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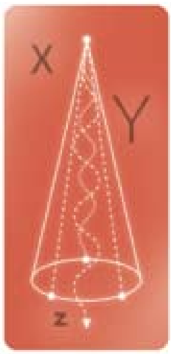

Cone Beam Computed Tomography: Evaluation of Maxillofacial Pathology

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ABSTRACT CBCT scans are increasingly used in evaluating osseous pathology in the maxillofacial skeleton, e.g., cysts, benign and malignant tumors, inflammatory conditions, paranasal sinus disorders, and soft-tissue calcifications. The authors discuss the diagnostic benefits and limitation of CBCT images compared to other imaging methods. CBCT scans provide superior diagnostic information compared to panoramic radiographs. In most maxillofacial diagnostic and surgical planning or follow-up needs, CBCT scans can replace multidetector CT scans.

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With the introduction of cone beam computed tomography, the diagnosis of orofacial conditions has significantly improved in the last decade. Some of the major uses of CBCT examination include implant planning, identification of inferior alveolar canals, and evaluation of the temporomandibular joints. CBCT examinations are also frequently used in the diagnosis of lesions appearing in the maxillofacial structures. This paper provides some of the evidence and examples of the benefits and limitations of CBCT in diagnosing maxillofacial disease. The paper also provides recommendations for ordering a CBCT scan in situations where the diagnostic benefits are most likely.

Traditionally, radiographic analysis of large lesions in maxillofacial structures is accomplished with panoramic radiography. Limitations of panoramic radiography include variable magnification, distortion, superimposition of structures, and reliably recording only structures located in the focal trough, CBCT images are superior to panoramic radiography in all these aspects. Depending on the field of view, a CBCT scan images a large area of the facial skeleton beyond the limits of a panoramic radiograph (**FIGURE 1**), or a small area of focused clinical interest. As the CBCT slices can be reformatted and viewed in multiple possible orientations (multiplanar views), anatomic structures are not superimposed.[1]

Prior to the introduction of CBCT, multiplanar views were created primarily with multidetector CTs, MDCT, and magnetic resonance imaging, MRI. Physical dimensions and cost of MDCT and MRI equipment are prohibitive for installation in a typical dental office.

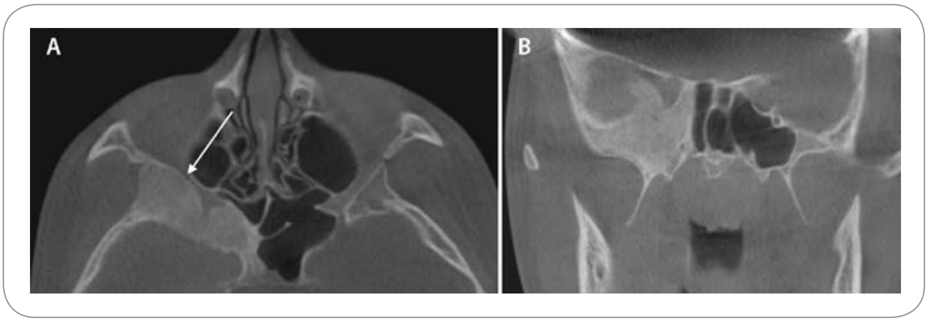

FIGURE 1. Fibrous dysplasia in an asymptomatic patient presenting for orthodontic treatment. Data acquired using an iCAT CBCT machine. Images are reformatted in iCATVision software. **(A)** Axial view at the level of the orbits shows fibrous dysplasia posterior to the right orbit and constriction of the optic canal (arrow). **(B)** Coronal view at the level of sphenoid sinus shows the fibrous dysplasia is encroaching into the middle cranial fossa. This fibrous dysplasia was not detected on panoramic radiograph.

