Advances in Head and Neck Imaging

Tao Ouyang, MD[a], Barton F. Branstetter IV, MD[b,*]

KEYWORDS

- Computed tomography • Magnetic resonance imaging
- Positron emission tomography
- Radiology in dental and craniomaxillofacial practice

After Wilhelm Roentgen discovered x-rays in 1895, the head and neck region began to be explored in ways that had never been possible before. Suddenly, the osseous structures and the overlying soft tissues could be visualized using various projections using plain film radiography. Fluoroscopy was subsequently introduced, enabling dynamic evaluation of the upper aerodigestive tract and the esophagus with excellent detail.

Linear tomography became available in the 1930s. Subsequently, circular, elliptical, and hypocloidal tomographic tube motions were introduced to evaluate the complex structures of the head and neck, including the facial bones and the temporal bones. Tomography continues to be fundamental in dental imaging with the use of panoramic oral radiographs.

Computed tomography (CT) and magnetic resonance imaging (MRI) were introduced in the 1970s and 1980s and have since become the mainstay of cross-sectional imaging of the human body. With the advent of multislice scanners, which increase resolution and decrease scan time, CT technology has been especially important in changing the landscape of oral and maxillofacial imaging. MRI, with its ability to delineate marrow and soft tissue pathology, especially with the use of gadolinium contrast material, is often complementary to CT. MRI is also vital in the imaging of the temporomandibular joint (TMJ).

Finally, advances have also been made in the field of nuclear medicine. Nuclear medicine had traditionally relied on isotopes, such as those of indium and gallium, for tumor and infection imaging. While the use of such isotopes had been useful, it has been made somewhat obsolete by advances in cross-sectional imaging, especially with the use of intravenous contrast material. However, combination positron emission tomography and CT (PET/CT), introduced in the 1990s, has revolutionized imaging and surveillance of head and neck cancer and has become a vital part of oncological care.

COMPUTED TOMOGRAPHY

When CT was first introduced, it was extremely time-consuming, requiring about 5 minutes per image. It was first used in brain imaging only where a few select slices were imaged. Since then, many advances have been made in CT to enable faster scanning. Helical multidetector CT (MDCT) is the new standard in CT imaging of facial trauma, infections, and neoplasms of the head and neck.

CT uses Hounsfield values as a measure of the attenuation of tissues and assigns shades of gray to different values in generating an image. Depending on the range of values, any particular image can be "windowed" to the anatomy of interest (eg, bone, soft tissues, or brain).

Conventional CT scanners use a single row or multiples (4, 8, 12, 32, and now 64) of solid-state detectors paired with a fan-shaped beam to capture the attenuated x-ray. MDCT depends on pitch, collimation, and reconstruction thickness to make an image. Pitch is the amount of movement of the table through the gantry during one revolution of the detectors. Collimation is the width of the detector

[a] Department of Radiology, Penn State Hershey Medical Center, Hershey, PA, USA
[b] Department of Radiology, University of Pittsburgh Medical Center, 200 Lothrop Street, PUH Room D132, Pittsburgh, PA 15213
* Corresponding author.
E-mail address: Bfb1@pitt.edu

Oral Maxillofacial Surg Clin N Am 22 (2010) 107–115
doi:10.1016/j.coms.2009.10.002
1042-3699/10/$ – see front matter

oralmaxsurgery.theclinics.com

elements. Multiple detectors enable acquisition of several (as many as the number of detectors or "slices") images at once. This increases the speed at which the scan can be completed and enables images made up of thinner slices, thus providing better spatial resolution. Sixteen-slice scanners have been widely available for years, while 64-slice MDCT scanners became available in 2004 and represent significant improvements in image quality and scan time.[1] Decreased scan time is extremely important in the trauma setting as patients are often clinically unstable.

Multislice helical imaging provides excellent detail and is superior to panoramic radiograph in displaying the multiplicity of fragments, degree of dislocation or rotation, and/or skull base involvement in trauma.[2] MDCT also accommodates multiplanar reformats (MPRs). Traditionally, facial CT was often performed in the direct coronal plane. Now all images can be acquired in the axial plane and reformatted into coronal and sagittal planes. Coronal MPRs, rather than direct coronals, are advantageous in the trauma setting because trauma patients, often with cervical spine injuries, are limited in terms of positioning for direct coronal scanning. New postprocessing software for MDCT also makes possible three-dimensional (3D) volume-rendered reconstructions, which can be very useful in surgical planning for trauma and reconstructive imaging of the face.

MPRs can aid in the detection of subtle fractures (**Figs. 1** and **2**). Fractures oriented in the horizontal plane often are occult on the axial images. A study of 35 patients with complex maxillofacial trauma showed that, in 26 cases (74%), MPRs and 3D reconstructions were able to either better detail axial findings or show new injuries not discernible on axial images alone.[3] The same study showed coronal MPRs to be particularly useful in imaging the cribriform plate and the orbital floor and roof. Sagittal MPRs represent an entirely new plane of imaging that would not be otherwise possible. Sagittal MPRs are powerful for visualization of mandibular fractures; in particular, they can offer information about the alignment of the TMJs and the integrity of the inferior alveolar canal.

