Maxillofacial Imaging: a 21st Century Perspective

Imagen Maxilofacial: una perspectiva Siglo 21

Richard Monahan, The University of Illinois at Chicago, USA, rmonahan@uic.edu
Carol S. Gonzalez, The University of Illinois at Chicago, USA, den3Dimaging@uic.edu

RESUMEN
Este artículo presenta una visión general de los sistemas de imágenes contemporáneas aplicables al complejo maxilofacial / craneofacial. Cada sistema se compara en términos de fortalezas y debilidades, ventajas y limitaciones. Entidades patológicas seleccionadas se utilizan para ilustrar el rendimiento diagnóstico de cada modalidad de imagen. Desde la justificación para la prescripción de un estudio de imagen se debe valorar el riesgo y el beneficio para el paciente, la carga de radiación de cada sistema de imagen se integra en el contexto de la discusión.

PALABRAS CLAVE
Imágenes Maxilofaciales, tomografía computada, tomografía computarizada, tomografía computarizada por haz de cono, CBCT, resonancia magnética, MRI

ABSTRACT
This article presents an overview of the contemporary imaging systems applicable to the maxillofacial/ craniofacial complex. Each system is compared in terms of strengths and weaknesses, advantages and limitations. Select pathologic entities are used to illustrate the diagnostic yield of each imaging modality. Since justification for prescribing an imaging study must balance the risk and benefit to the patient, the radiation burden of each imaging system is integrated within the context of the discussion.

KEY WORDS
Maxillofacial imaging, computed tomography, CT, conebeam computed tomography, CBCT, magnetic resonance imaging, MR

Recibido: 31 agosto, 2015
Aceptado para publicar: 26 octubre, 2015

INTRODUCTION

Over the last 100 years, two-dimensional radiographs have assisted an untold number of clinicians in providing exceptional treatment for their patients. The diagnostic capability of traditional films remained unchallenged until the advent of computer-based imaging. The 21st century provides doctors with the opportunity to incorporate the latest advancements in diagnostic imaging into their practice. The benefits of modern technology allow the doctor to view their patients from a three-dimensional perspective and provide state-of-the-art diagnosis and treatment. This article reflects on the benefits of traditional imaging then moves the clinician forward into the world of 3D.

BACKGROUND

The information gained from an imaging study is called the "diagnostic yield." The higher the diagnostic yield, the more information the clinician receives about his/her patient. However, the information gained must be of clinical relevance to the doctor. It must provide answers to diagnostic questions that allow the clinician to better understand the anatomic or pathologic condition under consideration. Selection of the appropriate imaging modality is paramount to obtaining optimal patient outcomes.

PRESCRIBING AN IMAGING STUDY – ALARA

Based on the clinical examination, medical history, patient dialogue and treatment objectives the doctor decides what, if any, imaging study is essential for a given patient. This is a professional judgment based on prevailing evidenced-based best practices. Once the decision to image has been made, strict adherence to the concept of ALARA is essential. ALARA (As Low As Reasonably Achievable) is often misinterpreted to be a guideline on when a patient should be imaged. As stated above, the decision on when a patient should be imaged lies within the professional judgment of the clinician. What ALARA dictates is that once the decision is made that imaging is necessary, the clinician prescribes an imaging study that will provide the required diagnostic yield and, at the same time, subject the patient to the least amount of ionizing radiation as possible. Inherent in the concept of ALARA is that the doctor limits the field of view to the anatomic area under consideration. Another concept embraced by ALARA is that the patient has adequate shielding during image acquisition. Having x-ray equipment properly calibrated, avoiding repeat examinations when possible and utilizing imaging systems with the lowest possible dose to the patient are all encompassed in ALARA.

A REFLECTIVE ANALYSIS OF TWO-DIMENTIONAL IMAGING

Projection radiology (PR) has been used for over a century to provide relatively reliable diagnostic information. In PR the patient is placed between the x-ray source and the image receptor. Selective absorption (attenuation) of the x-ray beam as it passes through the patient creates a pattern that reflects the various anatomic structures under examination. In general, the thicker and denser the anatomic structure being imaged the more x-rays it will attenuate. Areas of high attenuation (bone) result in a relatively white (radiopaque) impression within the final image. Areas of low attenuation (soft-tissue) result in a radiolucent presentation.