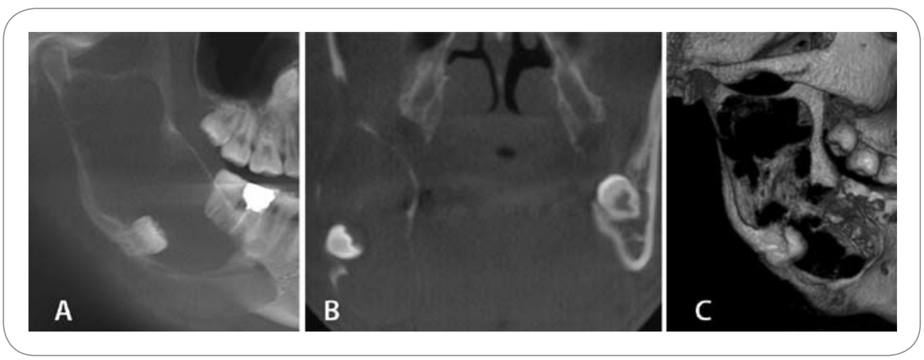

FIGURE 2. Ameloblastoma. An 18-year-old male. Data acquired using an iCAT CBCT machine. Images are reformatted in OnDemand 3-D, a third-party software. **(A)** Sagittal view of the right mandible showing a large multilocular lesion and inferior displacement of the third molar. **(B)** Coronal section through the angle of the mandible. Compared to the normal left side, the right side shows expansion in buccolingual aspect and lower border of the mandible. The third molar is next to the buccal cortical plate. **(C)** A 3-D reconstruction of the involved area, showing the thinning and perforation of the cortical plates. The superimposing structures (vertebra, hyoid bone) are subtracted by segmentation.

Smaller physical dimensions, lower cost, and easier operation have led to rapid acceptance of CBCT units in dental offices. In many situations, CBCT scans are a valid alternative to MDCT scans. However, the need of MDCT and MRI examinations in dentistry is not obsolete. Dentists who have been using MDCT scans, may find the quality of CBCT images equal or better.[2] Previously, when MDCT scans were delivered on a printed film sheet, the dentist had no capacity to reformat the image in any other orientation or convert the data into a 3-D surface model.

More recently, the ordering dentists receive a MDCT scan on a CD from a hospital. Such a CD usually contains a basic version of the image viewing software, with only limited ability to generate 3-D models. Reviewing the maxillofacial skeleton and relationship of the dental arches in 3-D models has high diagnostic value. Several CBCT manufacturers provide free software to reconstruct 3-D models. These 3-D surface models generated from CBCT data may be slightly inferior to that from MDCT, but are usually of acceptable quality.[3]

In MDCT, the images are obtained by a series of rotations of the radiographic tube. CBCT images are obtained using rectangular or cone-shaped X-ray beam centered on a 2-D sensor, and are obtained in a single rotation around the patient's head. The single rotation of the CBCT units reduces the scan time and also the radiation dose to the patient. The image quality of the CBCT machines depends on the scanning protocols, reconstruction settings, and also on the equipment.[2,4] A study that evaluated the image quality of bone structures acquired by five different CBCT machines and one MDCT machine showed that the image quality of one CBCT machine was superior to that from MDCT machine while images from other CBCT units were comparable to MDCT images.[2] However, soft tissues are still better displayed on MRI and soft-tissue window MDCTs. Currently, neither MDCT nor CBCT can replace the MRI where soft-tissue diagnosis is the primary aim. These situations include analysis of soft-tissue tumors, extension of intraosseous tumors into surrounding soft-tissue, and position of the disc in temporomandibular joints.

In most clinical situations where a MDCT scan is likely to provide diagnostic information, a CBCT scan can be a reliable alternative. The following subsections provide recommendations for using CBCT in different maxillofacial disorders.