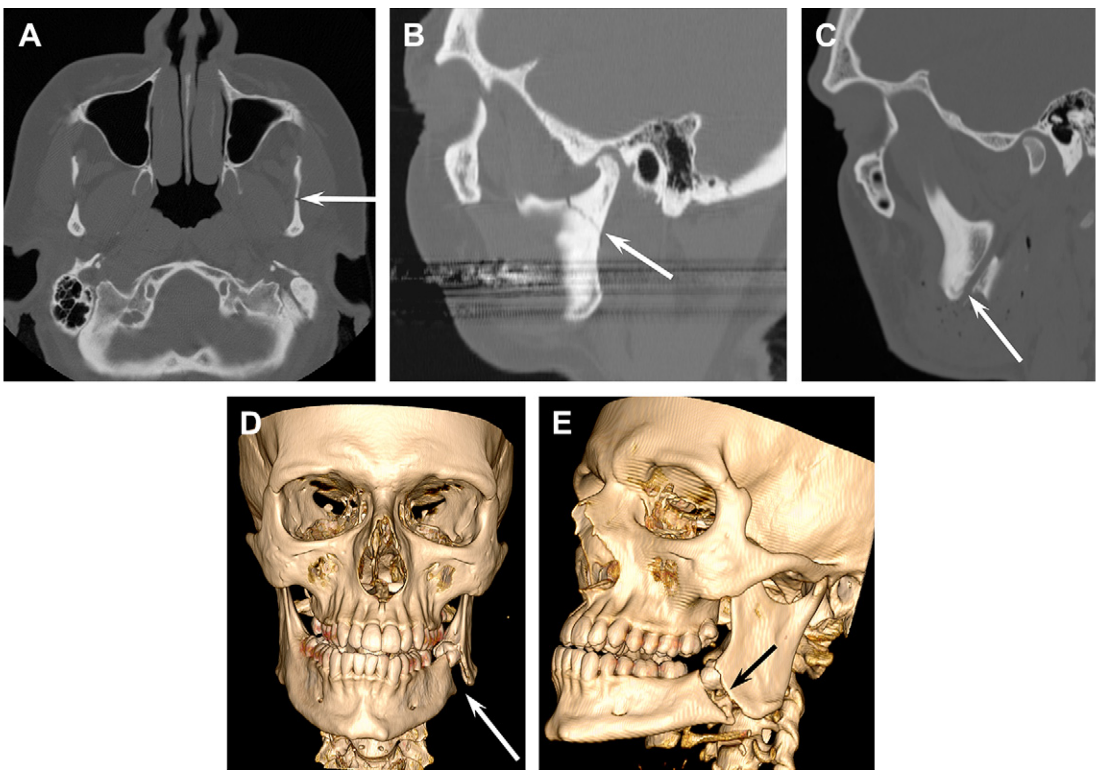

Fig. 1. Utility of CT postprocessing in the evaluation of mandibular fractures. (*A*) Axial CT image through the mandibular ramus depicts a subtle fracture of the left sigmoid notch (*arrow*). The fracture might be easily overlooked in this plane. (*B*) The subcondylar fracture (*arrow*) is much more evident, and better characterized, on sagittal reformatted image. (*C*) Sagittal reformatted image in another patient demonstrates the relationship between the fracture and the inferior alveolar canal (*arrow*). (*D*) Surface-rendered 3D reconstruction in frontal projection provides surgeons with an excellent gestalt of the fracture pattern (*arrow*). (*E*) Surface renderings can be performed in any projection to best depict the fracture (*arrow*).

