus imaging. The purpose of our study was to evaluate the potential use of CBCT in general diagnostic sinus imaging, and to quantify the potential dose reduction gained by using CBCT versus traditional multidetector CT (MDCT) scanners.

MATERIALS AND METHODS

Patient Selection and Image Acquisition

Our institutional review board approved this study, with waiver of informed consent. All CT examinations included in this study were performed as standard-of-care, and the results were retrospectively analyzed.

We searched our electronic medical record to identify patients with CT examinations of the maxillofacial bones performed at our academic university hospital for the evaluation of sinusitis. Radiology reports from May 1, 2012 to May 1, 2013 were searched using the keywords “sinusitis,” “sinus congestion,” and “rhinitis.” These keywords, as opposed to keywords incorporating established American Academy of Otolaryngology–Head and Neck Surgery Foundation established major and minor symptoms of rhinosinusitis, were chosen based on established local imaging ordering practice patterns at our institution. Patients were excluded if there was excessive motion rendering the original scan nondiagnostic or if data regarding clinical follow-up were not available. Demographic data collected included age and sex. Clinical data included presenting symptoms; presentation to the emergency department, outpatient clinic, or inpatient ward; specialty of ordering clinician; imaging results; and postimaging clinical management. All maxillofacial studies at our institution are interpreted by fellowship-trained certificate of added qualifications-certified neuroradiologists who are part of a dedicated otolaryngology imaging team.

CT examinations were performed on two 4-slice and four 64-slice MDCT scanners (LightSpeed Plus and LightSpeed VCT, respectively; GE Healthcare, Milwaukee, WI), with three of the 64-slice scanners having the adaptive statistical iterative reconstruction option activated. MDCT acquisitions were performed according to standard protocols by scanning from maxilla through the frontal sinuses using the axial technique. Technical parameters for the different MDCT scanners in our institution are provided in Table I. Coronal and sagittal reformations were provided on all examinations.

Radiation Dose Measurements

Volume CT dose index (CTDvol) values, displayed by the scanner at the end of each patient’s scan, were recorded for each type of scanner we used in our study (Table I). These CTDvol values are values automatically selected by the scanner after the examination protocol parameters are selected by the scanner operator. CTDvol values are from the look-up table’s measurements made by the manufacturer and preprogrammed in each scanner’s CTDvol dose metric database. The values represent x-ray doses to a 16-cm acrylic standard head phantom and are specific to each combination of technical parameters selectable on the operator console. In our study, CTDvol values did not vary between adult patients on a given, individual scan because manual fixed mA was used for each scan, and no other parameters could be modified by the technologist among patients once the standard protocol was approved and programmed onto the specific scanner. However, CTDvol values differ between scanner types due to inherent hardware differences. We specifically did not limit our study to only one type of scanner, because in a typical clinical setting at a large institution, variations in scanner generations and hardware capabilities are commonplace.
Image Analysis
Radiology reports from all CT examinations were reviewed retrospectively. The initial radiology report served as the reference standard for all findings present in a given patient. Reviewers were asked to record the findings from the radiology report and determine which findings would have been seen if the examination had been performed on a CBCT scanner, using the bone algorithm images as a theoretical cone beam CT on the same patient. As a conservative approach, we assumed that all soft-tissue findings that were not at an air–soft-tissue interface (i.e., within the paranasal sinuses or nasal cavity) would have been missed on a CBCT examination. We also assumed that all findings in the imaged brain parenchyma as well as the soft tissues of the face, including the orbits, premaxillary, and retroantral fat would have been missed on a CBCT. If the radiology report was unclear, the reviewer was able to look at the source images from the examination.

Missed Findings on Theoretical CBCT Studies
To determine the value of traditional multidetector CT versus CBCT in general diagnostic sinus imaging, we tabulated the number of potential missed findings on CBCT compared to traditional MDCT. Through a search of the electronic medical record, we then determined which of those findings were previously unknown, and which, if any, change in the patients’ clinical management would have resulted if the finding had been missed on a CBCT.

