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DENTAL CONE BEAM CT AND ITS JUSTIFIED USE IN ORAL HEALTH CARE

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While dental 2D radiology is still the most frequent diagnostic tool, the inherent nature of jaws and teeth might surely benefit from 3D diagnosis. Nowadays, dental cone beam computed tomography may offer high quality images at low radiation doses and costs. Yet, effective dose ranges of CBCT machines may easily vary from 10-1200 microsievert, being an equivalent of 2 to 240 dental panoramic radiographs. The same holds true for diagnostic image quality, which exhibits a huge variation amongst machines and parameter settings. For segmentation accuracy, lower limits of accuracy are around 200 micrometer, yet again, larger inaccuracies may apply. For linear accuracies, values below 500 micrometer are feasible, with some machines and CBCT parameter settings allowing linear accuracies of up to 200 micrometer. Apart from the radiodiagnostic possibilities, dental cone beam CT may offer a vast therapeutic potential, including possibilities for surgical guidance and further treatment via CAD/CAM solutions for crown and bridgework on teeth or implants. In conclusion, dental CBCT imaging could be justified when dealing with specific indications including jaw bone and maxillofacial surgery, endodontic retreatment, traumata, jaw bone lesions and TMJ pathology. Yet, guidelines for CBCT optimisation and justification are mandatory, especially when used for pediatric indications.

Key-words: Computed tomography (CT), image processing – Jaws, CT – Teeth.

Imaging is the most important and most frequently used diagnostic tool in dentistry. More than one quarter of all medical radiographs in Europe is made by dentists, in some countries this number even approaches 50% (e.g. Sweden). The importance of radiographs for dental diagnosis is illustrated by the fact that hardly two weeks after discovery of the x-ray by WC von Röntgen, German dentist Walkhoff already made a first radiographic image of human teeth. For more than a century this type of dental radiographs has been the dominant source for diagnostic information on the maxillofacial complex, jaws and teeth. Yet, 2D projective techniques cannot fully display complicated 3D anatomical structures and related pathologies such as impacted teeth, root resorption, apical granulomata, periodontal breakdown, cystic lesions or benign tumors (1). In the eighties, a first revolution came with the introduction of digital dental (radiographic) imaging in dentistry. A second shockwave came in the nineties when three-dimensional imaging modalities for typical dentomaxillofacial applications appeared on the market. Yet, in the nillies, there has been a very important and steep upward trend in using 3D information as an aid in dento-maxillofacial diagnostics. This 3D acquisition was initially realized by conventional computed tomography. Nowadays, dental cone beam computed tomography enables volumetric jaw bone imaging at reasonable costs and doses and often with a relative advantage of having this equipment nearby. The latter aspect is very important when considering the fact that the power of a dental 3D dataset is not only situated in the diagnostic field, yet also in a multitude of presurgical and therapeutic applications. Indeed, currently, the rapid advances of digital technology and computer-aided design/computer-aided manufacturing (CAD/CAM) systems are creating exciting opportunities for diagnosis, surgical planning and delivery of restorative dentistry. Because dentists are considered prolific users of digital diagnostic software, there is a huge demand for even better interactive software as such to obtain the maximum diagnostic benefit from radiographic, optical and other clinical photographic images. Concomitantly with these evolutions, the public becomes more and more medically demanding and informed, therefore wishing even greater explanation and demonstration of what treatment options are possible. The latter often involves image manipulation to demonstrate therapeutic stages and likely outcomes.

The present review will evaluate whether the inherent three-dimensional nature of the skull and related pathologies of jaws and teeth would benefit from 3D diagnosis. Demonstrating potential benefits and indications might surely apply to pre-operative planning of jaw bone surgery, which is a relatively common procedure, yet not without risks. Furthermore other tooth- or jaw bone related pathologies might gain from three-dimensional diagnostics. Such 3D diagnosis might be accomplished via de dental cone beam CT. Up till now, as it is a relatively new technique, there are no consensus guidelines and a wide variety of machines and performances, stressing the need to establish the optimization strategies for CBCT use.

By critically reviewing the available evidence, the aim of the present literature study is twofold: 1) to provide some support for the hypothesis on use of 3D information for jaw bone surgery; 2) to attempt formulating some guidelines for justified and optimized use of CBCT during the various implant treatment phases.

Is cross-sectional imaging justified for dental indications?

Although various dentomaxillofacial imaging options are available for a multitude of dentomaxillofacial indications, cross-sectional imaging seems to be favoured for specific indications. The most important one being the presurgical planning of implant placement, primarily to avoid neurovascular trauma, but also to enable integration of anatomic, functional, biomechanic and esthetic factors (2, 3) (Fig. 1).

Although panoramic and intraoral views are the first choice radiographs to assess teeth and periodontal

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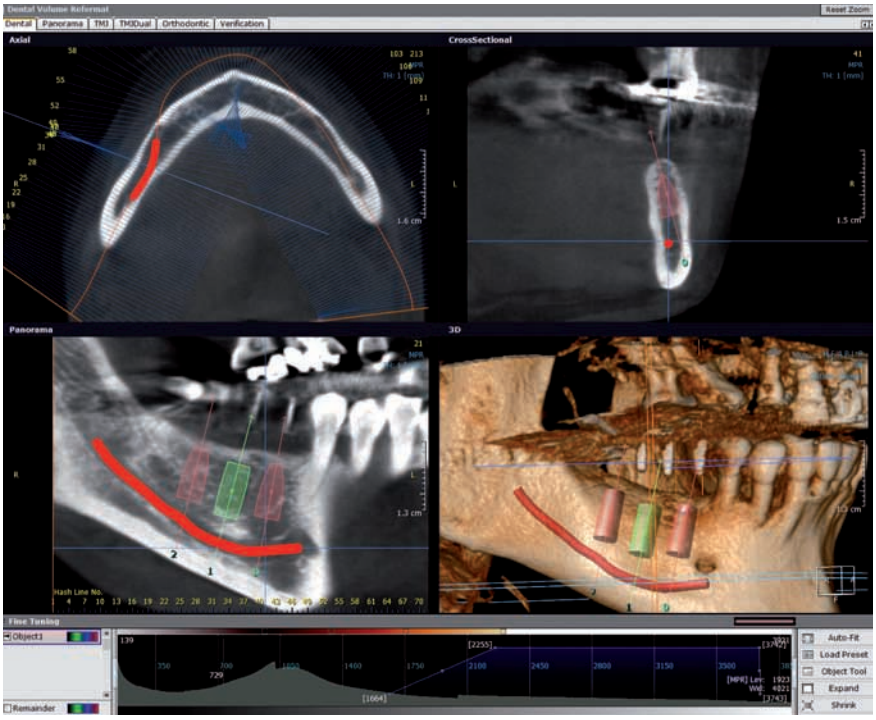