Use of CBCT for Benign Lesions and Cysts

One of the primary benefits of CBCT is its capacity to display the scanned area in multiplanar orientation. In evaluating cysts or benign tumors, a single, intraoral radiograph may not fully record the supero-inferior and mesiodistal dimensions of the lesion. Thus, multiple intraoral radiographs or a panoramic radiograph are often exposed. These multiple radiographs still show only the two dimensions of the lesion. Observation of the third dimension, i.e., buccolingual extension of a lesion, requires additional radiographs obtained

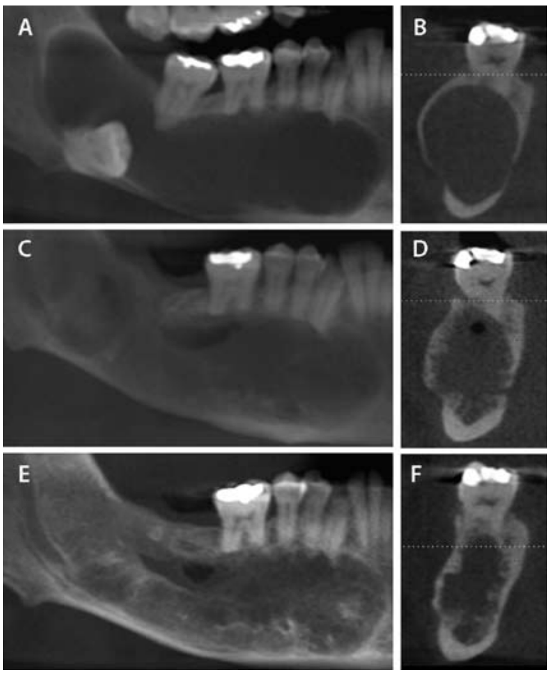

FIGURE 3. Follow-up of a keratocystic odontogenic tumor (OKC). Data acquired using an iCAT CBCT machine. Images are reformatted in iCATVision software. **(A)** Presurgical scan showing a large lesion in the right mandibular body and inferior displacement of the third molar. **(B)** Presurgical coronal view through the first molar area shows significant buccal expansion and localized thinning. **C** and **D** are eight months postsurgical. **(C)** Second and third molars were removed and lesion was marsupialized. **(D)** Eight-month postsurgical coronal view through the first molar area shows lesser expansion of the buccal cortical plate compared to the presurgical view. Note new bone formation on the inner aspect of the cortical plates. E and F are 20 months postsurgical. **(E)** The cavity has increased density, indicating almost uniform osseous healing. The surgical window is visible distal and inferior to the first molar. **(F)** Twenty-month postsurgical coronal view through the first molar area shows substantial reduction in the buccal expansion of the lesion. The cortical bones are thicker compared to that on the presurgical scan.

at 90 degrees from the original view.

In contrast, all three dimensions are recorded by multiplanar CBCT imaging. Such multiplanar views provide important information on the presence and extent of bone resorption, sclerosis of neighboring bone, cortical expansion, and internal or external calcifications.[5] Multiplanar sections (axial, coronal, and sagittal planes) are preferred when examining cysts or tumors deep in the tissues.[6] Alternatively, 3-D reconstructions are most useful for morphological analysis and spatial relationship of the neighboring structures for growth and developmental anomalies, gross tumor development, or fracture displacement[6,7] (**FIGURE 2**). Clinicians can depend on panoramic radiography for 2-D information if the margins of a cystic or benign lesion are well-defined.[8] If the margins are ill-defined, CBCT is a better option for diagnosis.[9]

From a surgical perspective, this is especially important when evaluating potential areas of cortical perforation of aggressive benign cysts or tumors (e.g., OKCs or ameloblastomas).

As a general surgical rule, where the lesions perforate the cortical bone, the resection should include the next anatomic plane (i.e., periosteum). Accurate presurgical knowledge of areas of perforation or extreme thinning of the cortex affords the surgeon the necessary information for planning the point in the dissection of an intrabony lesion, at which a supraperiosteal dissection is required and where subperiosteal dissection is acceptable.

Apart from presurgical evaluation of aggressive benign cysts or tumors, CBCT is also helpful in postsurgical follow-up of lesions that may have a high recurrence rate (**FIGURE 3**). Any new expansion or destruction of the cortical plates in the follow-up images can alert the radiologist and the surgeon of possible recurrence.