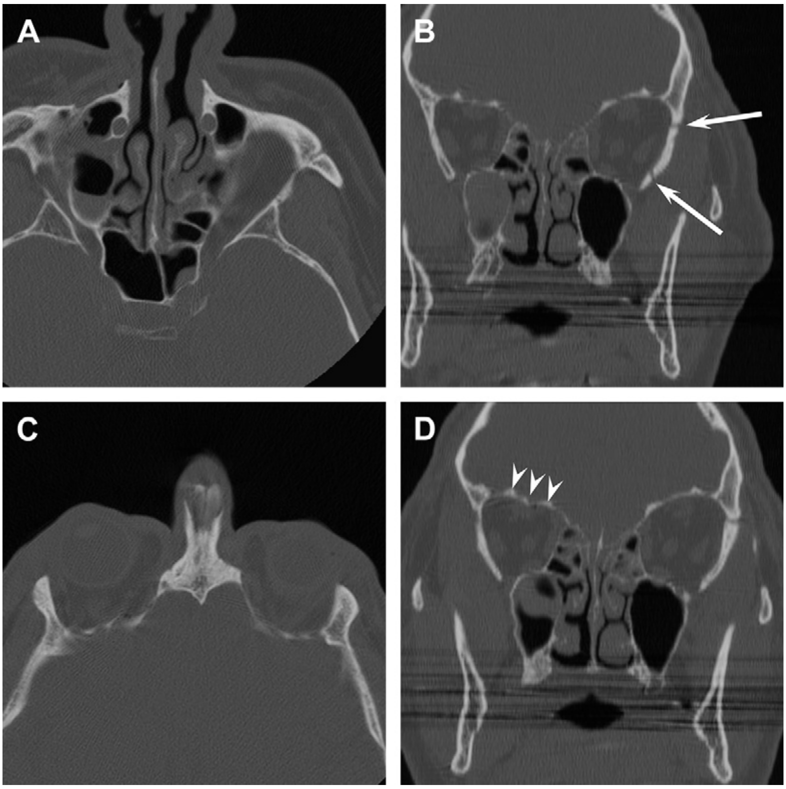

Fig. 2. Utility of CT postprocessing in the evaluation of orbital fractures. (*A*) Axial CT through the orbits does not identify any orbital fractures. (*B*) Coronal reformatted image clearly shows the two fractures (*arrows*) of the left orbital wall. (*C*) Axial CT in another patient demonstrates apparent symmetry between the orbital roofs. (*D*) Coronal reformatted image shows the depressed fracture of the right orbital roof (*arrowheads*).

Because information can be acquired in the helical mode in MDCT, axial reformats can also be rendered. These renderings can be very helpful if the patient positioning was suboptimal, which is often the case in trauma settings. This obviates rescanning the patient, saving radiation dose as well as time.

Panoramic reformats can also be obtained. This is useful in surgical planning for dental implants.[4] Oblique reformatted images can be obtained through the axis of each tooth (**Fig. 3**). This represents a significant advantage over traditional panoramic radiographs for several reasons, not the least of which is higher resolution. Panoramic radiographs, because of the curved cassette used in their acquisition, present a special challenge to digital conversion and storage in a readily available digital archiving system. Traditional films are easily lost, not easily transportable, and require space and manpower to store in libraries. However, the panoramic radiograph is by no means obsolete. Panoramic radiographs are inexpensive and easily accessible. They are also easy to perform in office settings, where they are often obtained. Therefore, the panoramic radiograph will continue to serve as a useful diagnostic and screening modality for dental disease, although MDCT is superior for evaluation of mandibular fractures and mass lesions.

Faster scan times using MDCT also permit dynamic maneuvers to better evaluate mucosa in the head and neck, in particular the "puffed-cheek technique," to examine closely opposing mucosal surfaces in the oral cavity (**Fig. 4**).[5] Other dynamic maneuvers include modified Valsalva, open-mouth, and phonation maneuvers.[6]

There are several limitations of MDCT as well. Chief among them is radiation risk. Artifacts can also be an issue, especially in the head and neck, where the anatomy is complex and many different tissues types are in close proximity. Beam-hardening artifact, from bone, hardware, or dental amalgam, can obscure images of nearby soft tissues. Motion (eg, from swallowing or phonation) can also cause artifacts, although this is less of an issue with the most current 64-slice scanners, which require less scan time.

Another advance in CT technology that merits discussion is cone-beam CT, which has been