Fig. 1. — The prime indication of dental CBCT is the presurgical planning of implant placement, primarily to avoid neurovascular trauma, but also to enable integration of anatomic and functional factors.

Fig. 2. — In this patient, a panoramic radiograph was taken as the basis of the presurgical planning protocol. The presence of the incisive nerve in the anterior jaw bone was ignored and the implant was placed right on top of the nerve, inducing a chronic neuropathia.

status, an obvious limitation is that these do not provide information on the buccolingual dimensions, jaw bone morphology and irregularities within the alveolar bone. Intraoral periapical images offer a high spatial resolution, making them valuable for detailed diagnosis of tooth-related pathologies. These radiographs might also give a rough idea of the trabecular bone structure, yet the anatomic structure overlap prevents detecting trabecular bone lesions. Furthermore, intra-oral radiographs lack the potential to visualise bone morphology. Finally, these images are limited in size, therefore depicting less anatomic information than sometimes required, meanwhile also preventing a comparison of a local problem with the environment or the contralateral side. This can be the case in the posterior mandible, where localisation of the mandibular canal and mental foramen is essential. Similarly, the maxillary sinus region may not always be sufficiently visualized (2). Usually, the visualization of odontogenic sinusitis problems is much lower with intra-oral radiographs than with CBCT. The latter also applies for panoramic radiographs, which are typically providing information on the gross anatomy of the jaws and related anatomical structures, allowing a global treatment plan to be made. The two-dimensional nature and substantial anatomic structure overlap, the inherent distortion and enlargement, the tomographic effect and limited resolution, make these images less well suited for evaluating details in teeth and bone, particularly in the horizontal planes (2). These drawbacks have a serious impact on assessing the relationship between anatomic structures, and limit detailed diagnosis. Furthermore, there is a true lack of accurately assessing the neurovascular structures, presenting a peroperative risk for neurovascular trauma (3) (Fig. 2).

Although the widespread use of both intra-oral and panoramic radiographs for typically dental and periodontal indications; the aforementioned drawbacks of either technique may explain their limited value when there is a need for visualizing anatomical structures in 3 dimensions, such as in preoperative planning of jaw bone and maxillofacial surgery. To overcome these drawbacks, cross-sectional or even true three-dimensional imaging may be advocated, if the radiation burden can be kept at low levels. Nowadays, the most obvious choice to obtain this, is by using the dedicated dental cone beam CT (CBCT). Since the introduction of the first dental CBCT in the nineties, the market has been exponentially growing. More than 50 devices are currently available. Unfortunately, this exponential growth has created a gap between scientific literature and available hardware. Indeed, available research evidence for one CBCT machine may not automatically apply to other equipment and research findings cannot simply be generalised.

Dental CBCT use beyond radiodiagnostics

As indicated above, the prime diagnostic tool for 3D image acquisition in dentistry, has rapidly become dental CBCT imaging. As the prime use of dental CBCT is related to oral implant placement (covering 2/3 of the indications), the exponential growth of the dental CBCT market has gone hand in hand with the

Fig. 3. — The dental CBCT is a compact and easy-to-operate equipment for use in a dental office.

increasing use of oral implants for tooth replacement. Dental CBCT is a novel technique, capable of capturing three-dimensional dentomaxillofacial radiographs at low radiation dose levels and low cost (1). The dental CBCT is reasonably affordable, compact and easy-to-operate equipment for in-office use (Fig. 3). The conical x-ray beam allows an entire volume to be scanned in one single rotation, with a reduced x-ray tube power, while using a flat 2-dimensional image receptor (4). The lower power configuration greatly reduces both costs and radiation (5), but is often associated with increased noise and -together with the smaller dynamic range of CBCT detectors- with a lower contrast resolution, making CBCT not suitable for soft-tissue imaging. Yet, due to the isotropic acquisition of CBCT and its image receptor, a high spatial resolution can be accomplished, needed for depicting small tooth or bony structures (6).

Its compact size (< 4 m²), the greatly reduced costs and maintenance, the low dose and high spatial resolution have led to an exponential growth of available CBCT systems for dentomaxillofacial applications. Unfortunately, CBCT images are generally hampered by a varying degree of artifact expression. Major artifacts may derive from patient jaw movement and from dense dental restorative materials. Furthermore; altering CBCT geometrical configurations create a variable expression of artifacts including truncation, partial volume and several other artifacts. In addition, varying reconstruction protocols greatly impact image output and artifact expression (such as beam hardening and metal streak artifact). On top of that, the large variations within CBCT units may lead to variable degrees of linear, diagnostic and 3D model accuracy all needed to refine diagnostic tasks, surgical planning and CAD/CAM transfer. Nowadays, studies are typically focused on overcoming inherent drawbacks of the