Data Analysis
Confidence intervals for the proportion of missed findings utilizing a theoretical CBCT were calculated using a continuity correction.21

RESULTS
Patient Selection and Image Acquisition
Three hundred sixty-two consecutive maxillofacial CTs were initially evaluated. One patient was excluded because information on clinical follow-up was not available; no patients were excluded due to excessive motion during the exam. The remaining 361 studies were included in our study. Forty-five percent of patients (161 patients) were male, with an average age of 51 years (range, 18–91 years).

Radiation Dose Measurements
For the complete examinations, the CT scanner automatically calculates the dose-length product utilizing the CTDIvol multiplied by the scan length. Patients were all adults aged 18 years or older. Therefore, the effective dose was estimated utilizing published anatomy-specific conversion coefficients (k factors) for “head” regional exposures: 0.0021 (in mSv mGy⁻¹ cm⁻¹) for adults older than 18 years.22 The k values are based on 1991 International Commission on Radiological Protection 60 tissue-weighting factors.22 Effective dose calculated for our scanners ranged from 0.67 mSv to 2.15 mSv.

Missed Findings on Theoretical CBCT Studies
Twelve of the 361 maxillofacial CTs (3.3%, 95% confidence interval [CI]: 1.9%-5.7%) demonstrated findings that would have potentially been missed had the study been performed with a CBCT. Three demonstrated areas of known encephalomalacia in the imaged portions of the brain parenchyma, two revealed soft-tissue infiltration compatible with cellulitis in patients already undergoing antibiotic therapy, one revealed an area of suprabasal soft-tissue swelling in a patient with recent trauma, one showed a known cerebral abscess, one imaged a known Meckel’s cave meningioma, one revealed a previously unknown left orbital apex mass, one revealed a previously unknown hypodense left frontal lobe mass in an immunocompromised patient, one revealed a previously unknown 2.9 cm parafalcine extraaxial mass, and one revealed tortuosity of the optic nerve and Meckel’s cave meningoceles in a patient who was subsequently diagnosed with pseudotumor cerebri.

Of the twelve findings listed above, only the last four (1.1%, 95% CI: 0.43%-2.8%) were previously unknown. The patient with the left orbital apex mass had been seen by her primary care physician with complaints of unilateral eye pain and a history of prior sinus infections. The study was ordered to evaluate acute sinusitis. The orbital apex mass was further imaged with magnetic resonance imaging (MRI), and in conjunction with her clinical findings was diagnosed as orbital pseudotumor. The patient was treated with corticosteroids. In the second patient, who was immunocompromised with unexplained fever, the sinus CT was ordered to evaluate for invasive fungal rhinosinusitis, and revealed a previously unknown left frontal lobe mass. This mass was imaged further with MRI and was felt to represent a cerebral abscess; unfortunately, the patient, who was immunocompromised and had disseminated Nocardia, died 7 days after the sinus CT. In the patient with the 2.9-cm parafalcine mass (Fig. 1), the study was initially ordered to evaluate for chronic rhinosinusitis and postnasal drip. The patient was subsequently imaged with an MRI, and is scheduled to be seen by a neurosurgeon with a presumptive diagnosis of a parafalcine meningioma. She did not have any symptoms attributable to the meningioma (i.e., headache, personality change) based on a review of the electronic medical record. The fourth patient found to have tortuosity of the optic nerves and Meckel’s cave meningoceles initially presented with a headache, had papilledema on physical exam with suspicion of pseudotumor cerebri, and was scheduled to have a head CT concurrently with the CT of the maxillofacial bones. The patient was subsequently treated with a ventriculoperitoneal shunt with improvement of her symptoms.