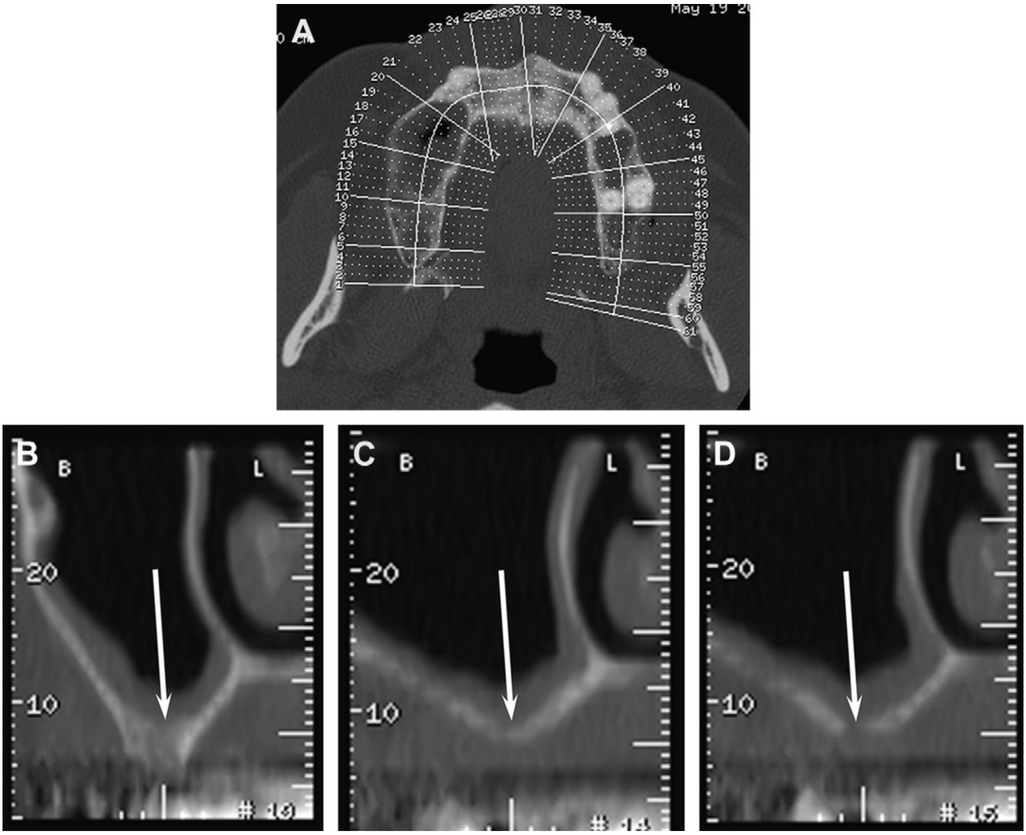

Fig. 3. Utility of CT postprocessing for evaluating the alveolus. (*A*) Scout axial CT image delineates the angles of the reconstructed sagittal oblique images designed to be perpendicular to the alveolar ridge. Each image is numbered so that the exact location can be referenced. The resulting reformatted images show normal thickness of the alveolar ridge (*arrow* in *B*), thinning of the ridge (*arrow* in *C*), or breakthrough into the maxillary sinus (*arrow* in *D*).

commercially available since the beginning of this decade. Cone-beam CT scanners use a cone-shaped beam, rather than a fan-shaped beam of x-rays. The x-ray source and detector make one full rotation around the patient's head and generate "projection data". These data are then processed to generate 3D volumetric data, from which reconstructed images in all three planes can be obtained. Cone-beam CT also has MPR and curved planar capabilities. Its chief advantages are lower radiation dose compared with MDCT,[7] rapid scan time (comparable with that of MDCT systems), availability of display modes unique to maxillofacial imaging, and smaller size and cost than conventional CT units, making it more suitable for use in clinical dental practices.[8,9] Currently, cone-beam CT is best suited to evaluate osseous structures in the craniofacial area (**Fig. 5**). MDCT remains preferable for evaluation of soft tissue processes, including tumors.

Fig. 4. Puffed-cheek technique. Axial CT image of a patient with squamous cell carcinoma of the lower lip demonstrates the lesion (*arrow*) surrounded by air instead of adjacent to the jaw. Buccal and gingival lesions may be difficult to distinguish and characterize without this technique. Furthermore, bone invasion can be confidently excluded.

MAGNETIC RESONANCE IMAGING

MRI imaging was introduced for clinical use in the 1980s and, because of its inherent multiplanar

