Cone Beam Computed Tomography – 3D Imaging in Oral and Maxillofacial Surgery

a report by

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Imaging plays an important role in oral and maxillofacial surgery diagnosis and treatment planning. A thorough history and clinical examination are vital in establishing diagnosis; however, the value of radiographic imaging cannot be overstated. 2D projection radiography has been in use for more than half a century for diagnosing congenital and developmental deformities in the maxillofacial region. Still, over the last few decades, the introduction of 3D imaging characterised by computed tomography (CT) and magnetic resonance imaging (MRI) technologies has had a tremendous impact on the practice and teaching of maxillofacial surgery. The tomographic nature of CT and MRI provides thin slices at much higher inherent contrast than achievable with 2D projection radiography, which in turn allows for a better delineation of the bone and soft-tissue boundaries and a deeper appreciation of the intricate interrelations of the complex anatomy of the maxillofacial region.

CT is used extensively in maxillofacial surgery for diagnosing osseous lesions and deformities, pre-operative planning of surgical interventions, intra-operative surgical navigation and fabrication of surgical stents and implants.¹⁻⁴ CT systems are largely accessible to surgeons residing in public and private hospitals in medical radiology departments, but for small private surgery clinics, hospitals and clinics, the installation, operating and maintenance costs and labour of a conventional CT machine are prohibitive. However, CBCT images suffer from several artefacts due to inferior detector efficiency and beam inhomogeneity.¹³,¹⁴ The influence these artefacts have on image quality and diagnostic accuracy is variable among the different manufacturers with respect to the different scanning and reconstruction settings. The objective of this article is to discuss some of the stated applications of CBCT compared with conventional projection imaging and MDCT in oral and maxillofacial surgery, as reported in the literature.

Tooth Impaction
Surgical removal of impacted teeth demands precise knowledge of the tooth location in the jaw and its relation to other teeth and surrounding anatomical structures. For instance, in the mandible the relationship of the roots of impacted third molars to the mandibular dental canal must be accurately assessed since the canal is frequently very closely associated with an impacted molar, and post-operative complications due to nerve impingement are reported.¹⁵,¹⁶ It is necessary to assess whether a physical contact between the root and the border of the canal is present or not. In the maxilla, localisation of impacted canines relative to the lateral and central incisors is central to their management. Information regarding the palatal orientation of an impacted canine and its proximity to the root of the lateral incisor is vital to allow for an effective and timely surgical intervention.¹⁷,¹⁸ Conventional panoramic radiographs are routinely obtained to evaluate tooth impaction pre-operatively. However, compared with CT, the 2D nature of the image and the superimposition of adjacent anatomical structures impede precise assessment of the tooth relative to adjacent anatomical structures.¹⁹⁻²¹ CBCT orthographic tomographic slices and panoramic reconstructions are superior to conventional panoramic radiographs in determining the location and orientation of an impacted tooth and its relationship to adjacent vital structures in the maxilla and the mandible (see Figure 1).²²⁻²⁴

Pathological Conditions
CBCT diagnostic applications in the maxillofacial region include evaluating the presence of osseous defects in the jaws, cysts, lesions, calcifications, teeth and bone traumas and fractures. CBCT is also playing an increasingly important role in the detection of “incidental” pathology in patients referred for dental treatment. Since most currently available CBCT systems acquire volumes that extend beyond the dentition and the surrounding alveolus, unsuspected lesions in the paranasal sinuses, parotid region, masticatory space, floor of the mouth and the hyoid region are frequently detected and reported.²⁰⁻²⁰ Evidently, the 3D nature of CBCT allows determination of the exact extension of the lesion in the affected region (see Figure 2).

Orthognathic Surgery
Several applications of CBCT in orthognathic surgery treatment simulation, guidance and outcome assessment have been developed. CBCT 3D surface
reconstructions of the jawbones are used for pre-operative surgical planning and simulation in patients with traumas and skeletal malformations (see Figure 3).37–39 Coupled with dedicated software tools, simulations of virtual re-positioning of the jaws, osteotomies, distraction osteogenesis and other interventions can now be successfully implemented. Pre- and post-operative 3D CBCT skull models can also be registered (i.e. superimposed on each other) to assess the amount and position of alterations in the mandibular rami and condylar head following orthognathic surgery of the maxilla and the mandible.40,41 3D reconstructions of the jawbones from CBCT are of sufficient quality for clinical work. However, 3D models of the dentition still suffer from deformations due to streak artefacts caused by metal fillings, crowns and bridges, orthodontic brackets and other metallic dental appliances.42 Therefore, virtual 3D models of the dentition are obtained by scanning the dental cast using a high-resolution surface laser scanner. Custom-made inter-occlusal wafers can also be scanned separately and then combined with CBCT 3D reconstructions of the jaws to create composite skull models.43–46 These ‘double scanning’ techniques have been successfully applied to patients with jaw asymmetry and in severe malocclusion cases.47–49

