

Advancements in computed tomography management of chronic rhinosinusitis

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ABSTRACT

Background: Advances in cone beam computed tomography (CBCT) technology have allowed for reduction in radiation dosages as well as the miniaturization of CT scanner units. This has given rise to new applications for CT scanning, including point-of-care (POC) in-office and intraoperative applications.

Methods: A review of recent changes to radiological modalities as applied to otolaryngology–head and neck surgery was performed. A discussion of the physics, applications, and role of diagnostic imaging in the evaluation of chronic rhinosinusitis (CRS) is conducted.

Results: The adaptation of cone beam technology has allowed for the practical implementation of CT scanning at the bedside, be it in the clinic or operating room setting.

Conclusion: Given their relative low cost, ease of storage, and low-dose radiation exposure, POC-CT scanners have become an indispensable tool in the diagnosis and treatment of CRS. In the setting of increasing antibiotic costs, overtreatment with antibiotics, and fewer required return visits, POC-CT challenges the conventional role of empiric medical therapy before progression to imaging for the diagnosis of CRS.

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Computed tomography (CT) and magnetic resonance imaging have revolutionized our ability to diagnose chronic rhinosinusitis (CRS). Widely regarded as the gold standard and first-line investigation for CRS, CT scanning has become the workhorse modality in a condition where clinical symptoms and endoscopy have relatively low sensitivity and specificity. In unoperated patients, it can provide information on the sinus status that endoscopy can not. Not only is it an important diagnostic modality, but it also plays a critical role in preoperative planning and is central to avoidance of surgical complications. Multislice CT scanners have increased speed of acquisition and reduced radiation dosage per CT scan. However, the most significant advance in imaging for CRS has been in the adaptation of cone beam CT (CBCT) technology for imaging of the sinuses. With lower radiation dosages and more compact designs, CBCT scanners have exploded with applications in point-of-care (POC-CT) and intraoperative CT (IOCT) settings.

HISTORY OF CONE BEAM

CBCT scanning was first adapted for clinical use in 1982, initially as an application for angiography.¹ In 1992, the technology was adapted for use as a guidance system for radiation therapy.² Eventually, the first CBCT became commercially available in 2001 as applied to dental and oromaxillofacial surgery. More recently, interest has been focused on head and neck applications, as well as spinal, abdominal, and orthopedic use.^{3–7} Although CBCT sacrifices potential soft tissue resolution, its strength lies in its spatial resolution. Furthermore, its relatively low radiation dose, compact size, and quick acquisition

time have made this technology a subject of interest as applied to intraoperative and in-office POC use.^{8,9}

PHYSICS OF CBCT

Conventional CT scanners use a fan-shaped emission of radiation that is detected by a row of detectors. As the source and detectors rotate, they are able to construct an axial slice. Translation of the patient through the source and detector in the z-plane (in the superior–inferior direction) then allows for multiple axial “slices” to be produced. Integrating all “slices” recreates the entire CT volume. This is a slight simplification because in reality, helical scanners are rotating while z-plane translation is occurring, which produces a volume of isotropic data rather than individual slices.

In contrast, CBCT scanners use a cone-shaped emission. The sensor is a flat-panel area detector. Flat panels are analogous to and a descendent of the detectors used for plain fluoroscopy. They have the advantage of smaller detector elements relative to multidetector CT (MDCT), which gives them a very high spatial resolution. Because of the larger area scanned in the z-plane (in the superior–inferior direction), CBCT scanners are able to obtain greater spatial resolution in a single revolution. This leads to reduced radiation exposure time. What is sacrificed, however, is dynamic range—difficulty discerning tissues of slightly different density, which translates to lesser ability to resolve soft tissues. Another sacrifice is slower response time or temporal resolution. Given that there is typically little patient movement during these scans, this is of minimal consequence.

As the multislice CT scanners evolve to include more rows of detectors, the two-dimensional row in the fan shape approximates the acquisition geometry of the cone beam system.⁸ With 320 rows of detectors on the latest generation of MDCT scanners, the detector array is similar in size to a flat-panel detector. Even so, the individual detectors in MDCT scanners are larger, providing lesser spatial resolution than CBCT scanners.

OFFICE-BASED POC-CT

As initial interest in intraoperative applications have moved toward in-office adaptations (Mini-CAT [Xoran Technologies, Ann Arbor, MI]; 3D Accutomo and 3D Accutomo 170, [J Morita Manufac-

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Figure 1. Typical arrangement and space requirements for mini-CAT scanner (Xoran Technologies, Ann Arbor, MI). A minimum of an 8' × 10' space is usually required.