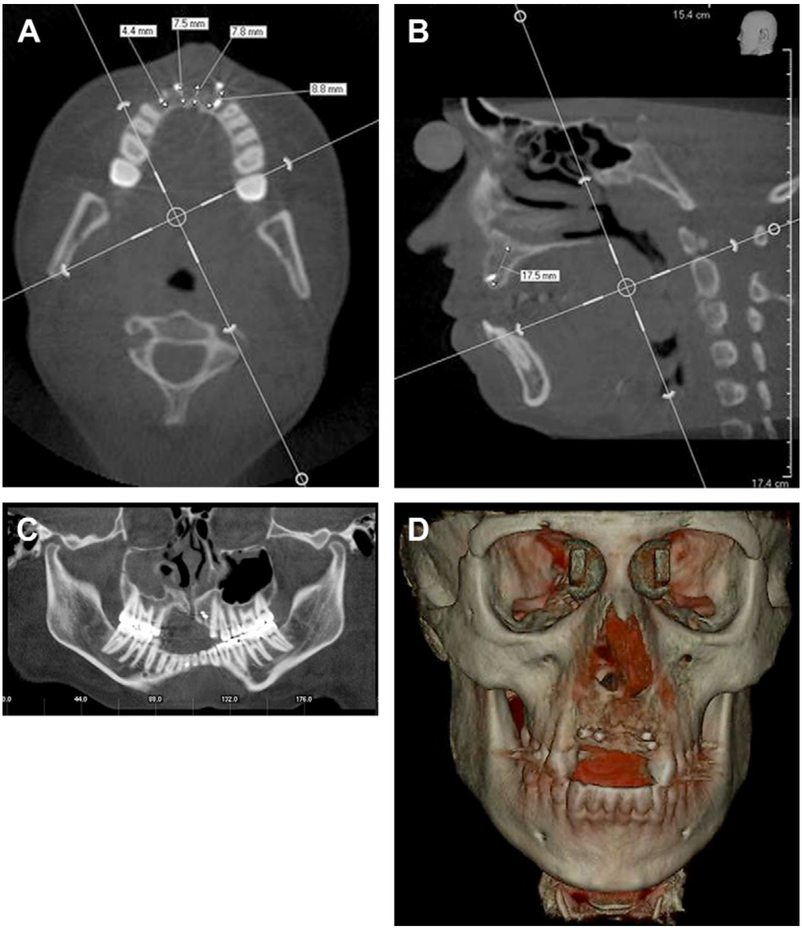

Fig. 5. Cone-beam CT. (*A*) Axial image from cone-beam CT in a patient with repaired dentoalveolar fractures of the anterior maxilla. Although image quality is lower than that for standard CT, and soft tissue is not evaluated, bone structures can still be accurately measured. (*B*) Multiplanar reformatted images are available, just as with standard CT. (*C*) Curved panoramic reformats may be useful for surgeons accustomed to panoramic radiographs. (*D*) Surface renderings do not have the same level of detail available from standard CT, but are usually adequate for surgical planning. (*Courtesy of* BJ Costello.)

capabilities and ability to delineate soft tissue pathology, has become a very powerful tool for imaging of the human body. Although MRI scanning is much more time-consuming and expensive than CT, and while MRI scanners are somewhat less accessible compared with the widespread availability of CT scanners, MRI is proven to have exciting and unique clinical utility in head and neck imaging.

Most clinical scanners available are 1.5 T or less, although 3-T scanners are becoming more widely used. MRI depends on the observation that protons become magnetized when a magnetic field is applied to them and the principle that protons in different environments behave differently when magnetized. These spins are picked up as “signal” and are mathematically process using Fourier transform to generate an image. MRI is much more flexible than CT, which depends solely on attenuation of x-rays by the tissue of interest. With MRI, sequences can be fine-tuned to take advantage of specific characteristics of tissues and the observation that diseased or inflamed tissues or neoplasms behave differently than normal tissue. MRI is particularly useful for evaluation of suspected osteomyelitis[10] and neoplastic conditions near bone since edema in the bone marrow and soft tissues can be easily detected by specific sequences, in particular inversion recovery sequences (**Fig. 6**).[11] MRI is also the preferred modality for identifying perineural spread of malignancy (**Fig. 7**).[12]

MRI imaging in head and neck infections and neoplasms nearly always requires the use of gadolinium-based intravenous contrast. Primary and secondary neoplasms often demonstrate

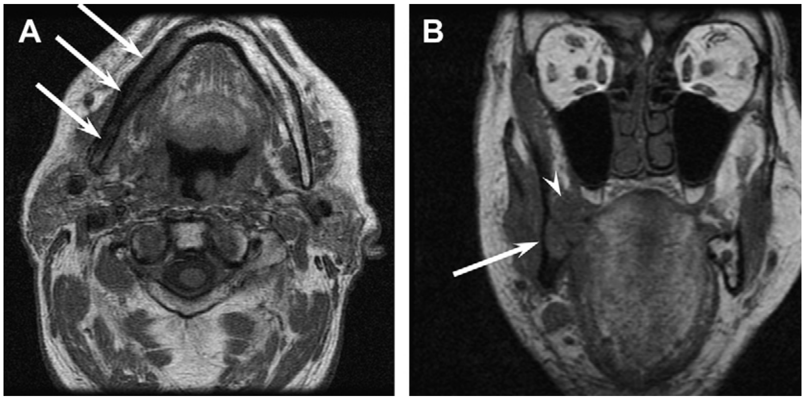

Fig. 6. MRI for bone invasion. (*A*) Axial T1-weighted image shows asymmetric low signal (*arrows*) in the marrow of the right hemimandible. (*B*) Coronal T1-weighted image confirms abnormal low signal in the right hemimandible with cortical thinning (*arrow*) and soft tissue adjacent to the mandible (*arrowhead*). These findings confirm invasion of the mandible by squamous cell carcinoma.

increased "enhancement" because of increased vascular permeability, increased extracellular space, and overall increased blood flow. Dynamic contrast-enhanced gradient-echo MRI imaging may be preferable to conventional contrast-enhanced spin-echo imaging for extent of tumor evaluation.[13]

Finally, MRI can elegantly evaluate TMJ pathology. Because the TMJ is a dynamic joint, sequences are performed in closed- and open-mouthed positions in sagittal and coronal planes. Some investigators advocate dynamic imaging of the joint, in which up to 16 images are generated in various positions, ranging from completely open to completely closed. However, this has not been shown to improve diagnostic accuracy.

In the closed-mouth position, the configuration of the condylar head and the glenoid, the integrity and shape of the intra-articular disc, joint effusion, and marrow edema can be evaluated (**Fig. 8**). In the open-mouth position, the movement of the joint as well as the position of the disc can be evaluated (**Fig. 9**).