The resultant image in all PR systems is compromised due to inherent distortion and overlap of adjacent structures. It does however provide baseline osseous relationships relevant to treatment planning objectives and related oral/maxillofacial procedures.

Projection radiology, in both analog and digital formats, continues to provide a relatively low radiation dose, technically straightforward, patient friendly and financially attractive means of assessing anatomic relationships and evaluating pathologic conditions. When a higher diagnostic yield is necessary tomographic (cross-sectional) imaging systems can provide undistorted images without the drawback of anatomic superimposition. The radiation dose to the patient (the radiation burden) is increased so a heightened risk - benefit analysis is mandatory before a tomographic study is prescribed. Often termed "advanced imaging" these cross-sectional systems include computed tomography, magnetic resonance imaging and the more recently developed conebeam computed tomography. The clinical applications, advantages and disadvantages of each of these modalities will now be considered.

COMPUTED TOMOGRAPHY

Invented in 1972 by Georges Houndsfield at EMI Institute in London, CT (also called CAT scan for computed - "axial"- tomography) has become the gold standard for maxillofacial imaging. Like projection radiology, CT uses ionizing radiation that is selectively absorbed as it traverses the body. The pattern formed by the x-ray beam after it exits the patient is captured by a detector. How CT differs from projection radiology is that as the x-ray source turns or revolves around the patient the detectors capture snapshots or profiles of the attenuated x-ray beam. The profiles are fed to a computer that uses algorithms to produce slices of the internal anatomy captured within the area of interest. Early clinical CT machines would generate a thin, fan-shaped x-ray beam that would revolve around a movable patient bed (the gantry). The gantry would incrementally move the patient as the x-ray beam would slice or knife its way through the anatomic area of interest. A set of ring-like detectors synchronized with the x-ray beam captured the attenuated radiation pattern as it leaves the patient and feed the data to a computer for image reconstruction and display.

Contemporary CT scanners utilize multiple arrays of x-ray detectors and sophisticated helical-shaped radiation emission patterns that allow for faster scans, more robust data collection and undistorted image display in all anatomic orientations (called MPR for multiplanar image reconstruction).

All clinical CT data sets allow for several standard viewing options termed "windows." A soft-tissue window will present the clinician with a view of the patient's anatomy that accentuates or focuses on those attenuation densities that provide optimal viewing of soft-tissues (versus bone).

Figure 1 is an example of a CT image set to optimize soft-tissue. Note the visualization of the pterygoid muscles. Osseous structures are viewable when the computer displays anatomy in the soft-tissue window setting, but with suboptimal resolution and contrast. The reverse is true when a clinician selects the "bone window" alternative.

Figure 1. CT image set to optimize soft tissue. The pterygoid muscle is easily identified.

CT data manipulation can generate three-dimensional images, volumetric display, transparency of select anatomic structures, surgical models, surgical stents and provide simulated outcome predications based on individualized treatment plans.

The tremendous diagnostic yield of a CAT scan comes with a risk in terms of radiation dose to the patient. Although advances in technology strive to reduce the x-ray exposure needed to obtain a scan, CT uses far more x-rays than traditional projection radiology.

CONEBEAM COMPUTED TOMOGRAPHY

Relatively new to maxillofacial radiology, conebeam computed tomography (CBCT) possesses a set of strengths that makes it a welcome addition to the spectrum of diagnostic imaging options. Utilizing a relatively low dose of ionizing radiation CBCT allows for image capture that displays excellent spatial resolution (image detail) of hard tissue in a patient-friendly imaging system that is both technically easy to operate and carries a relatively light economic burden.

While traditional CAT scanners can be thought of as using multiple slices or ribbons of x-rays that cut through the patient, a CBCT scan uses a cone-shaped x-ray beam that turns around the patient one time and covers the entire anatomic area of interest. Profiles or snapshots of the attenuated radiation beam are captured on a single flat-panel detector which feeds into a local computer for instantaneous display and manipulation. Like a traditional CT scan, CBCT data sets can be integrated with diagnostic software programs.