Table 1 Relative radiation dosage estimates for x-ray and computed tomography (CT) modalities

Imaging Modality	Radiation Dosage (mSv)	Equivalent Radiation Exposure at Sea Level
Chest x-ray	0.1	10 days
Mini-CAT CT Sinus 600 Frame	0.17	20 days
Mammogram	0.7	3 mo
CT sinus	1	4 mo
CT head	2	8 mo
CT chest	8	2 yr
CT pelvis	10–20	3–6 yr

Source: Adapted from XoranTechnologies (www.radsafe.xorantech.com/).

turing, Irvine, CA); ILUMA CBCT, [IMTEC, Ardmore, OK and GE Health Care, Chalfont St. Giles, U.K.]), attention in CBCT technology has focused on imaging of the sinonasal tract, temporal bone, and skull base. CBCT is particularly useful at depicting these areas, because most clinically relevant scenarios require a high-resolution view of the bony anatomy, with less emphasis on soft tissue resolution.

In addition to ease of access and compactness, (Fig. 1), POC-CT scanners also have relatively low radiation exposures per scan with little compromise in resolution. Alspaugh *et al.* compared CBCT to 16-section and 64-section multislice scanners. They found that for equivalent resolutions of 0.4 mm, cone beam scanners of the sinuses could be obtained at 0.17 mSv and 64-multislice scanners used 0.87 mSv¹⁰— $\sim 1/5$ the dose (Table 1). The cone beam radiation dose equivalent is approximately the background exposure accumulated by living ~ 20 days on earth. Rafferty *et al.*¹¹ were able to establish proof of principle for CBCT's adaptability to functional endoscopic sinus surgery, concluding that resolution was sufficient to aid in navigation of the frontal sinus in cadavers. Meanwhile, Batra *et al.* were able to visualize frontal sinus stent locations as well as residual bony partitions in 25 revision sinus surgery patients.¹²

Finally, the excellent three-dimensional reconstruction and improved planar reformatting over conventional CT lends well to applications for intraoperative use. Because many POC-CT scanners are now compatible with image guidance systems, patients can be offered seamless upload without concern for compatibility issues. Simultaneously, accurate confirmation of anatomy is provided, allowing veri-

fication of completeness of dissection and minimizing potential complications of surgery.

The use of POC office CT has been examined in our practice both prospectively and retrospectively.^{13,14} In these analyses, patients who met the Rhinosinusitis Task Force symptom criteria for CRS, but who had equivocal endoscopic findings, were studied, because this reflects a subpopulation where we hypothesized that POC-CT would influence diagnostic precision and medical decision making. Retrospectively, 100 patients with clinical symptoms meeting Rhinosinusitis Task Force criteria for CRS and negative endoscopy were compared with POC-CT scan findings. We observed that $<50\%$ of patients with this profile actually had sinusitis as defined by Lund-Mackay scoring of ≥ 3 or scores <3 with symptoms localizing to the affected sinuses. This drops to 20% if using more stringent and commonly used CT cutoffs of Lund-Mackay scores of ≥ 4 . The mean Lund-Mackay score in the scan-positive group was ~ 4 , suggesting that even when sinusitis was present it tended to be mild by radiological criteria. Furthermore, a rigorous multivariate model revealed that those with CT confirmation of disease were 16 times more likely to receive antibiotics ($p < 0.001$). We concluded that POC-CT averted prescription of unnecessary medical therapies in 50–80% of this group, where oral antibiotics (and possibly steroids) would have otherwise been prescribed empirically. As such, POC-CT can avert the risk of adverse events associated with unnecessary antibiotics and steroids. Furthermore, as rates of antibiotic resistant organisms continue to rise, the reduction in inappropriate antibiotic prescriptions may help stem these changes.

Prospective investigation has supported the aforementioned findings with an antibiotic overtreatment rate of 60–80% and has also shown that POC-CT at the time of initial presentation also correlates with greater degrees of patient compliance. Of those randomized to the upfront CT arm, 100% of patients maintained treatment and follow-up adherence. Meanwhile, despite repeated reminders to encourage follow-up, 50% of patients did not return for subsequent visitation.