MRI does have a few limitations, including relatively high cost and long scan time compared with other modalities. Some patients with extreme claustrophobia cannot tolerate MRI because of the narrowness of the gantry. Gadolinium-based contrast agents, generally considered safe and key in infection/inflammation and tumor imaging, have recently been associated with development of a rare systemic disease called nephrogenic systemic fibrosis in patients with renal insufficiency. Therefore, new guidelines are being established about the safety and dosage of contrast agents to such patients. Lastly, patients with

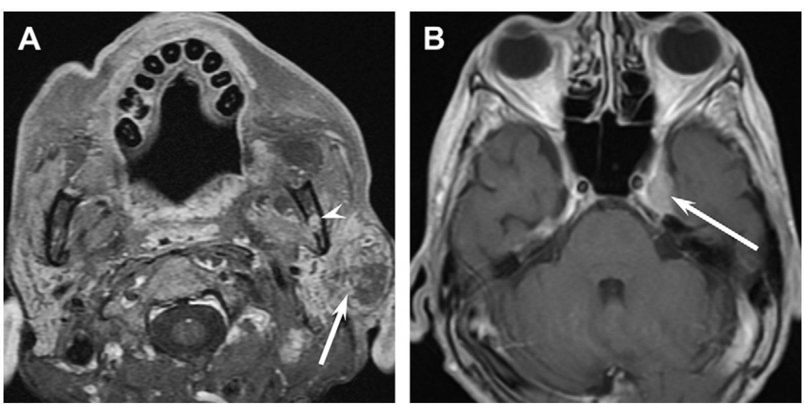

Fig. 7. MRI for perineural spread. (*A*) Axial contrast-enhanced T1-weighted image shows a large enhancing left parotid mass (*arrow*) with abnormal enhancement in the mandibular foramen (*arrowhead*) related to perineural spread along the auriculotemporal nerve to the mandibular nerve. (*B*) More superior image reveals abnormal enhancement in left Meckel cave (*arrow*) from perineural spread of the parotid tumor intracranially.

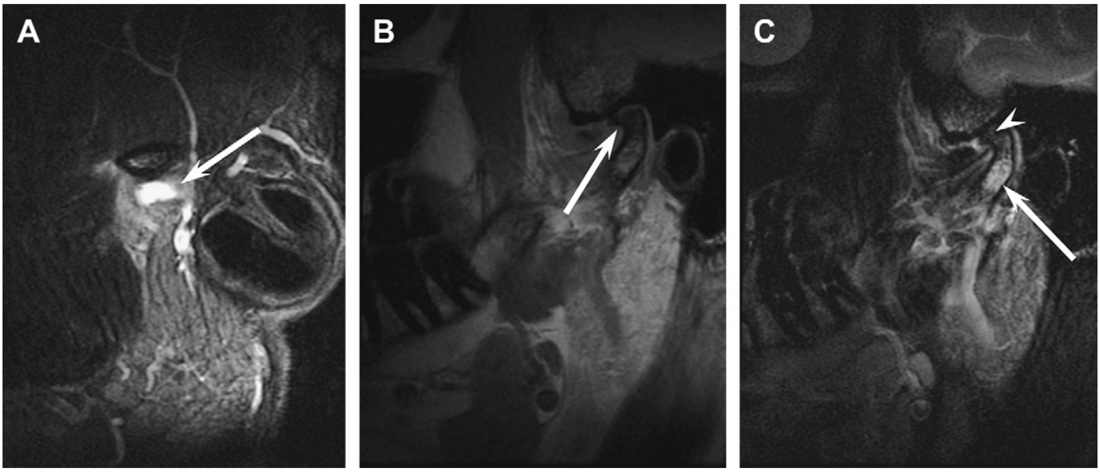

Fig. 8. MRI for TMJ osteoarthropathy. (*A*) Sagittal oblique T2-weighted image shows a high-signal collection (*arrow*), indicating joint effusion. (*B*) Sagittal oblique T1-weighted image reveals a beak-shaped osteophyte on the anterior aspect of the mandibular condyle (*arrow*), as well as narrowing of joint space. (*C*) Sagittal oblique T2-weighted image shows secondary signs of degenerative osteoarthropathy, such as subchondral cysts (*arrowhead*) and bone marrow edema (*arrow*).

