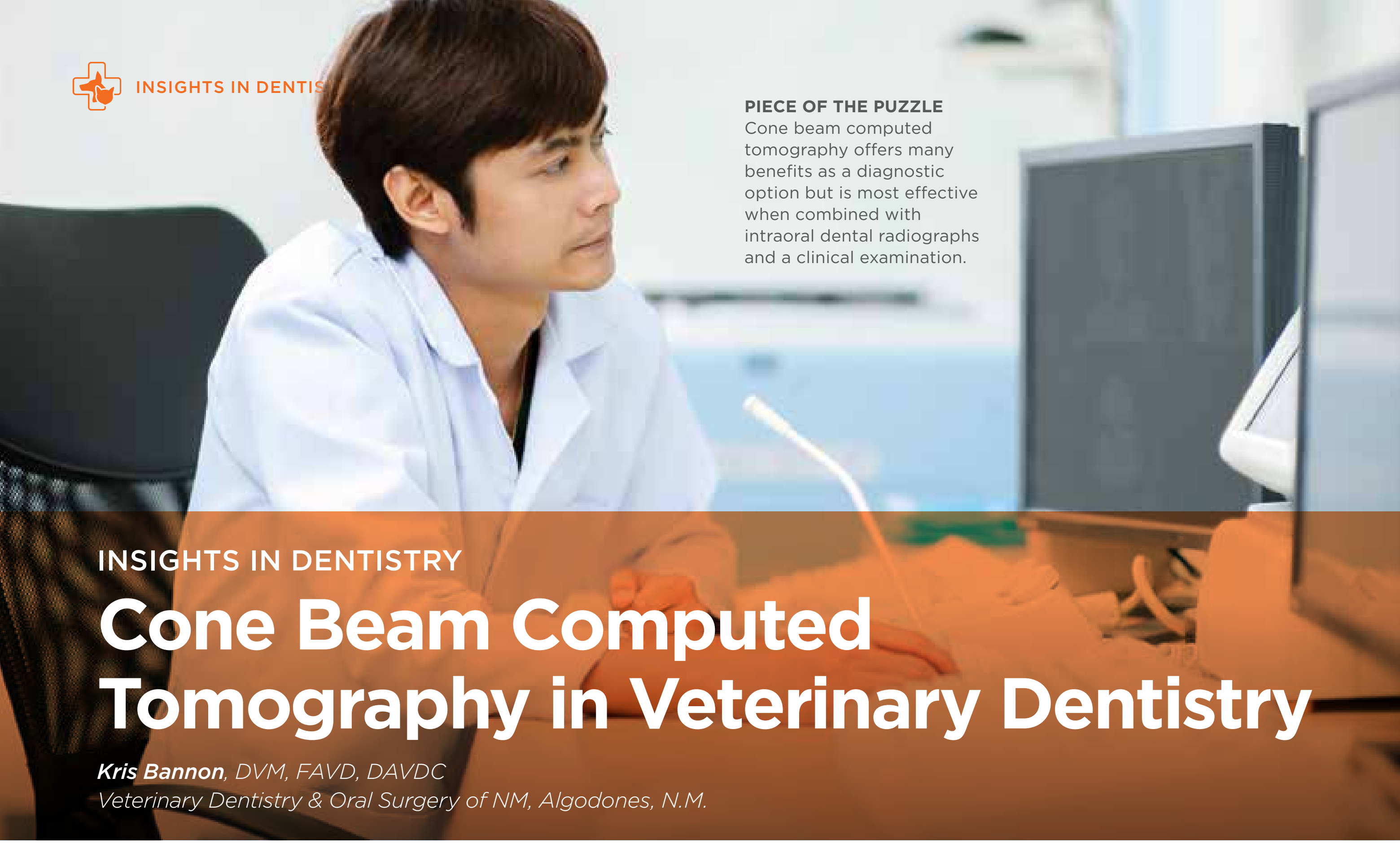

PIECE OF THE PUZZLE
Cone beam computed tomography offers many benefits as a diagnostic option but is most effective when combined with intraoral dental radiographs and a clinical examination.