Multiple extraoral plain film radiographs, oriented at 90 degrees to each other, can provide adequate information of the size of a lesion, if the borders can be visualized. Information on the spatial relationship of the lesion with other anatomic landmarks on such images is limited, and often difficult to interpret. Because of superimposition of large tissue volume, extraoral plain film radiographs often cannot provide reliable information on the internal structure of a lesion. Multiplanar views provide superior visualization of the size and extent of the lesion with respect to the internal and neighboring critical structures.[10] Such information is essential for surgical planning (**FIGURE 4**). In the case of a maxillary ameloblastoma, the exact dimensions and its encroachment into critical structures may be better viewed on MRI.[11]

Some other benefits of CBCT are accuracy in measurement and lack of image distortion. For surgical planning, a lesion may need to be measured from different angles of viewing. For osseous components, when compared to gold standard dry skull, the measurements on CBCT images are acceptably accurate with less than 1 percent error.[12,13] In comparison, images on panoramic radiographs are easily distorted due to errors in patient positioning and are not reliable for size measurement.[14]

Use of CBCT for Malignant Lesions

Early detection of malignant lesions is of paramount importance; however, it can be difficult using plain films. Small lesions that can be "hidden" by superimposed dense tooth structures can be clearly identified on a CBCT scan (**FIGURE 5**). MDCT images can also provide information in the early stages of a malignant lesion. The advantage of CBCT over MDCT lies in the lower radiation dose and low cost.[15] Whenever a malignancy is suspected to involve osseous components, cross-sectional imaging with MDCT or CBCT must be obtained. If the lesion originates in soft tissues, only MDCT or MRI is indicated as CBCT can only be useful for evaluating any bone erosion. If a malignancy is likely to be

FIGURE 4. Calcifying odontogenic cyst involving anterior maxilla. Data acquired using an iCAT CBCT machine. Images were reformatted in iCATVision software. **(A)** Axial view shows resorption of the hard palate and presence of calcified entity (arrow). **(B)** Reformatted panoramic view shows the mesiodistal dimension of the lesion, but does not show presence of two inversely impacted teeth as viewed on **C**, **D**, and **E**.

FIGURE 5. Gingival squamous cell carcinoma in the region of tooth No. 27. A and B were acquired using Accuitomo 3-D CBCT machine. Images were reformatted in One Data Viewer. **(A)** Axial sections through cervical region of tooth No. 27 shows expansion and thinning of the buccal cortical plate (arrow). **(B)** Coronal section through tooth No. 27 shows expansion and thinning of the buccal cortical plate (arrow). **(C)** Sectional panoramic radiograph shows only a small horizontal bony defect near the cervical region of No. 27.

metastatic in nature, other examinations, such as scintigraphy, are needed. Multiple examinations using CBCT, MDCT, MRI, or nuclear medicine may be needed for a complete diagnostic work-up of a patient. The referring dentist should consult with an oral and maxillofacial radiologist to identify the appropriate examinations.

Small lesions on cortical bone, such as mucoepidermoid carcinoma on the hard palate, are difficult to diagnose using panoramic or occlusal radiographs. If clinical examination suggests such a lesion, a small field of view CBCT scan can reveal the extent of the tumor (**FIGURE 6**).

Use of CBCT for Inflammatory Changes in the Bone

Features of malignancy and osteomyelitis can look similar on plain radiography and can lead to a difficult diagnosis. On plain radiographs, malignant lesions and osteomyelitis both show irregular margins, which is an important diagnostic feature. A malignant lesion is less likely to develop a new layer of periosteal bone, while chronic infection frequently results in such layering. Periosteal reaction (**FIGURE 7**) and cortical destruction, as viewed on multiplanar images, can be useful in differentiating these radiographically similar lesions of widely different prognosis.[16]