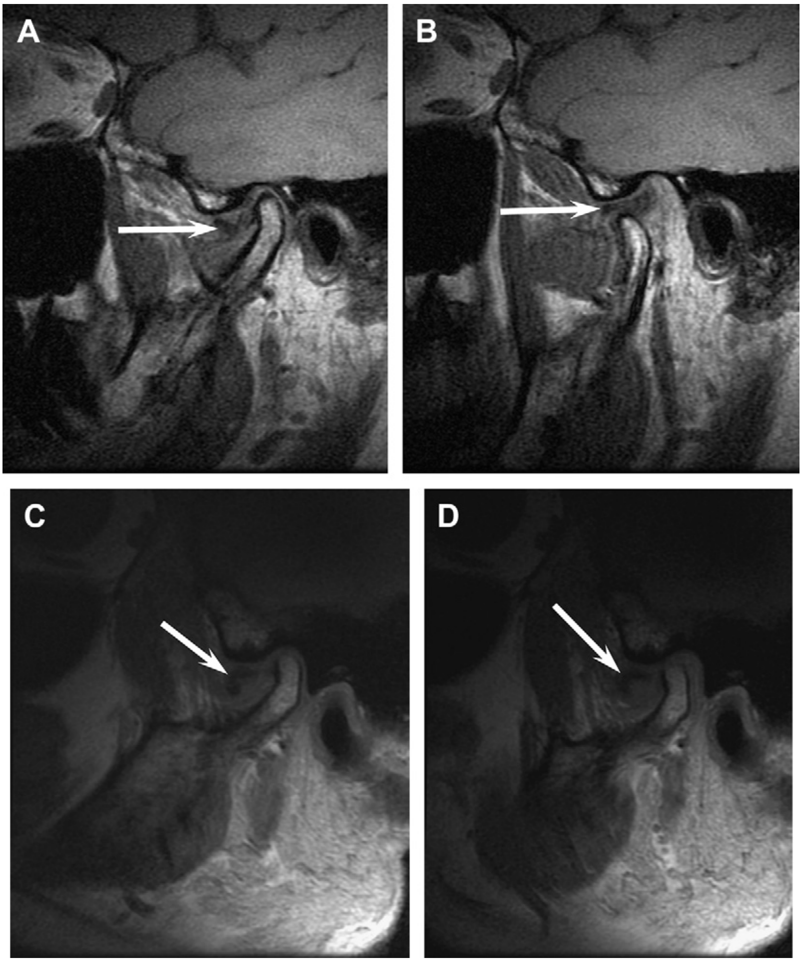

Fig. 9. MRI for disc pathology of the TMJ. (*A*) Sagittal oblique T1-weighted image in closed-mouth position reveals anterior dislocation of the low-signal articular disc (*arrow*). (*B*) Sagittal oblique T1-weighted image in open-mouth position shows recapture of the dislocated disc (*arrow*). (*C*) Sagittal oblique T1-weighted image in closed-mouth position from a different patient also shows anterior dislocation of the articular disc (*arrow*). (*D*) In this second patient, the disc (*arrow*) remains dislocated in the open-mouth position.

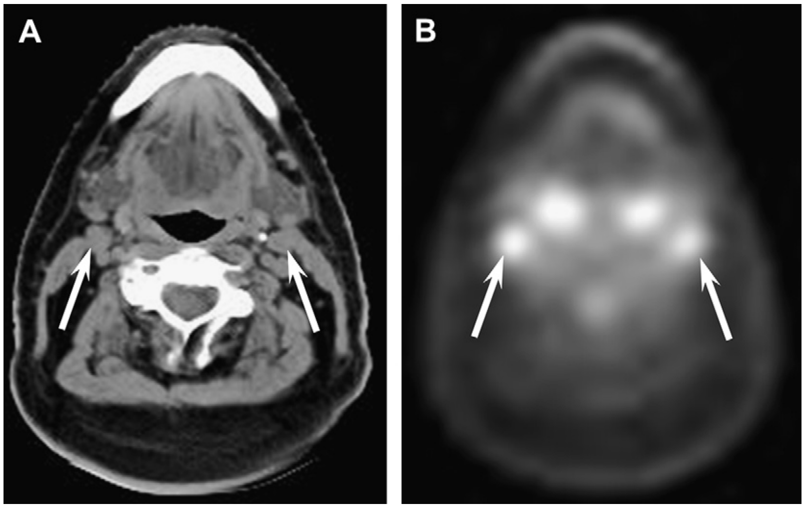

Fig. 10. Combined PET and CT (PET/CT). (*A*) Axial CT image through the upper neck shows normal-sized, symmetric jugulodigastric nodes (*arrows*). (*B*) PET image at the same level demonstrates FDG avidity (*arrows*), indicating metastatic disease.

certain implanted devices, such as pacemakers, some neurostimulators, and metallic fragments near vital structures (eyes, vessels, major organs), cannot undergo MRI scanning because of potential heating, movement, and/or malfunction that the powerful magnetic field might cause.