INSIGHTS IN DENTISTRY

Cone Beam Computed Tomography in Veterinary Dentistry

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Cone beam computed tomography (CBCT) is a useful tool for 3-dimensional (3-D) evaluation of the dentoalveolar and maxillofacial structures in canine and feline patients. A single scan produces a wide variety of angles and views of structures in the maxillofacial region, useful for treatment planning for patients that have endodontic disease or need to undergo oncologic or trauma surgery.

Although CBCT has been available in human dentistry for many years, it is new to the veterinary field. Many veterinary dentists have started using CBCT technology, and in some cases, general practitioners can also benefit from its use in the treatment of maxillofacial disease. This article is intended to introduce CBCT to the general practitioner and to provide an understanding of the technology available on a referral basis.

WHAT IS CONE BEAM COMPUTED TOMOGRAPHY?

CBCT is a type of 3-D imaging that uses radiation, similar to conventional computed tomography (CT). However, with conventional CT the x-ray beam is in the shape of a fan, and with CBCT the beam is in the shape of a cone.

The cone is designed to be the size of the area of interest and originates from a flat x-ray generator. CBCT uses the cone-shaped beam to encompass the area of interest, and the x-ray source makes only 1 pass around the patient to acquire all the data needed for the image. A sensor located on the opposite side of the patient collects the information (**FIGURE 1**). The average dose of radiation to the canine or feline patient with a single CBCT scan is similar to that of a thoracic radiograph. Because of its compact design and low radiation, CBCT is more readily available than conventional CT and is perfect for imaging the maxillofacial area.

The maxillofacial region is a complicated area of the body. Canine and feline skulls have an average of 50 bones in a very complex 3-D arrangement. The typical adult dog has 42 teeth and the typical adult cat, 30 teeth. The sinuses are filled with turbinates, which are radiopaque. The upper and lower jaw contact each other inside the temporomandibular joint. All these factors create significant overlap and confusion in the interpretation of the images of head and dental structures. The 3-D images produced by CBCT help clarify the locations of maxillofacial structures and enable more appropriate interpretation of pathology.

WHAT OTHER IMAGING MODALITIES ARE USED FOR MAXILLOFACIAL IMAGING?

Skull radiographs are the easiest images to obtain. However, due to the complicated arrangement of bone, joint, and dental structures, skull radiographs are the most difficult to interpret and have the lowest diagnostic yield. The overlapping structures make it very easy to overinterpret suspected abnormalities and overlook true abnormalities.

FIGURE 1. Working area of a cone beam computed tomography system. The x-ray generator and a flat collection plate are on opposite sides of the patient. The machine makes a single rotation around the patient to collect the data.

FIGURE 2. Helical computed tomography system that requires movement of the patient through the x-ray beam.

Conventional and helical CT scanners provide 3-D images. With conventional CT, the x-rays are generated from a high-output rotating x-ray anode tube. Images are captured at different levels of the patient in individual slices as the patient moves in increments through the machine. Over time, most conventional CT scanners have been replaced by helical (spiral) CT scanners (**FIGURE 2**), for which a circular generator rotates as the patient moves through the unit, creating images in a spiral fashion. The images must overlap slightly and are reconstructed by the computer into a 3-D image.

Dental (intraoral) radiographs are the gold standard for evaluating dentition and the bone around the teeth. Because the x-ray sensor is placed in the mouth and the x-rays are very focused, the teeth and bone around the teeth can be easily visualized with minimal overlap of other structures. For dental cleaning procedures, dental radiographs are often used to evaluate the root structure and health of the teeth, both inside (endodontic) and outside (periodontal). Among other things, dental radiographs enable evaluation of the teeth to determine:

- if a damaged tooth has become nonvital or has a periapical lesion (**FIGURE 3A**)
- if a tooth with bone loss is associated with periodontal disease significant enough to warrant extraction (**FIGURE 3B**)
- the cause of clinically evident tooth mobility (**FIGURE 3C**)
- the proximity of the roots to neighboring teeth before extraction (**FIGURE 3D**)

Magnetic resonance imaging (MRI) is very useful for evaluating the soft tissue of the head and neck, especially in trauma patients when brain injury or brain involvement is suspected. However, use of MRI to evaluate the dental and maxillofacial bone structures is limited.