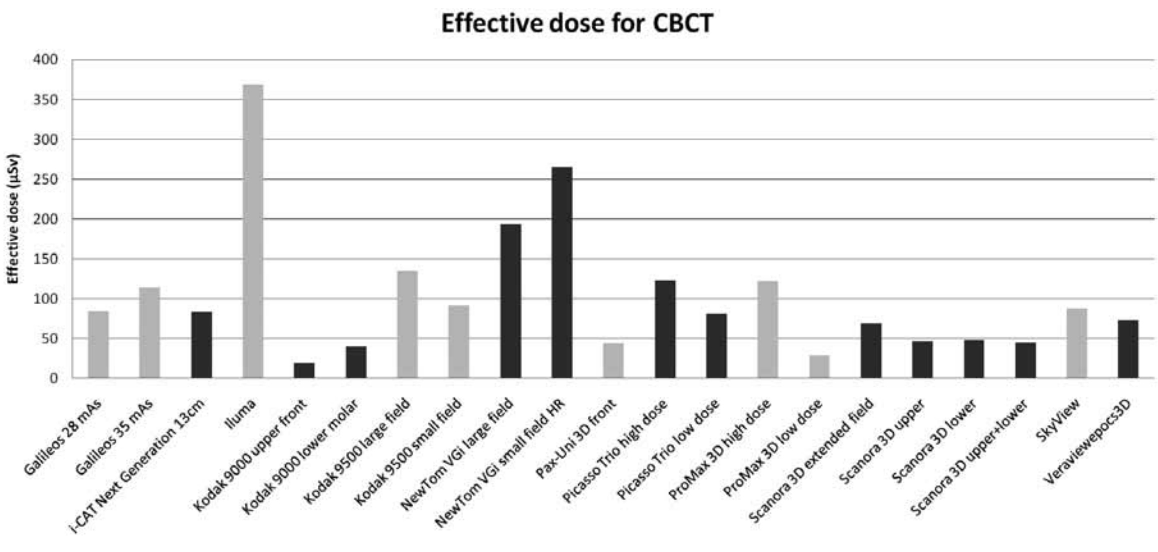

Fig. 4. — Radiation dose levels vary amongst and within CBCT devices, with the lowest ones approaching the dose of one or two panoramic radiographs (9).

Fig. 5. — A CBCT could easily replace a diagnostic cast considering an inherent segmentation accuracy of up to 200 µm (17).

technology by exploring modified scanning protocols or by fusion of CBCT image datasets with optical datasets to overcome the drawback of artefacts caused by metallic dental restorations (7). These optical datasets are derived from three-dimensional optical cameras, most of them introduced in the nillies, and have a potential to turn the conventional dentistry completely upside down. Such optical camera systems may indeed offer the opportunity to avoid traditional, analog impression-taking, eliminating not only the necessity of impression materials to be placed in the mouth, yet also reducing time and handling limitations associated with the impressions. The available intraoral 3D scanners may have the potential to offer excellent accuracy (up to 20 µm) with a more comfortable experience for the patient and a far more efficient workflow for the office. Fusions with basic CBCT data would thus allow a digital cast with an accurate surface to be used or transferred for therapeutic applications via CAD/CAM procedures.

This semi-automation may eliminate manual steps and inevitable human errors when producing dental restorations. Nowadays, CAD/CAM procedures based on 3D information are used in dental practice, dental laboratories or elaborate production centers. As a result of continuous developments in computer hardware and software, new methods of production and new treatment concepts are to be expected. It may lead to simplification and more automation, resulting in dental restorations that are more precise in fit and more customized to the individual patient.

Furthermore, it should also be mentioned that integrated facial scanning has become possible in several CBCT units. The latter implies a concomitant laser 3D laser acquisition of the soft tissues of the face, during the CBCT acquisition. The latter allows a fully integrated planning with the 3D facial tissue scan on top of the bony skull image. The availability of fully integrated and accurate three-dimensional information of both face and bone, allows a more effective planning and predication of the treatment outcome. It not only enhances the transfer to the surgical field, yet also increases possibilities for radiation free follow-up of such surgical cases.

Dosimetric aspects of dental CBCT

Radiology is essential to dentists for determining the presence and extent of disease in jaw bone and teeth. It also has roles in treatment planning, monitoring disease progression and in assessing treatment efficacy. However, an integral part of radiology is exposure of patients and clinical staff. Unlike most medical imaging, dentists use radiology often as one of the diagnostic tools available in the dental practice, for intra-oral radiography even available chairside. At the same time, dentists may use such techniques to a relatively greater extent on children and young adults, so the need for thoughtful use is of paramount importance. Effective radiation doses should be typically far below the levels of clinical spiral CT, to be accepted as a true advantage. It should preferably be an equivalent of 2 to maximally 10 panoramic radiographs (20-100 µSv). Unfortunately, many of those systems seem to vary enormously. Reported radiation dose levels vary according to the CBCT device being assessed, from around 10 µSv to 1200 µSv (which is an equivalent of 2-240 panoramic radiographs; 8, 9) (Fig. 4). It should also be considered that even in the same machine, there can be a huge range of variable options in field-of-view, resolution and exposure parameter setting, with as a consequence an effective dose range of the same order as the variability amongst the machines (9).