If the infection is acute, neither plain film radiography nor CBCT scan is useful, since early infection does not cause enough bony change to be radiographically detectable. If an aggressive infection persists for two weeks or more, the primary finding on any radiographic examination is a lytic lesion with irregular margins. If the infection is chronic or moderate to low grade, the bone appears of mixed density. As a defense mechanism, the body walls the infection off by depositing layers of periosteal bone. Additionally, the margin of a chronic infection is often sclerotic and can be adequately viewed on plain film radiographs. To identify periosteal bony reactions, dentists traditionally used occlusal radiographs. However, incorrect exposure factors or angulation can limit the utility of an occlusal film to demonstrate a thin periosteal bony layer. With CBCT images, diagnosing new periosteal bone formation resulting from osteomyelitis is easier since the thin bone layer can be viewed by changing image orientation and adjusting density and contrast. From a surgical perspective, when compared with plain film, CBCT is better able to manifest small bony sequestra associated with osteomyelitis, which requires surgical debridement.

Features of osteomyelitis are also seen in bisphosphonate-related osteonecrosis of the jaws, ONJ (**FIGURE 8**). In evaluating ONJ, multiplanar images by CT and MRI are better than panoramic radiography. Currently, all these imaging modalities have limited values in detecting early stages of the disease.[17,18] Since ONJ progresses rapidly and the management of this disease is difficult, a reliable and efficient imaging protocol should be developed. Recent recommendations by the American Association of Oral and Maxillofacial Surgeons should be followed to diagnose and manage ONJ. The current recommendation is available at aaoms.org/docs/position_papers/bronj_update.pdf.

Use of CBCT for Diseases of Paranasal Sinuses

Currently, a few CBCT manufacturers are marketing their units to otorhinolaryngologists as an efficient in-office imaging tool. The benefit of using a CBCT in an ENT office is to identify less-complicated disease conditions quickly, cheaply, and

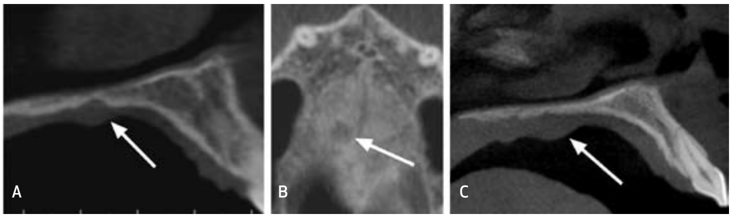

FIGURE 6. Mucoepidermoid carcinoma of the hard palate. Data acquired using an iCAT CBCT machine. Images were reformatted in iCATVision software. **A** and **B** are from the same patient. Arrows show areas of the tumor. Arrows on panels **A** and **C** show small soft-tissue growth. Arrow in panel **B** shows small area of bone resorption.

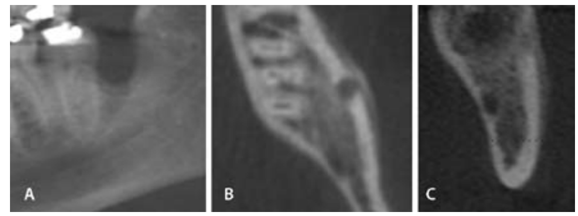

FIGURE 7. Osteomyelitis following third molar extraction. Data acquired using an iCAT CBCT machine. Images were reformatted in iCATVision software. **(A)** Reformatted panoramic view shows sclerosis of bone distal to the socket of No. 17. **(B** and **C)** Axial and coronal sections through the area of No. 17 show disruption of the buccal cortical plate and periosteal new bone formation.

with lower radiation dose compared to a MDCT examination. In many situations, an ENT specialist obtains adequate information on a CBCT scan to render a diagnosis. CBCT scans are also used to select cases that need further examinations.