WHY CHOOSE CONE BEAM COMPUTED TOMOGRAPHY?

CBCT Versus Conventional CT

CT has an advantage over CBCT when assessing soft tissue structures, enabling visualization of both soft tissue and bone. Contrast can be administered intravenously to highlight areas of inflammation or

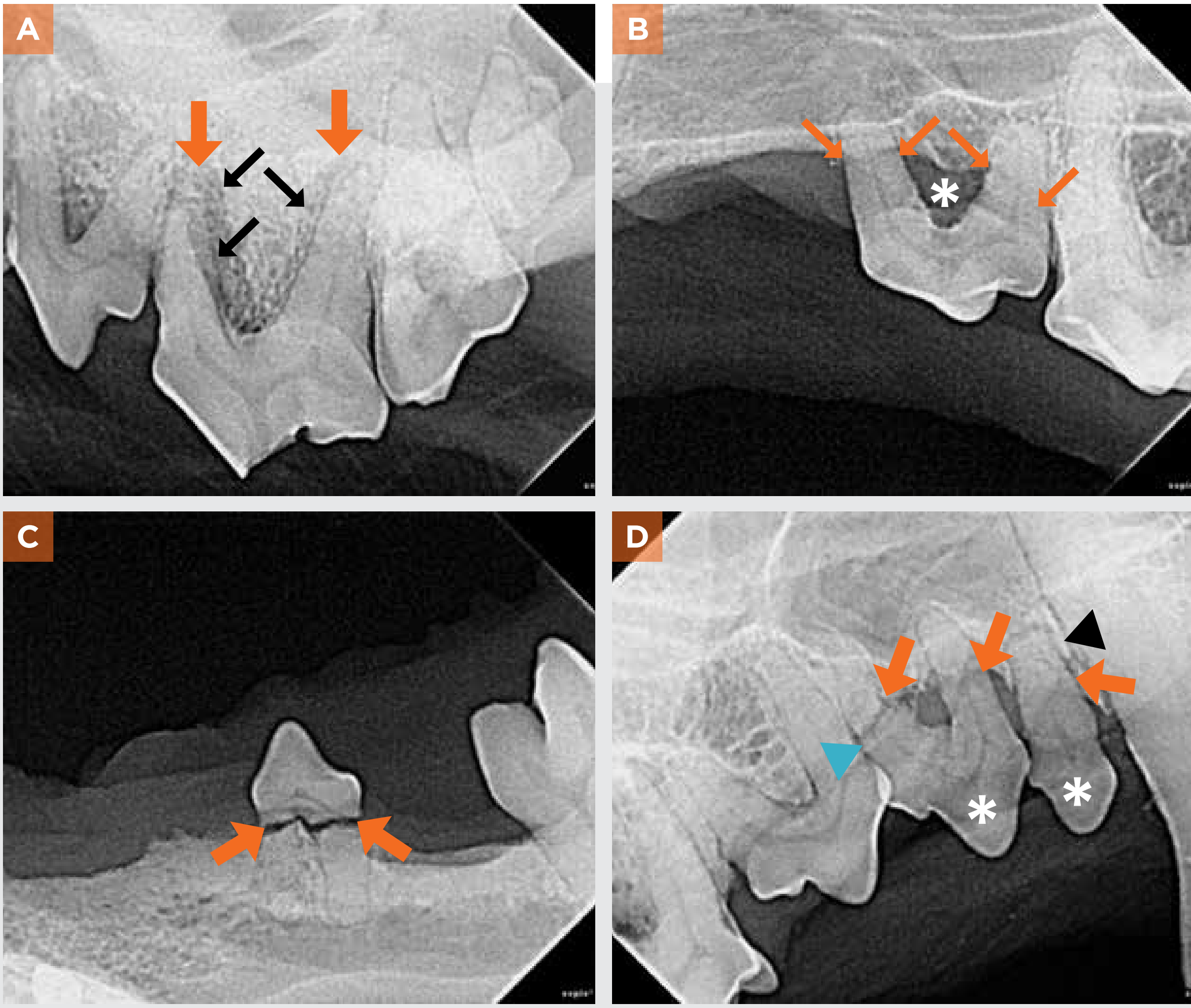


FIGURE 3. Dental radiographs showing endodontic and periodontal diseases. **(A)** Fractured, nonvital left maxillary 4th premolar (208) in a dog, demonstrating extensive periapical **(orange arrows)** and subsequent periodontal **(black arrows)** bone loss. **(B)** Left maxillary 3rd premolar (207) in a dog with horizontal bone loss **(orange arrows)**, complete furcation exposure **(asterisk)**, and end-stage periodontal disease. **(C)** Left mandibular 3rd premolar (307) in a dog; the tooth was clinically mobile. Radiographs identified the cause of the mobility as root fractures **(orange arrows)**, necessitating identification and removal of the roots independent of removal of the crown. **(D)** Right maxillary premolars in a dog. Crowding and horizontal bone loss **(orange arrows)** necessitated extraction of the 1st and 2nd premolars (105 and 106) **(asterisks)**. The proximity of the distal root of 106 to the mesial root of the 3rd premolar (107) **(blue arrowhead)** and of 105 **(black arrowhead)** to the canine tooth (104) can be appreciated by using dental radiographs to minimize the risk for iatrogenic damage to the remaining teeth.

areas of increased vascularity, such as some tumors. Thus, the downside of CBCT imaging is its decreased ability to differentiate soft tissue structures and decreased contrast enhancement, which results from the design of the system. However, some CBCT manufacturers are refining the soft tissue imaging quality (**FIGURE 4**); therefore, future improvements in this area are likely.