Cone beam CT as the method of choice for cross-sectional imaging oral health care

Cross-sectional imaging in oral health care was initially realized by conventional computed tomography, associated with relatively high radiation dose levels and costs. Nowadays, dental cone beam computed tomography enables volumetric jaw bone imaging at reasonable costs and doses. A potential drawback is that this is often associated with increased noise and a lower contrast resolution, preventing soft-tissue imaging. Nevertheless, the most important dentomaxillofacial diagnostic requirement is high 3D spatial resolution for depiction of small bony structures (1). Numerous scanners have now been developed for dentomaxillofacial use. Patient scanning is most often standing or seated which makes in-office units resemble compact panoramic machines (see Fig. 3). However, most scanners differ in geometrical configuration. This leads to a wide range of different field-of-views (FOV) with truncation or partial volume artifacts since the entire volumes are often not covered by the detector. In addition, data reconstruction may be very different, leading to variations in image quality and radiation dose. On top of that, exposure parameters further influence image quality within one system. Measurement accuracy has been found to be adequate for CBCT and MSCT, yet large differences between and within units may depend on exposure parameters (10, 11). Thus, despite the excellent properties and growing use of CBCT and even though the excess of studies demonstrating CBCT's added value over other imaging techniques within almost all areas of dentistry, research is inconsistent in technology, exposure parameters or settings. Therefore, evidence-based guidelines are being established dealing with justification, optimization and referral criteria of CBCT for clinical practice (12, 13). Besides justification of 3D examinations, adequate training is required to ensure responsible

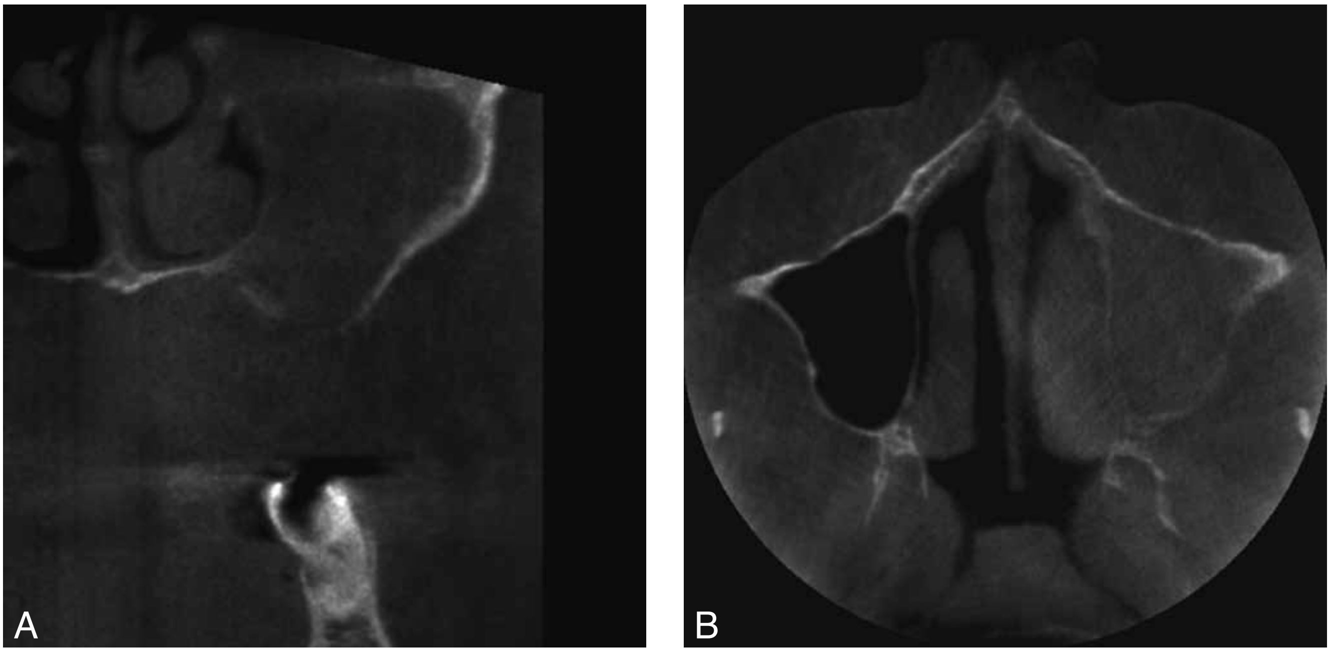

Fig. 6. — As molar root often protrude in the maxillary sinus, extraction may easily cause a oroantral perforation (A). If the latter is large and the apical tooth region infection, this perforation does sometimes not heal, causing odontogenic sinusitis (B).

use and adequate diagnosis of possible additional findings (12).

Indications of Cone Beam CT in oral health care

The EADMFR basic principles on the use of Cone Beam CT published by Horner et al. (12) are a useful guidance for the justification and optimization. Typically, CBCT examinations should not be carried out unless a history and clinical examination have been performed. CBCT should add new information to aid the patient's management. It should not be repeated routinely on a patient without a new risk/benefit assessment. The referring dentists should supply sufficient clinical information (which can include 2D radiographs) to allow performing the justification process and optimize the scanning.

The following indications have been identified

- preoperative planning of implant placement and autotransplantations of teeth;
- dental anomalies;
- eruption problems with impaction of permanent, surnumerary or supplementary teeth;
- cleft-lip and palate;
- maxillofacial surgery;
- surgical wisdom tooth removal, with assumed interrelation between mandibular canal and wisdom tooth apices;
- assumed presence and follow-up of dento-alveolar trauma;
- diagnosis after endodontic treatment failure to assess the prognoses and potential retreatment strategy;
- bone-related TMJ problems;
- diagnostic and/or therapeutic approach of benign jaw bone tumors and cysts;

Oral implant placement

The use of osseointegrated implants has revolutionized oral health care.

Up till now there were no international consensus guidelines regarding the use of CBCT for pre-implant imaging. Some have advocated cross-sectional imaging for specific clinical circumstances (14) whereas others have proposed that cross-sectional imaging is the method of choice for most implant patients (15). The introduction of CBCT, offering imaging at low dose and relatively low costs, has increased the applicability and strengthened the justification of cross-sectional presurgical imaging. Apart from the reduction in radiation dose, there an also be a gain in image quality. Nowadays, it is therefore considered by far the most frequent application of dental CBCT.

Oral implant treatment can be divided in different phases, with imaging playing a significant role in each of these phases (2).