For a dentist, identifying the condition of the maxillary sinuses is important for implant planning, endodontic therapy, and also to rule out sinus disease as a cause for orofacial pain. Sinusitis, a common inflammatory disease involving the maxillofacial skeleton, is often of odontogenic origin.[19,20] In some cases with sinusitis, endodontic therapy of the offending tooth may fail, requiring surgical intervention.[21] If sinusitis originates from the first maxillary molar, the periapical lesion is associated with the palatal root in 53 percent of cases.[22] If the causative tooth is a second molar, a periapical lesion of the mesiobuccal root causes the highest occurrence (60 percent). CBCT not only provides diagnostic information of the status of extension of periapical lesions into the maxillary sinuses, but also provides reliable information on the septa of the sinus and presence of exostoses. This is useful presurgical information when planning sinus floor augmentation in preparation for implant placement.[23] For the purpose of diagnosing sinus disease, altering the scan time is not required. A long acquisition time may provide better image quality and less noise compared to a short scan, but the images appear to have similar diagnostic value.[24]

Prior to the availability of multiplanar imaging, the Waters' sinus view was the most common radiographic examination for identifying sinus disorders. Studies show that Waters' sinus views are inadequate in detecting maxillary sinus opacification, and "very poor" in detecting masses in the ethmoid, frontal, and sphenoid sinuses.[25,26] These studies recommend the use of a low-dose and high-resolution multiplanar examination to evaluate the sinuses.[25] CBCT images are also helpful in identifying mucous retention phenomena, antral polyps, sinonasal polyposis, and malignant tumors of the sinuses (**FIGURE 9**). In addition, a dentist should consider a CBCT scan if there is a suspicion of oroantral fistula formation or if an implant is displaced into the sinus.

A limitation of CBCT is its poor resolution of soft tissues.[27] Sinus masses can be composed of different types of soft tissues with or without fluid accumulation. In addition, the fluid may be a thin watery secretion, blood, or a purulent mixture. On a CBCT scan, a mass in the sinus usually has a uniform density. Therefore, differentiation of the density into a fluid or soft-tissue mass is often not reliable. CBCT data can be relied on for the size and margin of the sinus mass, status of the sinus wall, and blockage of the ostium. Some software allows accurate measurement of the air space.[28,29] Fungal sinusitis often accumulates calcified materials. On a CBCT scan, these calcified materials can be easily differentiated from the soft-tissue component of the sinusitis.

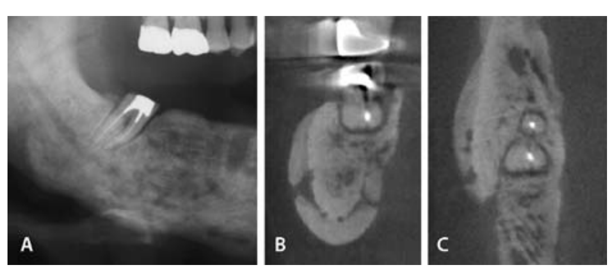

FIGURE 8. Bisphosphonate-related osteonecrosis of the jaws. B and C were acquired using J. Morita CBCT machine. Images were reformatted in One Data Viewer. (A) Section of a panoramic radiograph showing sclerotic mandibular bone with discrete radiolucencies. (B) Coronal section thorough mandibular second molar. Note prominent periosteal new bone formation around the body of the mandible with localized disruption. The bone is sclerosed with indistinguishable trabecular pattern. (C) Axial section of the mandible. Note prominent dense periosteal bone formation on the buccal aspect.