ECONOMIC IMPACT OF POC-CT ON THE MANAGEMENT OF CRS

Current guidelines for the diagnosis and management of CRS were created in an era where CT scanning was expensive and relatively inaccessible. Rhinosinusitis Task Force guidelines have advocated involving the use of empiric medical therapy followed by CT scan reserved for nonresponders—both for diagnosis and preoperative planning. With the advent of POC-CT scanners, decreasing costs associated with CT and increasing costs of medications, Leung *et al.* were able to show a clear cost savings by adopting an upfront CT strategy.¹⁵ The upfront CT algorithm involves patients with clinical symptoms meeting CRS criteria and with negative endoscopic exams (Fig. 2). These patients would undergo POC-CT scanning in the same visit, which would stratify patients into CRS, rhinitis, and facial pain spectrum diagnoses. CRS patients would then receive a course of maximal medical therapy, incorporating oral antibiotics, oral steroids, and intranasal steroids. At follow-up 6–8 weeks later, asymptomatic patients would continue with maintenance intranasal steroids, whereas symptomatic patients would be considered for a repeat CT at the surgeon's discretion and counseled for endoscopic sinus surgery. Integration of the clinical pretest probabilities for each diagnosis; the treatment response rates; and the Medicare costs of prescriptions, office visits, endoscopy, and CT scanning was performed, comparing the impact of upfront POC-CT scanning versus the currently recommended empiric medical therapy. This would result in \$492.20 per patient in savings compared with current guidelines, or $>US\$2.25$ billion saved per year. Even biasing all probabilities in favor of empiric therapy by keeping medication costs minimized, medication response rates maximized, and antibiotic adverse event rates mini-

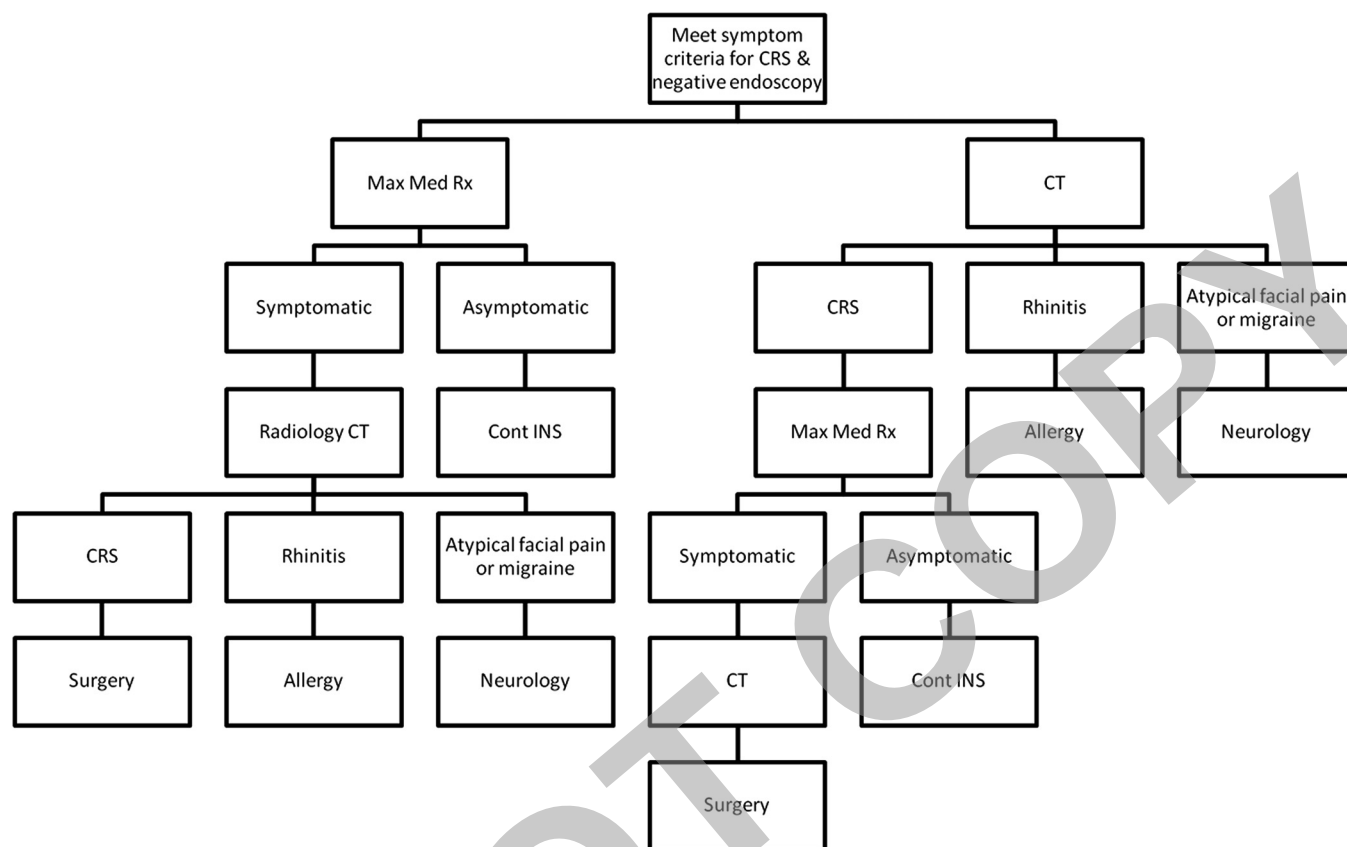


Figure 2. Classic empiric medical therapy algorithm and new suggested upfront computed tomography (CT) algorithm. The upfront CT strategy further reduces the number of patient visits, inappropriate prescriptions for antibiotics, and exposes patients to lower radiation doses than with conventional CT under the empiric medical therapy strategy.

mized, there continues to be a \$278 savings advantage associated with upfront CT scanning.