The initial preoperative diagnostic phase should follow the clinical examination, during which it becomes obvious that implants might be a good alternative for the global treatment of the consulting patient. If it turns out that implants are needed in areas with a potential risk to damage vital structures, one may afterwards opt for adding the third dimension. More provocative, but probably also more efficient is the following reasoning: if a clinical examination reveals several edentulous areas, while pocket probing indicates some severe periodontal breakdown with the presence of crown and bridges weakening the roots, it could be hypothesized that the initial examination becomes a 3D low dose Cone Beam CT scan. The latter would then enable the practitioner to make an individualized reconstructed panoramic image, not suffering from the inherent tomographic effect nor from the cumbersome soft tissue overlap. This panoramic reslice could subsequently be used as an orientational reference to indicate where to place implants and where to inspect remaining teeth. It could even be used as a diagnostic cast considering an inherent segmentation accuracy of up to 200 μm, surely when the CBCT model is fused with a digital impression which then becomes very useful in the subsequent phase (11, 16, 17) (Fig. 5).

The next phase is the preoperative planning, that should consider bone quality, bone quantity and anatomic limitations while incorporating prosthetic demands. In addition to a thorough clinical evaluation, imaging assessment is crucial in determining the regional morphologic and structural bony characteristics of the proposed implant site and the location of anatomical landmarks (Fig. 6). In addition, implant dimensions and the potential need for additional treatment prior or during implant placement (such as bone augmentation procedures) may be determined (see Fig. 1). The perioperative treatment phase involves all surgical and clinical aspects of implant and prosthesis placement. Cross-sectional imaging, particularly CBCT, may aid the transfer of the preoperative planning data to the surgical field. There are basically 2 methods of perioperative image-based planning transfer: 1. surgical navigation; 2. surgical template guidance. While this was previously based on spiral CT data, more recently, image guided surgical techniques have been developed to incorporate initial CBCT imaging into computer-assisted operative strategies (18, 19). In this respect, it is also important to mention the intra-operative C-bows, which are derivatives of a CBCT imaging and may find indications for intra-surgical navigation, e.g. in complex maxillofacial surgery, in combination with implant placement (20).

Risks for neurovascular trauma during jaw bone surgery

With the increasing use of oral implants, the number of reported surgical complications has also been emerging. The latter applies for both maxilla and mandible and may include sensory disturbances as well as severe hemorrhage.

Sensory disturbances can be caused by direct trauma to the nerve, indirect trauma (e.g. pressure by haematoma in canal) or chronic stimulation to the mandibular nerve or any of its branches (21).

If an implant is situated aside of or on top of the nerve, then the nerve can be stimulated recurrently each time when biting or chewing. It is likely that such chronic stimulation may therefore end up as chronic neuropathy (3). Hypoaesthesia, anaesthesia and paraesthesia may display as a sensory disturbance. In some case, the sense of pain is mainly disturbed, but in others the tactile and temperature senses are also disturbed. All these changes can be transient or persistent, depending on the degree of damage to the nerve tissue involved.

Extensive hemorrhage in the floor of the mouth may occur during or after implant placement in the mental interforaminal region and may cause acute airway obstruction (21). The hemorrhage can not only be induced by instrumentation through a perforation of the lingual cortical plate, but may also be caused by touching and damaging the neurovascular bony canals, such like lingual canals. Vascular supplies from lingual artery, sublingual artery and submental artery are anastomotic for superior, inferior and lateral foramina. The multiple vascular anastomoses may thus lead a profuse bleeding even from a broken small size bony canal. A review of the literature shows 12 references describing 13 cases of hemorrhage in the floor of the mouth and potentially life-threatening upper airway obstruction, after the placement of implants in the anterior mandible (22) (Figs. 2 and 7). Importantly, the vascular size and canal diameter have often been identified as large enough to cause significant damage and bleeding when touching (3).

In the maxilla visualization of pertinent anatomic structures, such as the nasoplatine canal, nasal fossa or maxillary sinus has received less attention in the literature. While the presence of these structures may impede and influence implant success, violation of these structures does not usually result in serious side effects (3, 21). Yet, even then, one should be cautious.

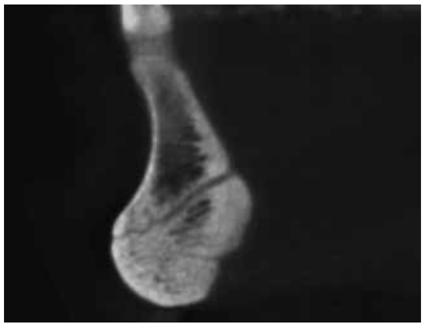

Fig. 7. — Placement of an oral implant in the neighborhood of the mandibular midline lingual canal may cause hemorrhage in the floor of the mouth and potentially life-threatening upper airway obstruction. As the canal has a neurovascular content with a significant size, neural disturbances may also occur.

Orthodontics

A correct orthodontic diagnosis needs to be based on accurate images of the craniofacial region and is crucial for the development of a valid orthodontic treatment plan.

Up till now, such images typically have a 2D nature, including panoramic radiography and lateral cephalography. Lateral cephalometric analysis has been used and developed for orthodontic treatment planning for decades (23). To suit this purpose, lateral skull radiographs with head fixation are generally used. Recently there has been an introduction of software which eases the orthodontists in indicating the anatomical landmarks, calculating the data and indicating the most suitable treatment plan. This technique allows orthodontists to analyse teeth alignment, jaw class, soft tissue profile and growth development of the patients. Yet, one should consider the drawbacks including overlap of left and right structures (with a different image enlargement), superimposition of teeth and other structures on the critical anatomical landmarks, and poor soft tissue profiles, all leading to incorrect landmark identification and incorrect calculations for the analysis. In normal cases, these factors may not interfere with the treatment planning but in borderline cases or severe skeletal malformation, they may affect the treatment planning and further therapeutic approach. Indeed, all structures studied (teeth, jaws, skull and their interrelation) and treated have a 3D nature and thus a true volumetric analysis may be assumed to come closer to reality.