DISCUSSION
The purpose of this study was to evaluate the potential utility of CBCT for general diagnostic imaging of routine sinus symptoms and to quantify the potential radiation dose reduction from such an approach. Our results indicate that CBCT can reliably be used in place of traditional MDCT for routine, general diagnostic sinus imaging in the vast majority of patients without fear of missing clinically relevant findings. Less than
3.5% of patients had abnormalities visible on traditional MDCT that would have been potentially obscured on a CBCT, and only a third of these were previously unknown findings. The more widespread use of CBCT would result in a substantial reduction in radiation dose per study, a particularly germane consideration, as patients with chronic rhinosinusitis may undergo repeat imaging to follow their disease or for operative planning. Although we are not aware of other large-scale studies evaluating the use of CBCT in general diagnostic sinus imaging, multiple reports have raised questions about its utility for such widespread use, due to a lack of soft-tissue contrast resolution. Specifically, concern has been raised about possible obscuration of findings ranging from incidental pituitary lesions, orbital masses, areas of bony dehiscence, and postoperative findings such as encephaloceles and subarachnoid hemorrhage. Although we would not argue with the specific concerns raised in prior studies, our results indicate that these findings are uncommon and patient selection is important.

We are not, however, advocating the widespread use of CBCT in lieu of MDCT in all patients. Specifically, in patients with concern for soft-tissue disease extension, CBCT would be inappropriate, as the findings would likely be obscured due to poor soft-tissue contrast resolution. Such patients would include immunocompromised patients, any patients in whom the diagnosis of invasive fungal rhinosinusitis is being considered or must be excluded, patients with suspected intracranial or periorbital complications of sinusitis, or patients in the immediate postoperative setting. In these cases, clear visualization of the soft tissues bordering the paranasal sinuses would be key in excluding or suggesting aggressive sinonasal infection as well as evaluating for any potential operative complications.

A second class of patients in whom CBCT would not be appropriate is those with symptoms not directly attributable to the sinuses. For example, in a patient with unilateral eye pain or papilledema on physical examination, it would be important to have clear visualization of the retro-orbital fat planes in addition to the paranasal sinuses. These are only illustrative examples, and this list is not meant to be exhaustive. As a starting point, CBCT may be most useful in the patient with possible chronic sinus disease in the absence of objective findings on nasal endoscopy. Recent data suggest that up-front imaging may be more cost-effective than empiric medical therapy for presumed CRS, and CBCT may be helpful in this patient population, especially with the advent of in-office scanners. However, further research is needed to determine the appropriate indications for CBCT and an open dialog between radiologists and referring clinicians is needed.

The most obvious benefit of CBCT in diagnostic sinus imaging is the significant radiation dose savings offered. There is extensive interest among both the general public and radiologists regarding how best to minimize radiation dose. This interest has resulted in multiple studies evaluating low-dose head CT protocols, as well as low-dose protocols in the temporal bone and paranasal sinuses. Although it is difficult to precisely quantify radiation dose in CBCT due to a lack of a widely accepted dose metric that can be used for comparison with traditional MDCT, multiple studies have estimated CBCT effective dose for the paranasal sinuses to be in the range of 0.1 to 0.2 mSv. This is significantly lower than that calculated for the relatively wide range of CT scanners used at our institution, which ranged from 0.67 mSv to 2.15 mSv. It must also be kept in mind that the lens, which is susceptible to deterministic radiation effects, is often included in exams of the paranasal sinuses. The importance of radiation dose savings is even further magnified in the population we studied, given the potential for repeat CT studies in patients with chronic sinus disease.

The principal limitation to this study was the lack of an actual CBCT comparison to traditional MDCT. However, it would be both unrealistic and unethical to expose patients to additional radiation for this purpose. Furthermore, we established conservative criteria for our simulated CBCT so that the potential false negative...
rate for CBCT would, if anything, be overestimated. Additional limitations include the retrospective nature of the study, but a prospective study would require a very large sample size given the low frequency of positive studies. The dose reduction from CBCT may be similarly achieved by using low-dose MDCT combined with advanced reconstruction algorithms; this is a potential area for further research.

CONCLUSION

In patients undergoing maxillofacial CT for evaluation of sinusitis, incidental findings of soft-tissue pathology were rare. Appropriate patient selection for CBCT may provide substantial reduction of radiation exposure without loss of therapeutic efficacy.

BIBLIOGRAPHY

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