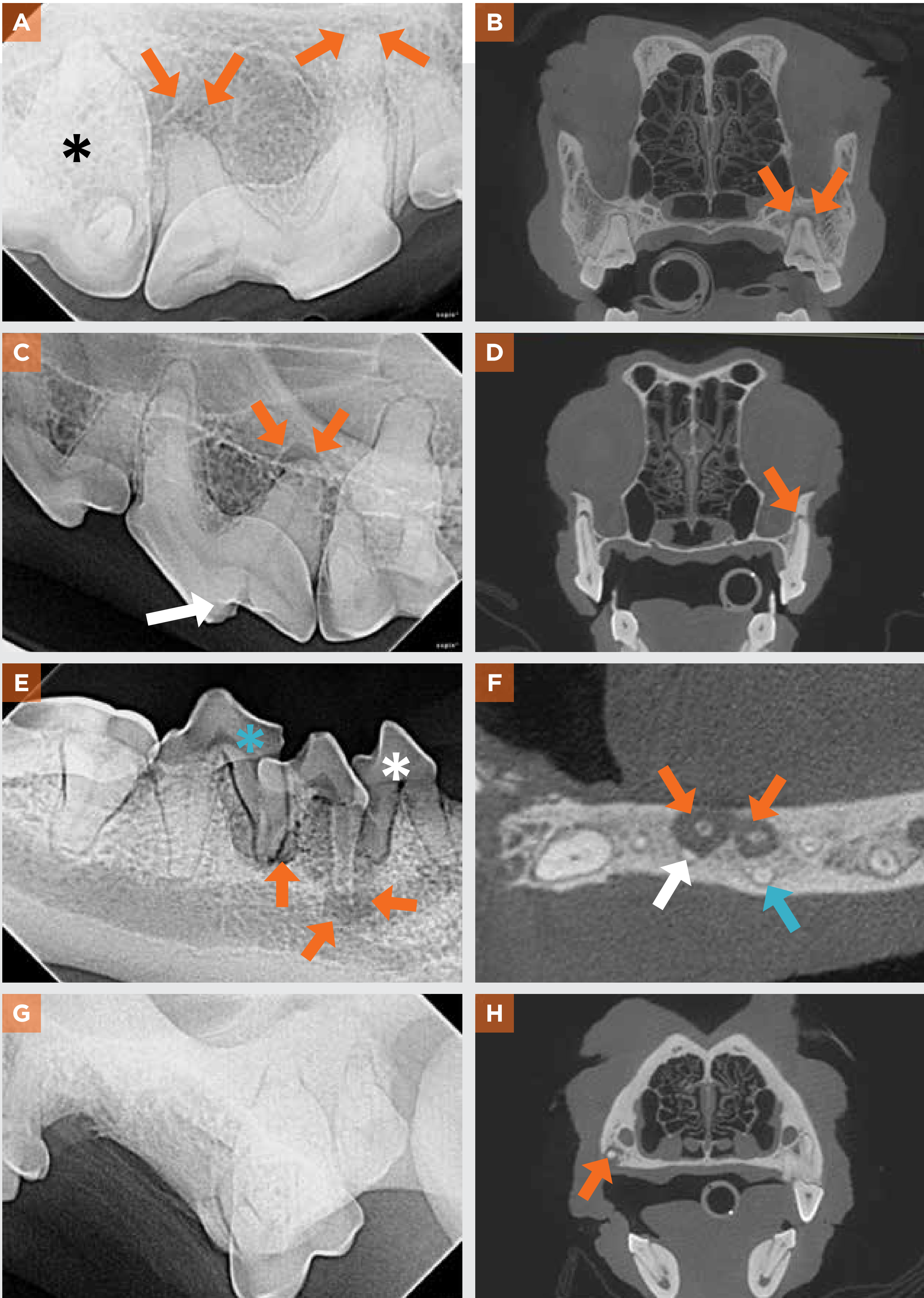
CBCT advantages over CT include the fact that the radiation level of conventional CT is higher, CT units are substantially more expensive, and CT units must be housed in a dedicated lead-lined room for radiation safety. The lower radiation dose of CBCT results from the cone-shaped beam and the need for only 1 pass around the patient, thereby exposing the patient to a substantially lower dose of radiation, approximately 10% less than conventional CT of the same area.[1] In addition, resolution of CBCT images tends to be higher than that of conventional CT images. CBCT slice thickness is smaller, allowing for detailed imaging of much smaller structures. Most conventional CT scanners obtain images in the range of 1 to 3 mm per slice, which means that an image is obtained every 1 to 3 mm. CBCT slice thickness is 0.1 to 0.4 mm. Although larger slices are not usually problematic when evaluating the thorax or abdomen, they can be problematic when evaluating dental structures, especially in smaller patients. For example, if the width of a tooth root falls within 1 to 3 mm, the root could be completely missed if perfectly positioned between slices.

CBCT Versus Dental Radiography

For many patients, dental radiographs combined with a detailed dental examination will provide an accurate diagnosis and treatment plan. Studies published in 1998 showed that dental radiographs provide substantially more information than a dental examination alone.[2,3] Dental radiographs of areas with pathology provided additional clinically useful information for 72.6% of dogs and 86.1% of cats. In areas that clinically appeared normal, dental radiographs showed incidental findings in 41.7% of dogs and 4.8% of cats. Dental radiographs demonstrated clinically important pathology in areas that appeared clinically normal in 27.8% of dogs and 41.7% of cats.

FIGURE 4. Image from a newer version of cone beam computed tomography (CBCT), designed to produce more radiation and perform limited maxillofacial soft tissue CBCT scans.