During the last decade, there has been an upward trend in using 3D information as an aid in dentomaxillofacial diagnosis. Initially, this was realized by conventional computed tomography, associated with relatively high radiation dose levels and costs. Nowadays, dental cone beam computed tomography (CBCT) enables volumetric jaw bone imaging at reasonable costs and doses. This offers numerous diagnostic potentials and may change treatment strategies in oral health care, as long as radiation doses, image quality, diagnostic yield and treatment outcome can be properly balanced. This surely applies for the orthodontic field where justification is needed for volumetric scanning in children in order to increase benefits

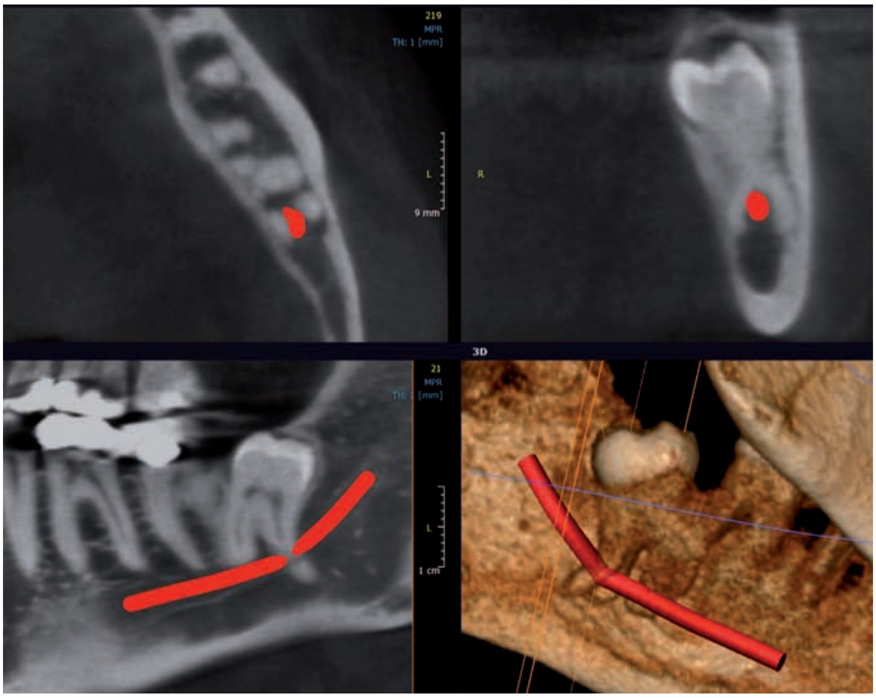

Fig. 8. — Damage to the inferior alveolar nerve during surgical extraction of deeply impacted third molars is a serious complication. The present case shows a complicated relation between the nerve (red line) and the roots of the impacted wisdom tooth.

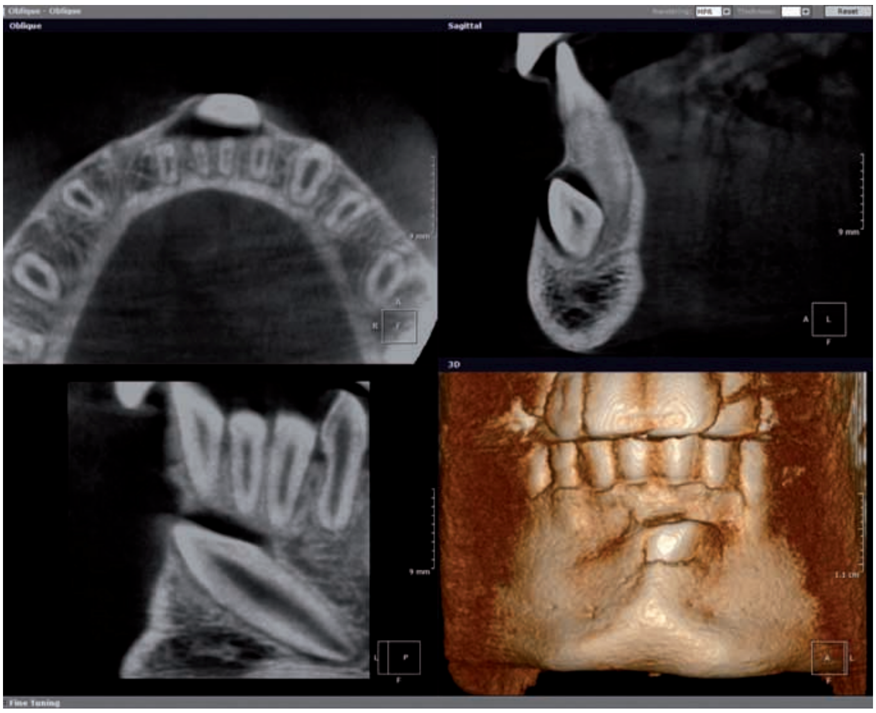

Fig. 9. — CBCT scans are superior to conventional panoramic radiographs in determining the location and orientation of an impacted tooth and its relationship to adjacent vital structures. The information can help to make the surgical exposure / removal minimally invasive.

in diagnosis, treatment planning and outcome (24-26). Yet, one should be aware that proper use of cone beam CT scanning should not necessarily imply an increased radiation dose to those children. Indeed, if cases are carefully selected, one cone beam CT volumetric scan may be able to yield all necessary information not only including the 3D volume and its internal bone and tooth structures, yet also including a panoramic reslice, a cephalometric analysis in 2D/3D and a virtual cast. Thus, it may be replacing a cascade of 2-D radiographic images and depending on the machine type and exposure parameters.

Up till now, some attempts have been made using the cone beam CT data for orthodontic treatment planning and 3D-cephalometric analysis (25, 26). Furthermore, some researchers have been performed to evaluate the accuracy of the 3D imaging technique (25-27). Yet so far, none has investigated the advantages of 3D over 2D imaging regarding diagnosis, treatment planning and therapeutic outcome for orthodontic applications.