As depicted in figure 2, anatomic areas of interest such as the

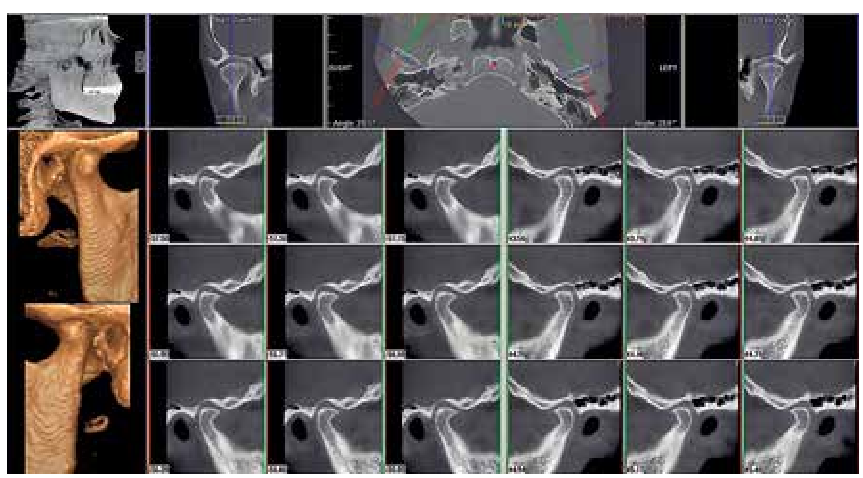


Figure 2. Cross-sectional and three-dimensionally rendered depictions of the osseous components of the TMJ.

osseous component of the temporomandibular joint can be evaluated in contiguous cross-sections images.

Figures 3 and 4 illustrate three-dimensionally rendered images of a tumor that occupies the left body and ascending ramus of the mandible.

Figures 3 and 4 illustrate three-dimensionally rendered images of an ameloblastic fibro-odontoma that occupies the left body and ascending ramus of the mandible.

As seen in figure 5, Volumetric analysis of the airway can be obtained using task specific software applications.

Figure 5. Volumetric analysis of the airway obtained using a task specific software application.

While these qualities are comparable with traditional CT units, an important advantage of CBCT is the relatively low radiation dose needed to capture the data set. Although imaging parameters effect the actual radiation dose of each tomographic scan a radiation reduction approaching 90% can be achieved with CBCT.

When compared with a CAT scan, a CBCT study can demonstrate excellent anatomic detail. Unfortunately, all CBCT studies exhibit relatively poor contrast resolution. Therefore, while the viewing parameters can be adjusted in a CBCT study to display the optimal inherent diagnostic yield, there is no true window that allows the clinician to distinguish soft-tissue anatomic structures of similar tissue density. When the radiographic work-up calls for differentiation of internal soft-tissue structures, CT should be considered superior to CBCT. In addition, the use of injectable contrast media to highlight vascular tissue, enhance lymph node visibility or outline anatomic boundaries is not clinically feasible with CBCT at this time.

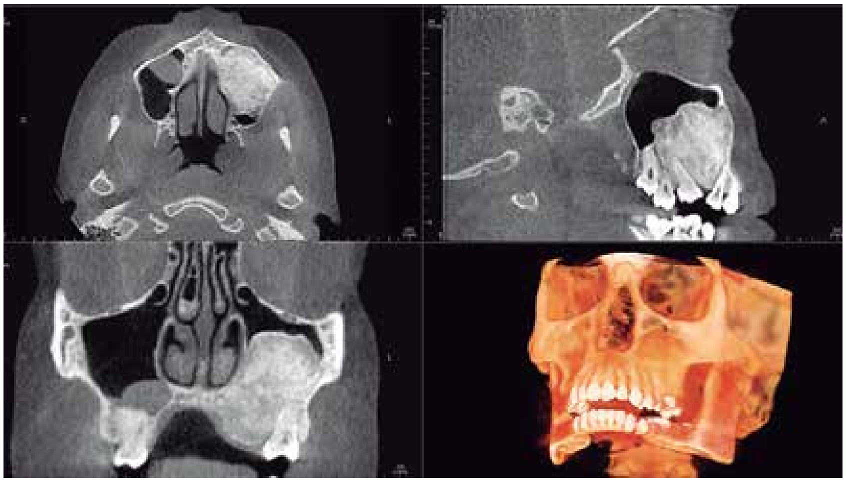
Figures 6 - 11 demonstrate CBCT images portraying various pathologies:

Figures 6, Coronal slide of anatomy showing a traumatic fracture of the lateral wall of the right maxillary sinus and associated blood-fluid level.