However, the dental radiograph is a 2-dimensional (2-D) image of a 3-dimensional object, which can result in pathology being missed or misinterpreted. Because dental radiographs are useful only in the area around the teeth, a relatively small area, evaluation of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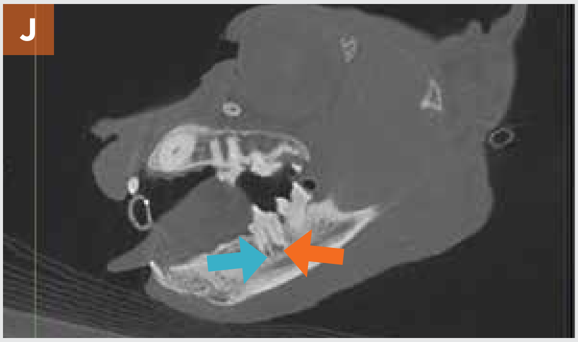

FIGURE 5. (A) Dental radiograph of a fractured right maxillary 4th premolar (108) in a dog with subtle but visible periapical pathology **(orange arrows)**. The 1st molar (109) appears normal **(asterisk)**. **(B)** Cone beam computed tomography (CBCT) image of the teeth in **(A)**, demonstrating periapical pathology also on the palatal root of the right maxillary 1st molar (109) **(orange arrows)**, which was not visible with dental radiographs. **(C)** Dental radiograph of a left maxillary 4th premolar (208) in a dog with a minor crown fracture **(white arrow)** and an area around the distal root tip **(orange arrows)** that was suspected to be a periapical lesion. **(D)** Transverse slice from the CBCT through the distal root of 208 in **(C)**. In this dog, the maxillary bone **(orange arrow)** around the root tip is very thin in this location, making the root tip falsely appear to have periapical pathology. **(E)** Dental radiograph of the overlapping right mandibular premolars in a dog showing bone loss **(orange arrows)** around a nonvital right mandibular 3rd premolar (407), which appears to have affected the 2nd and 4th premolars (406, **white asterisk**, and 408, **blue asterisk**, respectively). **(F)** Close-up of a dorsal slice from the CBCT showing the roots of the right mandibular premolars in **(E)**. The area of bone loss around the mesial root of 407 **(orange arrows)** does affect the distal root of 406 **(white arrow)**; however, the distal root of 407 does not involve the mesial root of 408 **(blue arrow)**. **(G)** Dental radiograph of a previously extracted left maxillary 4th premolar (208) in a dog, which appears to demonstrate a complete extraction. **(H)** Transverse slice through the area of the absent 208 in **(G)** clearly identifying a small, retained tooth root fragment **(orange arrow)** with periapical bone loss. **(I)** Dental radiograph of the left mandibular premolars and molar in a cat. Both remaining teeth were clinically normal. **(J)** Close-up of a sagittal slice from a CBCT image through the left mandibular 4th premolar. Internal **(blue arrow)** and external root **(orange arrow)** resorption can be appreciated at the apex of both roots.

large tumors or maxillofacial trauma is limited. Size 4 phosphor plate radiography systems are available to provide larger intraoral views than those that a conventional size 2 sensor can provide, but even a size 4 phosphor plate provides only 2-D images.

For some patients undergoing (apparently) routine dental procedures, 2-D dental radiographs may not accurately or adequately provide a diagnosis. In these situations, referral for 3-D imaging may be necessary. Sample situations include:

- a subtle periapical lesion that has not yet demineralized the periapical bone sufficiently to cause visible radiographic changes (**FIGURES 5A AND 5B**)
- normal anatomy or overlap, which may be mistaken as a periapical lesion (**FIGURES 5C–F**)
- a retained tooth root with pathologic bone loss but not clearly visible radiographically (**FIGURES 5G AND 5H**)
- diagnosis of the presence or extent of root resorption (**FIGURES 5I AND 5J**)

There are also situations in which 2-D radiographs may not provide all the information needed to perform a procedure safely and successfully. This limitation may contribute to complications encountered during dental procedures. Sample situations would be the need to determine:

- how close an unhealthy tooth is to a vital anatomic structure (e.g., the infraorbital or mandibular canal or suborbital space) (**FIGURE 6A**)
- whether a tooth has an anatomic abnormality that may change the surgical approach (e.g., the angle or extent of a "hook" on the end of a root) (**FIGURE 6B**)
- whether the tooth has an anatomic abnormality that may change the treatment plan (e.g., internal resorption of a fractured tooth referred for root canal therapy) (**FIGURE 6C**)
- whether the natural location of the tooth roots might increase the risk for complications (e.g., root tips are naturally in the infraorbital canal, mandibular canal, or sinus cavity) (**FIGURE 6D**)

The main advantage of using CBCT over dental radiography is the ability to see the dental and maxillofacial structures in 3 dimensions. This information is especially useful when planning an advanced oral surgery, such as removal of a large tumor or repair of a traumatic jaw fracture. Knowing exactly how the structure of the jaw has been damaged and shifted will help determine repair options and may affect the long-term prognosis.