Tooth impaction

Impaction is defined as a failure of tooth eruption at its appropriate site in the dental arch, within its normal period of growth, or with a delayed eruption time and not expected to erupt completely based on clinical and radiographic assessment. Dental impaction has been reported to affect as much as 25% to 50% of the population (28). The teeth predominantly involved in tooth impaction are third molars (28). Permanent maxillary canines are the second most frequently impacted teeth after the third molars (29). The prevalence of impacted third molars is variable in different populations, while the incidence appears to be increasing (30). 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 (30). Before planning extraction of an impacted mandibular third molar, the topographic relationship between the mandibular canal and the molar should be clearly inspected as such to avoid damaging the inferior alveolar nerve (31). Damage to the inferior alveolar nerve during surgical extraction of deeply impacted third molars is a well-known complication. Over the years, numerous reports of inferior alveolar nerve injuries after wisdom teeth surgery have been recorded (31) (Fig. 8).

Maxillary canine impaction occurs in approximately 1% to 3% of the population with a 2:1 female to male ratio for review (29). The maxillary canines are more commonly impacted than the mandibular canines.

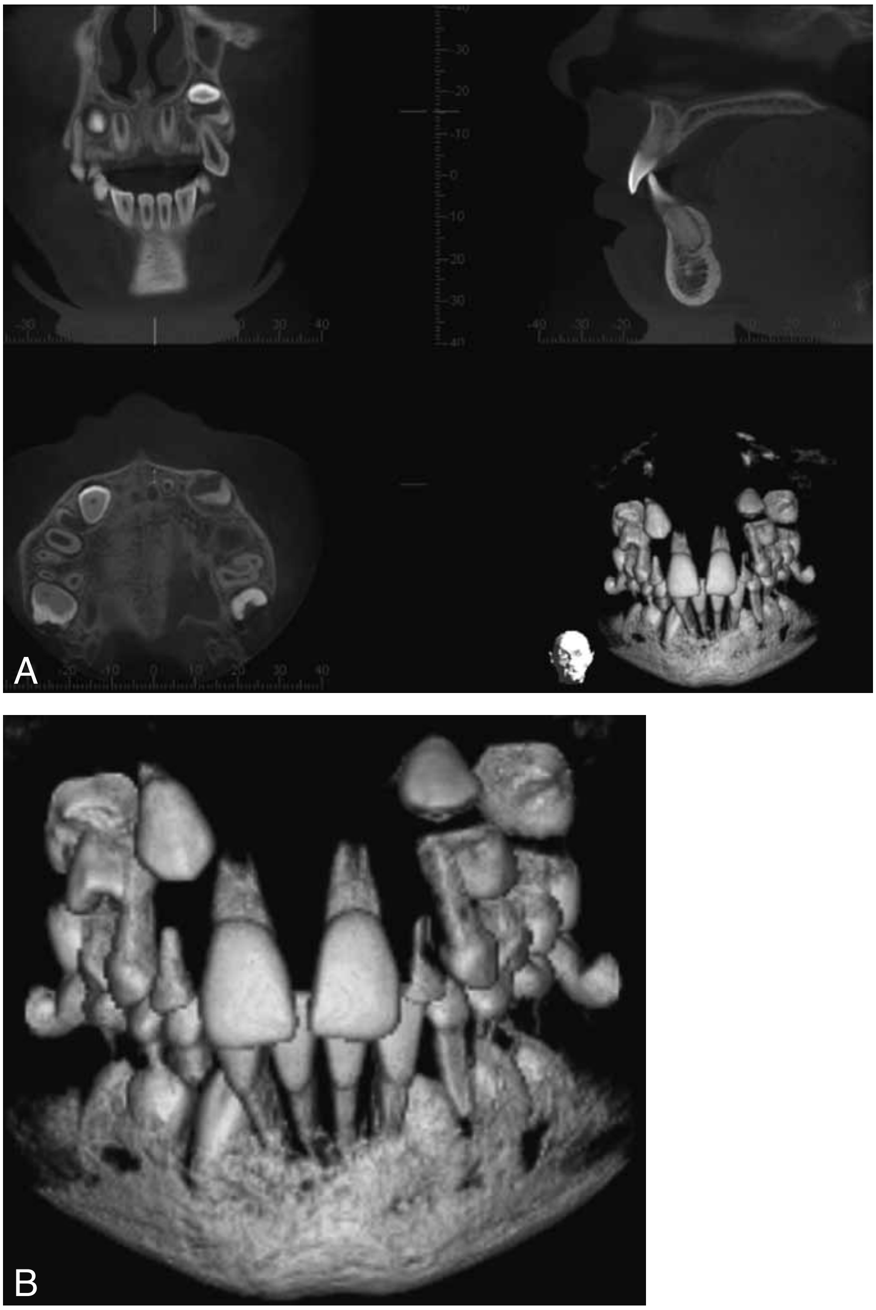

Fig. 10. — This patient has agenesis of 12 and 22 (A), and horizontal impaction of 23 (B). In such case, orthodontic treatment planning might benefit from 3D imaging.

Other teeth are less frequently impacted. In the Caucasian population, canines are impacted palatally at least 2 to 3 times more frequently than labially. In Asian subjects, however, it appears that impacted canines are usually bucal in position. To develop a treatment strategy, localisation of impacted canines relative to the incisors and premolars is crucial. Information regarding the palatal orientation of an impacted canine and its proximity to the roots of neighboring teeth is essential to allow for an effective and timely surgical intervention. Conventional panoramic radiographs are routinely obtained to evaluate tooth impaction pre-operatively. However, the 2D nature of the image and the superimposition of adjacent anatomical structures impede precise assessment of the tooth relative to adjacent anatomical structures. CBCT scans are superior to conventional panoramic radiographs in determining the location and orientation of an impacted tooth and its relationship to adjacent vital structures (Fig. 9).