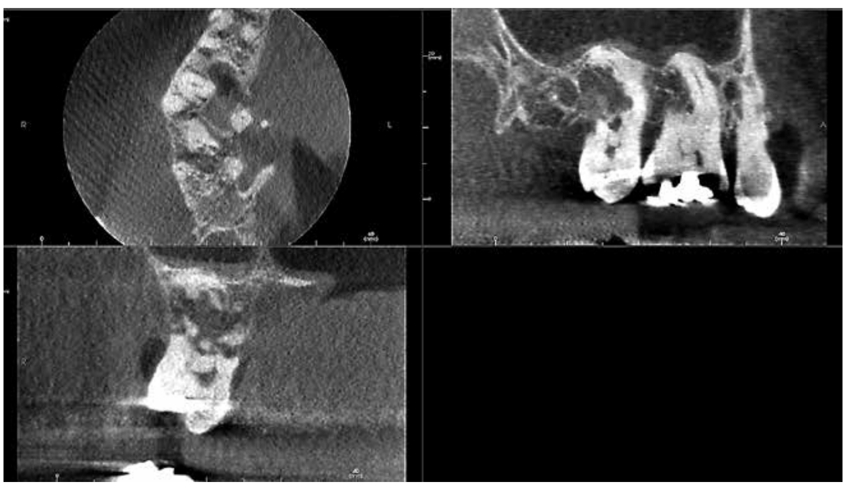
Figures 7. Same case as seen in Figure 7 with a different software visualization tool.

Figures 8. Calcifications within the veins of the right muscular envelope (phleboliths) associated with a history of hemangioma.

Figures 9. Calcinosis circumscripta associated with scleroderma is seen in the right soft-tissue envelope of the mandible.



Figures 10, Cemento-ossifying fibroma expanding the palate and occupying the left maxillary sinus. Unassociated mucus retention cyst is noted in the right maxillary sinus.



Figures 11. Cancer of the maxilla as depicted in s small field-of-view CBCT scan.

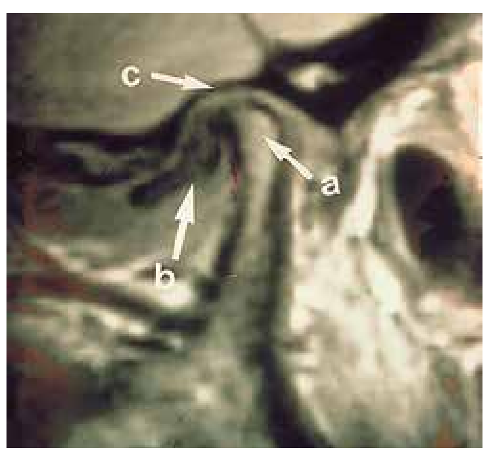


Figure 12. MR image of the temporomandibular joint complex. Arrow "a" identifies the condylar head, arrow "b" the disc and arrow "c" the roof of the glenoid fossa.

MAGNETIC RESONANCE IMAGING

MRI is unique in that it does not use ionizing radiation. Instead of x-rays MRI utilizes a combination of magnetic energy and radiofrequency waves to generate an image. During the examination the patient is placed in a strong magnet and the resultant electromagnetic energy temporarily changes the relationship of the hydrogen protons within the body. The area being examined is then subjected to radiofrequency waves. The energy of the radiofrequency waves is transferred to the hydrogen protons which causes a momentary shift in their alignment. When the RF waves cease, the absorbed energy is released and detected by an antenna. This signal is then process into a measurable density that is reflective of the imaged anatomy.

The abundance of hydrogen in the water of soft tissue provides an excellent source of protons which can be used to generate an MR image. Differences between adjacent soft tissue, such as fat and muscle, can be easily distinguished. MRI can also differentiate blood vessels and nerves from surrounding soft tissue. This type of anatomic detail is far superior to other imaging modalities and constitutes the principal benefit of an MRI study. Figure 12 illustrates an MR image of the temporomandibular joint complex. Note arrow “b” identifies the TMJ disc. Diagnostic imaging systems that utilize ionizing radiation rather than magnetic energy are unable to produce this level of soft-tissue visualization. To date, there are no scientifically documented radiobiologic harmful effects from the clinical utilization of MRI. Due to potential interaction with the strong magnetic field, possible contraindications to MRI include the presence of cardiac pacemakers, ferromagnetic intracranial aneurysm clips, certain neurostimulators, select cochlear implants and ferromagnetic foreign bodies or electronic devices.