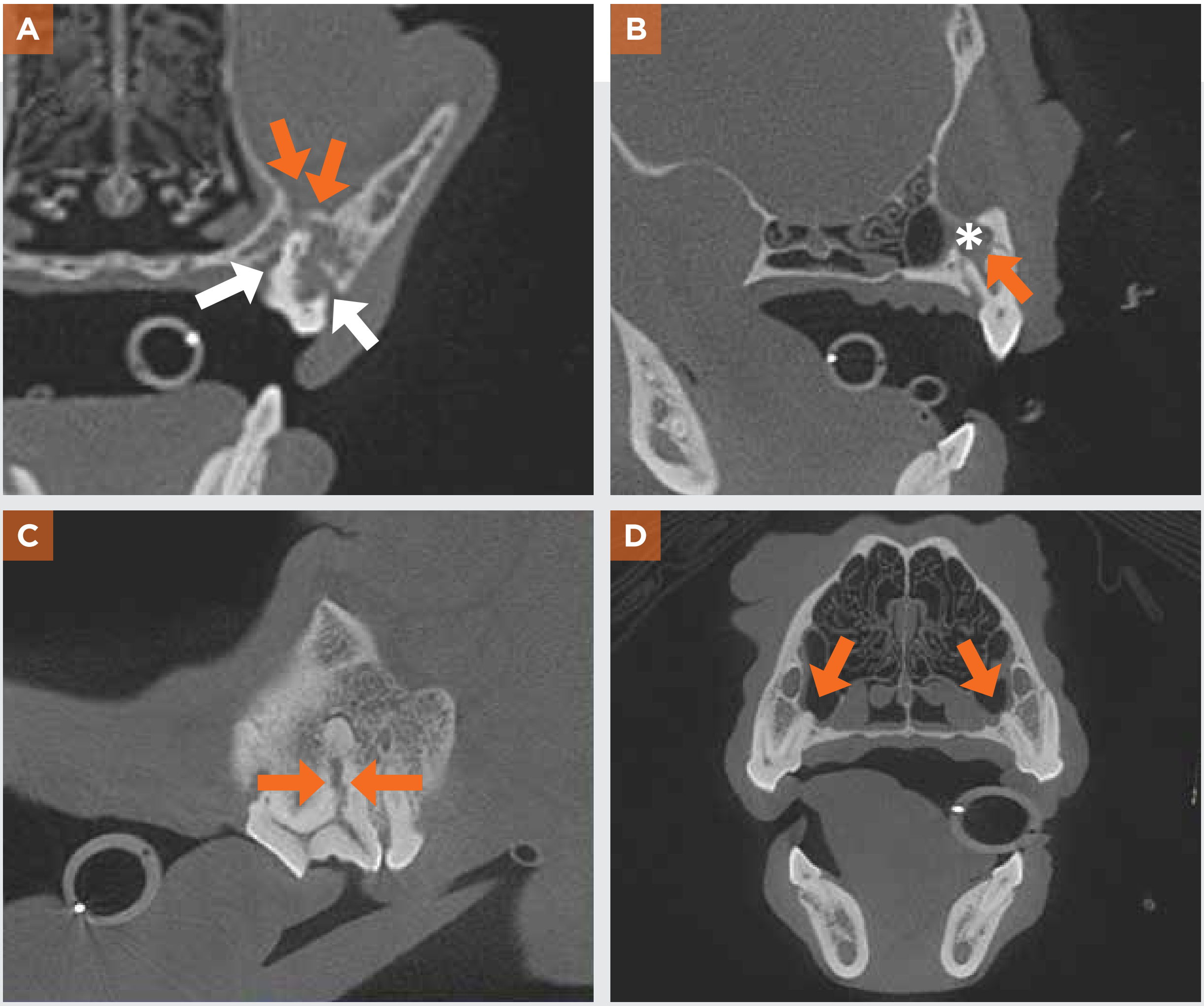

FIGURE 6. Some situations in which 3-dimensional imaging may decrease the risk for complications compared with 2-dimensional imaging. **(A)** Close-up of a transverse slice from a cone beam computed tomography (CBCT) of periodontal bone loss **(white arrows)** around the right maxillary 4th premolar (108) in a cat, which led to a direct communication with the suborbital tissues **(orange arrows)**, increasing the risk to the orbit during evaluation (probing) and extraction. **(B)** Close-up of a transverse slice from a CBCT image through the mesial roots of an upper 4th premolar in a dog. There is a hook on the end of the mesiobuccal root **(orange arrow)**, which could easily break and require additional surgery for retrieval. On the same tooth, the apex of the mesiopalatal root is within the infraorbital canal **(asterisk)**, which significantly increases the risk for iatrogenic trauma to the infraorbital artery during extraction. **(C)** Internal resorption **(orange arrows)** visible on a close-up view of a sagittal slice from a CBCT image of a nonvital, fractured left maxillary 4th premolar (208) in a dog that was referred for root canal therapy; the resorption will increase the risk for complications associated with root canal therapy. **(D)** Transverse slice of a CBCT image of a dog through the mesiobuccal and mesiopalatal roots of the maxillary 4th premolars (108 and 208). The normal anatomy in this dog is that the root tips naturally end in the sinus cavity **(orange arrows)**, which would increase the risk for unwanted translocation of these roots into the sinus during extraction.

In preparation for and prior to advanced oral surgery, many board-certified veterinary dentists will use conventional CT or CBCT in addition to dental radiographs. A few examples of common indications for 3-D imaging before maxillofacial surgery are as follows:

- Evaluating maxillofacial trauma. For patients with traumatic injuries, nearly twice as many skull fractures are identified with CT than with skull radiographs alone.[4]