In our practice, all CT scans are reviewed and a formal report is rendered by a neuroradiologist. Other otolaryngology practitioners may choose to render their own readings and to reserve radiology consultation for unusual or uncertain findings. Although evaluation of relevant diagnostic imaging is within the scope of otolaryngology training, we suggest that clinicians implementing office-based CT imaging obtain a formal reading from a qualified radiologist whenever possible. This lessens medicolegal exposure and may even be a requirement in particular municipalities or health care systems.

IOCT SCANNING

Image guidance technology has become an invaluable tool for the surgeon; however, conventional systems are based solely on preoperative imaging. Intraoperative imaging can enhance the precision and safety of complex skull base and craniofacial surgeries with the assessment of extent of resection, integrity of critical structures, and status of anatomic landmarks. Additionally, real-time updates can be provided to the image guidance system. Solares *et al.*¹⁶ performed a series of cadaveric endoscopic ligations of the anterior ethmoid artery as a proof of concept for epistaxis. Verification with IOCT scans revealed that only two of the six specimens with arteries on mesenteries were clipped successfully. Although the authors observed poor feasibility of the technique overall, they were also able to show that the IOCT findings can allow surgeons to change surgical approaches if initial ligation is unsuccessful.

With the development of more compact and portable systems, IOCT scanning is now becoming more practical. Conley *et al.*¹⁷ eval-

uated the value in lateral and anterior skull base surgery of three portable scanners: NeuroLogica CereTom (NeuroLogica Corp., Danvers, MA), Xoran xCAT (Xoran Technologies, Inc.), and Medtronic O-ARM (Medtronic, Inc., Minneapolis, MN). The NeuroLogica CereTom uses the traditional MDCT-based technology whereas the Xoran xCAT and Medtronic O-ARM use the CBCT-based technology. All scanners were found to provide good bone windows for intraoperative consideration and integration into the image guidance system. Overall, the MDCT devices have the superior soft tissue resolution ability albeit while delivering a higher absorbed radiation dose per scan when compared with the CBCT scanners; however, the MDCT can be used at a lower radiation level to provide images comparable with those obtained from CBCT devices. The CBCT devices, in addition to administering a lower radiation dose to obtain high-quality bone windows, yield less metal artifact, particularly from the reference arrays placed on the patient for image guidance purposes.

Physical constraints of the operating room and patient anatomy will also influence feasible use of intraoperative scanners. For instance, the O-ARM, the largest of the scanners, will require adequate room size and the CereTom, which acquires images by rolling across the floor for the length of the field and has a 12.5-in. bore diameter, will require a flat and smooth floor surface to preclude motion artifact and can not accommodate patients with significant kyphosis.

The advantages and limitations of each intraoperative scanner device would need to be considered for each particular patient case and circumstance. In the study by Conley *et al.*, it was found that IOCT scanning was both logistically feasible and technically useful in surgical decision making in 75% of patients. Future refinements would augment the functionality and application of these devices.

CONCLUSION

Imaging of the sinonasal tract remains a critical tool to the practicing otolaryngologist. This is true not only in the role of diagnosing chronic sinusitis and sinonasal neoplasms, but also in preoperative planning.

CT scanning remains the gold standard for delineating bony anatomy and identifying defects in the bony orbit and skull base. Magnetic resonance imaging will provide additional information about the soft tissue characteristics and fluid intensities, especially in the evaluation of nasal masses picked up on endoscopy or CT scan.

The advent of in-office CT scanning has added a new dimension to the diagnosis and initial management of CRS. Lower radiation dosage and increased convenience can be achieved without compromise of image quality.

Detailed preoperative review of imaging is critical to the success and minimization of complications of surgery. An organized approach to the evaluation of sinonasal imaging will help ensure that pathology, anatomic variations, and potential surgical pitfalls are not missed. As a result, the clinician can minimize the risks of surgery.

CT scanning does not replace clinical decision making and should not be ordered indiscriminately. Instead, it should serve as a complement to a complete history, physical examination, and endoscopy.

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