Hard tissue, such as bone, contains less water and consequently less available hydrogen protons than soft tissue. Since protons are used to generate the image, bony structures are not well defined with MRI. CT/CBCT remain the state of the art when evaluating osseous contours, defining clefts, diagnosing fractures or detecting subtle changes in cortical bone.

CONCLUSION

Every imaging system has its strengths and weaknesses. The key to taking advantage of each imaging modality is to frame the clinical question in terms of diagnostic yield: “What information will the imaging study provide that will affect how I manage this case?” The answer to that question is then balanced with the principle of ALARA. When the radiographic findings are integrated with the clinical examination, medical history and patient dialogue the doctor can then provide optimal treatment.

Dr. Richard Monahan
Director of Radiology
University of Illinois College of Dentistry
Chicago, Illinois, USA

Carol S. Gonzalez
Radiology Coordinator
University of Illinois College of Dentistry
Chicago, Illinois, USA

Correspondence: Rmonahan@uic.edu

BIBLIOGRAFÍA

Alamri HM , Sadrameli M , Alshalhoob MA , Sadrameli M , Alshehri MA. (2012) Applications of CBCT in dental practice: a review of the literature. General Dentistry 60(5):390-400.

Carter L, Farman AG, Geist J et al. (2008) American Academy of Oral and Maxillofacial Radiology executive opinion statement on performing and interpreting diagnostic cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 106, pp. 561–562.

De Vos W, Casselman J, Swennen G. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature. Int. J. Oral Maxillofac. Surg.

Fernandez T, Adamczyk J, Polti M , José Fernando Castanha, Henriques J, Friedland B, Garib D. (2015) Comparison between 3D volumetric rendering and multiplanar slices on the reliability of linear measurements on CBCT images: an in vitro study. J. Appl. Oral Sci. vol 23.

Harnsberger HR, Glastonbury CM, Michel MA, Koch BL, Phillips CD, Mosier KM et al. (2009) Expertddx. Head and Neck. Salt Lake City, USA: Amirsys Press.

Haskell J, Haskell B, Spoon M, Feng C. (2014) The relationship of vertical skeletofacial morphology to oropharyngeal airway shape using cone beam computed tomography: Possible implications for airway restriction. The Angle Orthodontist: Vol. 84, No. 3, pp. 548-554

Hasso AN. (2012) Diagnostic imaging of the head and neck. New York, USA: Lippincott, Williams and Wilkins Publishers.

Kau C, Bozic M, English J, Lee R. (2009) Cone-beam computed tomography of the maxillofacial region – an update. Int J Med Robotics Comput Assist Surg; 5: 366–380.

Kennedy DW, Bolger WE, Ziinreich, SJ. (2001) Diseases of the Sinuses. London: BC Decker.

Koenig, LJ. (2012) Diagnostic Imaging Oral and Maxillofacial. Salt Lake City, USA: Amirsys Press.

Kumar T, Puri G, Aravinda K,Laller S, Malik M, Bansalt, (2015) CBCT: a guide to a periodontist. SRM J Res Dent Sci:6:48.

Ludlow JB, Ivanovic M. (2008) Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 106, pp. 106–114.

Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. (2015) Correction to Effective dose of dental CBCT—a meta analysis of published data and additional datafor nine CBCT units. Dentomaxillofac Radiol; 44: 2015.

MacDonald D. (2011) Oral & Maxillofacial Radiology. Chichester, West Sussex, England: Wiley-Blackwell.

Robb, R.A. (2000) Biomedical imaging, visualization, and analysis. New York: Wiley-Liss, Inc.

Saki O. (2011) Head and neck imaging cases. New York, USA: McGraw-Hill Publishers.

Scarfe W, Farmen AG, Sukovic P. (2006) Clinical Applications of cone-beam Tomography in Dental Practice. J Can Dent Assoc; 72(1):75–80.

Singer SR, Creange AG. (2016) Diagnostic imaging of malignant tumors in the orofacial region. Dent Clinics of North America. v60 (1) 143-165.