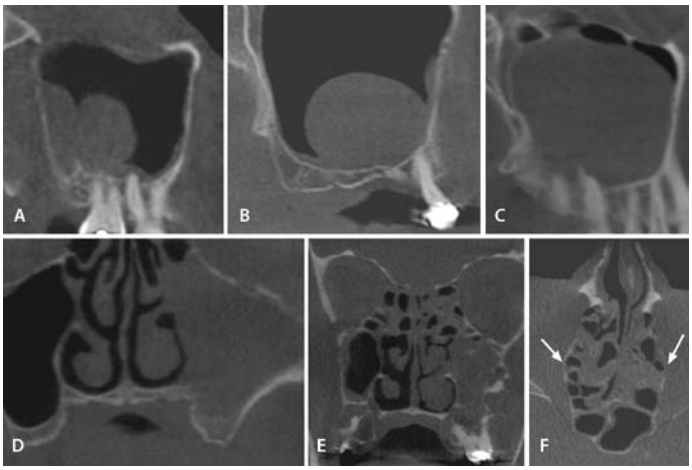

FIGURE 9. Disease of the maxillary sinuses. Data acquired using an iCAT CBCT machine. Images were reformatted in iCATVision software. **(A)** Sagittal view of maxillary sinus showing antral polyps. **(B)** Sagittal view of maxillary sinus showing retention phenomenon. **(C)** Sagittal view of maxillary sinus showing mucocele. **(D)** Coronal view of maxillary sinus showing non-Hodgkin's lymphoma. Panels E and F are from the same patient. **(E)** Coronal view of the maxillary sinuses showing sinonasal polyposis. Note prominent destruction of the lateral wall of the left maxillary sinus. **(F)** Axial view through ethmoid air cells. Note lateral expansion (arrows) of the ethmoid walls and intact septa of the air cells.

Use of CBCT in Detecting Foreign Bodies in the Maxillofacial Complex

Compared to CBCT images, MDCT images have superior soft-tissue resolution. In the maxillofacial area, the soft-tissue information on a MDCT scan can be degraded by artifacts arising from metal restorations. Extensive bridgework can make a MDCT scan virtually nondiagnostic. Such artifacts from metal objects are lower on CBCT images.[30] Therefore, a CBCT is a better imaging modality to assess metal fragments in the face, such as fragments embedded from a gunshot, automobile or industrial accidents, and for localizing retained broken dental needles.[30,31]

Use of CBCT Scans in Soft-Tissue Calcifications

Although CBCT images have low contrast (soft-tissue) resolution, they can be better than MDCT in depicting soft-tissue calcifications, such as carotid athrosclerosis[27] (**FIGURE 10**). Other calcifications, such as tonsilloliths and sialoliths, are adequately viewed on CBCT images. Small calcifications, which can be important diagnostic clues for some types of cysts and tumors, (e.g., CEOT or Pinborg tumor, COC or Gorlin cyst) are easier to identify on a CBCT scan than panoramic or intraoral radiographs.

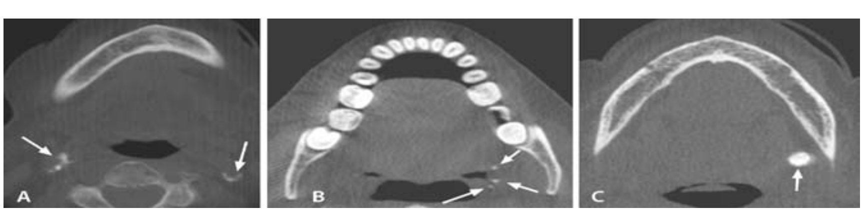

FIGURE 10. Calcifications in the soft tissues in the neck area. Data acquired using an iCAT CBCT machine. Images were reformatted in iCATVision software. **(A)**Axial section shows bilateral calcified carotid atheromas with irregularly curved margins. **(B)** Axial section shows discrete tonsillar calcifications. **(C)** Axial section shows a well-defined sialolith in the submandibular gland.

Conclusion

In the last decade, CBCT has become an important diagnostic tool for the dentists, oral and maxillofacial surgeons and otolaryngologist. The benefit of this imaging modality can be better utilized by realizing its capacities and limitations. As the technology now stands, with respect to evaluating maxillofacial disease, CBCT is mostly a tool for diagnosing diseases of the osseous structures. Currently, it is not useful for study of lesions limited to soft-tissue. When a lesion in question needs further evaluation, consultation with a trained oral and maxillofacial radiologist may be extremely beneficial. A thorough and knowledgeable interpretation is necessary to extract the extensive information available in the CBCT data set. ■■■■

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