- Assessing confirmed or suspected temporomandibular joint disease, dislocation, luxation, or fracture
- Assessing integrity and amount of remaining bone associated with cystic lesions
- Assessing the extent of palatal bone loss associated with oronasal communications and cleft palates
- Gauging extent of disease when evaluating invasion of oral tumors into hard tissue of the maxilla and mandible

Of all the types of dental and alveolar bone lesions in cats, CBCT identifies more pathology than dental radiographs alone and significantly more retained tooth roots, tooth resorption, horizontal bone loss, and root fractures.[5]

When the patient is a brachycephalic dog, interpreting dental radiographs can be clinically challenging. In a study comparing CBCT to dental radiographs in small to medium brachycephalic patients, all categories of dental disorders (except root fractures) were identified more readily by CBCT and the findings increased to a statistically significant level for detection of abnormal eruption, abnormally shaped roots, periodontitis, and tooth resorption.[6] These studies confirm that practitioners may be missing clinically significant pathology when performing dental radiography alone. Particularly for a patient with persistent clinical signs and no radiographic explanation, CBCT may provide the needed information for diagnosis and appropriate treatment.

SHOULD CONE BEAM COMPUTED TOMOGRAPHY REPLACE DENTAL RADIOGRAPHY?

CBCT is an extremely useful part of the armamentarium of diagnostic options available to practitioners, typically on a referral basis. However, CBCT is most useful when the information is combined with full mouth intraoral dental radiographs and a detailed clinical examination (periodontal probing and charting) to determine the best treatment plan. Thus, completely replacing intraoral dental radiographs with CBCT is not recommended at this time.

For the typical small animal practice, dental radiographs are clinically sufficient and at a price point that is generally acceptable to both veterinarians and clients. TVP

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