Temporomandibular Joint Imaging

The temporomandibular joint (TMJ) is a complex entity with hard- and soft-tissue components. TMJ disorders (TMJs) are common but widely variable. MRI has sustained its position as the gold standard imaging modality for diagnosing TMDs since it provides excellent visibility of the disk and the associated joint muscles. Nonetheless, most TMJ examinations start with a panoramic radiograph to visualise any gross changes in the condylar head and temporal components. However, panoramic radiography has a low diagnostic accuracy in detecting TMDs so a negative indicator on a panoramic radiograph does not exclude the presence of osseous defect.50–52 CBCT parasagittal and coronal slices show crisp, clear images of the condylar head and the glenoid fossa. CBCT is more accurate than panoramic radiography and conventional tomography for diagnosing TMDs (see Figure 4).53–57 A CBCT exam was also recommended before image-guided puncture operation of the superior compartment of the joint space.58

Cleft Lip and Palate

In cleft lip and palate patients, information regarding the number and orientation of teeth, dental and skeletal age and the amount and quality of available bone in the cleft region are considered vital for the clinical management of such cases. Panoramic radiographs are often used to investigate the incidence and number of missing teeth and to determine dental and skeletal age in cleft lip and palate patients.59,60 However, the amount and quality of available bone cannot be accurately assessed on a panoramic radiograph. Therefore, medical CT is typically used to quantify the amount of bone present, but the young age of cleft patients makes the routine use of medical CT problematic due to the relatively high radiation dose involved. CBCT is rapidly replacing medical CT for this task since it provides excellent 3D visualisation of the palate at the pre-maxilla region at a lower patient dose (see Figure 5).51–53 CBCT is used to determine dental age, and when a large scan field of view (FoV) selection is present, 3D reconstructions of the cervical vertebrae can be made and employed to determine skeletal age.61 Additionally, CBCT has been used to show any deformities in the piriform margin in the nasal platform and the antero-posterior depression of the nasal alar base.62,63 3D CBCT reconstructions of the skin surface of the face and nose for cleft lip assessment are also possible.

Dental Implants and Bone Grafts

Imaging plays a crucial role in the pre-operative assessment of oral implant placement. After a thorough clinical examination, imaging should be used to evaluate bone quality and quantity, its morphology and relation to vital anatomical structures such as the mandibular canal. Panoramic and intra-oral radiographs are widely used in implant evaluation, yet the inherent 2D nature of those techniques hamper detailed pre-operative planning that would allow to integrate all necessary parameters with respect to the anatomical restrictions, the required implant position and axis in relation to anatomy, neurovascuarisation, biomechanics and aesthetics.64,65 Moreover, the inherent distortion of panoramic radiographs makes those images less suited for reliable implant planning. The introduction of CBCT, offering 3D imaging at relatively low dose and costs, has increased the applicability and strengthened the justification of cross-sectional pre-operative imaging. In addition, the convenience and easy access to CBCT has drastically expanded its use.66 The benefits of 3D imaging in a virtual planning environment include improved integration of all information on aesthetics, biomechanics and anatomy.64,65 In fact, the rapid escalation in the number of CBCT units installation is deemed to go hand in hand with the steep increase in implant therapy. The latter holds especially true for computer-aided implant planning applications, where implant placement is first simulated then transferred to the operation site using either navigation or surgical templates or so-called drill-guides (see Figure 6).67–69 This technique surely has advantages for more complicated surgery, such as planning grafting procedures.69,70 Indeed, the graft can currently be virtually modelled such that the receptor bed is well prepared to precisely fit to an a priori optimally shaped graft (see Figure 7). From the statements above, it is obvious that CBCT is striving to become the method of choice for pre-operative implant planning procedures.
maxillofacial applications. However, when CBCT is compared with MDCT technology, the situation is slightly different. As the latest generation of MDCT scanners are progressively advancing towards ‘volumetric scan’ acquisition modes with 32-, 64- and 256-detector array arrangements and more coupled with rapid scan time, sub-millimetre isotropic voxel size, superb tissue contrast and steady decreasing radiation doses, it has become increasingly more difficult to cite the proclaimed advantages of CBCT over latest-generation MDCT as self-evident. The two technologies are developing concurrently at a rapid pace with new systems appearing on the market each year. However, this does not necessarily indicate that one technology will triumph over the other in all clinical indications; rather, the comitant accumulation of clinical experience and evidence-based research will appropriate the use of each modality to specific applications.

**Discussion**

The use of CBCT is expanding in dental and maxillofacial imaging. The multitude of 2D and 3D reconstructions possible with this imaging technique supplements the clinical decision with novel insight with respect to the formation of the anatomy and the extent of pathosis. CBCT is evidently more advantageous than 2D projection radiographs in several important orthodontic, dental, and maxillofacial applications.