NUCLEAR MEDICINE

Traditionally, the role of nuclear medicine in head and neck imaging has primarily entailed the use of indium and gallium for infection imaging and radioactive iodine for thyroid imaging. Technetium 99 bone scans are helpful to determine bone metabolic activity and may indicate active growth or infection. Use of gallium and indium for infection has been made essentially obsolete by advances in cross-sectional imaging. However, the development of PET with 18-fluorodeoxyglucose (18FDG), especially when fused with diagnostic CT imaging (PET/CT), has revolutionized oncological imaging as a whole, including head and neck cancer imaging.[14,15] PET imaging is based on the principle that neoplastic processes demonstrate altered glucose metabolism compared with normal tissue. PET is performed by injecting 18FDG intravenously, waiting for approximately 1 hour, and then placing the patient in the scanner. Each positron particle emitted from the patient annihilates into two photons of equal energy in opposite directions. The points of origin of these photons are mathematically determined and mapped to create an image. In general, primary malignancy and metastases show increased 18FDG uptake. CT of the patient is obtained on the same scanner to allow for fusion of the images and precise anatomic localization of foci of abnormal 18FDG uptake.

PET and, in particular, PET/CT are used for staging and surveillance of a variety of head and neck malignancies, most commonly squamous cell carcinoma. These can also be used for salivary gland tumors and thyroid carcinoma, the latter when thyroglobulin levels are elevated but iodine I 131 scan is negative.[16] It is also standard of care for evaluation and follow-up of lymphoma. Aside from identifying the primary malignancy, which in the head and neck is often clinically evident, PET/CT is particularly useful for finding lymphadenopathy because of the shortcomings of CT alone or MRI alone for such identification. With either CT or MRI, no single imaging feature definitively determines malignancy (**Fig. 10**). On the flip side, PET/CT is useful to exclude malignancy in lesions that are indeterminate by CT but do not have increased 18FDG uptake; this is particularly valuable in post-treatment scans. Finally, using the spatial information provided by fusion technology, PET/CT can help guide biopsies either of the primary lesion or, more likely, in suspected recurrence.[17]

SUMMARY

Imaging plays a key role in dental implantation, management of maxillofacial trauma, facial reconstruction, TMJ pathology, and evaluation and treatment of neoplasms and infections. In addition to traditional conventional radiography, recent advances in CT, MRI, and PET/CT fusion technology have made radiology an even more vital component of patient care in dental and cranio-maxillofacial practice.

REFERENCES

1. McCabe KJ, Rubinstein D. Advances in head and neck imaging. Otolaryngol Clin North Am 2005;38:307–19.
2. Schiknecht B, Graetz K. Radiologic assessment of maxillofacial, mandibular and skullbase trauma. Eur Radiol 2005;3:560–8.
3. Preda L, La Fianza A, DiMaggio EM, et al. Complex maxillofacial trauma: diagnostic contribution of multiplanar and tridimensional spiral CT imaging. Radiol Med 1998;3:178–84.
4. Schwarz MS, Rothman SL, Chafetz N, et al. Computed tomography in dental implantation surgery. Dent Clin North Am 1989;33:555–97.
5. Weissman JL, Carrau RL. “Puffed-cheek” CT improves evaluation of the oral cavity. AJNR Am J Neuroradiol 2001;22:741–4.
6. Henrot P, Blum A, Toussaint B. Dynamic maneuvers in local staging of head and neck malignancies with current imaging techniques: principles and clinical applications. Radiographics 2003;23:1201–13.
7. Schulze D, Heiland M, Thurmann H, et al. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac Radiol 2004;33:83–6.
8. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. Can Dent Assoc 2006;72:75–80.
9. American Academy of Oral and Maxillofacial Radiology executive opinion statement on performing and interpreting diagnostic cone beam computed tomography. Farman AG, editor. Oral and Maxillofacial Radiology 2008;106:561–62.
10. Kaneda T, Minami M, Ozawa K, et al. Magnetic resonance imaging of osteomyelitis in the mandible. Comparative study with other radiologic modalities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79:634–40.
11. Lee K, Kaneda T, Mori S, et al. Magnetic resonance imaging of normal and osteomyelitis in the mandible: assessment of short inversion time inversion recovery sequence. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96: 499–507.
12. Caldemeyer KS, Mathews VP, Righi PD, et al. Imaging features and clinical significance of perineural spread or extension of head and neck tumors. Radiographics 1998;18:97–110.
13. Escott EJ, Rao VM, Ko WD, et al. Comparison of dynamic contrast-enhanced gradient-echo and spin-echo sequences in MR of head and neck neoplasms. AJNR Am J Neuroradiol 1997;18: 1411–9.
14. Branstetter BF 4th, Blodgett TW, Zimmer LA, et al. Head and neck malignancy: Is PET/CT more accurate than PET or CT alone? Radiology 2005;235: 580–6.
15. Schoder H, Yeung HW, Gonen M, et al. Head and neck cancer: clinical usefulness and accuracy of PET/CT image fusion. Radiology 2004;231:65–72.
16. Schoder H, Yeung HW. Positron emission imaging of head and neck cancer, including thyroid carcinoma. Semin Nucl Med 2004;34:180–97.
17. Agarwal V, Branstetter BF 4th, Johnson JT. Indications for PET/CT in the head and neck. Otolaryngol Clin North Am 2008;4:23–49.