Supplementary and surnumerary teeth

Polygenesis, the formation of one or more supernumerary teeth occurs much less frequently than agenesis. Supernumerary teeth can be found anywhere within the jaw, but the anterior midline of the maxilla is the most common site, in which case the supernumerary tooth is known as a mesiodens (32).

Their presence may give rise to various clinical problems. Such teeth may have a highly aberrant form, often tucked-in to the lingual of the normal tooth row. Detection of supernumerary teeth is best achieved by thorough clinical and radiographic examination. Reports in prevalence of supernumerary teeth can be as high as 3.6% in the permanent dentition, depending on the population studied (32). An inverted supernumerary tooth is rather uncommon. Eruption of inverted teeth is extremely rare, but has been described for mesiodens and premolars (33). Treatment depends on the type and position of the supernumerary tooth and on its effect on adjacent teeth. By adequate diagnosis in 3 dimensions using CBCT and a further image-based presurgical planning, minimal invasive surgery can be performed, enhancing efficiency while reducing post-operative complaints.

Tooth agenesis

Agenesis of one or more teeth is one of the most common of human developmental anomalies (34). Failure of formation of one or more third molars occurs in a fifth of the population. The reported incidence of other missing teeth varies from 1.6% to 9.6%.

Next in frequency of absence are the upper lower second premolars (3%) followed by the maxillary lateral incisors (2%). Absence of just a single premolar happens frequently. The absence of four or more teeth (other than third molars) occurs in 0.25% of the population. When a deciduous tooth is missing, its permanent counterpart is also absent. Occurrence of other anomalies in the deciduous dentition is a good predictor of anomalies in the corresponding teeth in the permanent teeth, although not necessarily of the same type. Although for tooth agenesis, a 3D image is not strictly required, those images can become a necessi-

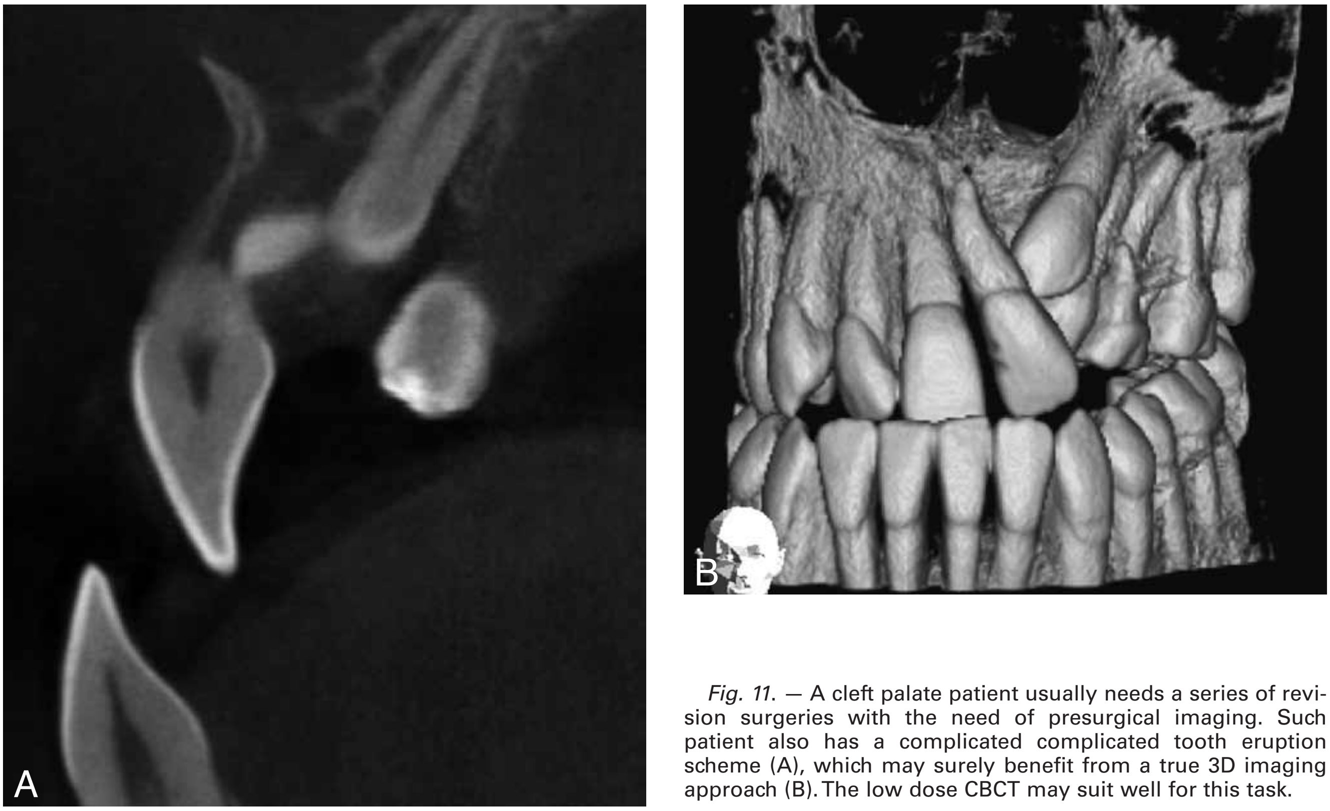

Fig. 11. — A cleft palate patient usually needs a series of revision surgeries with the need of presurgical imaging. Such patient also has a complicated complicated tooth eruption scheme (A), which may surely benefit from a true 3D imaging approach (B). The low dose CBCT may suit well for this task.

ty for the treatment options. When dealing with tooth agenesis, it may be decided to go for orthodontics and as seen in the aforementioned paragraph, the use of 3D imaging may be a valuable treatment option (Fig. 10). Should one however prefer to keep the deciduous tooth in place as long as possible, adult life may be reached as such that the location can then be prepared for oral implant installation. Such surgical strategy demands a presurgical CBCT-based planning. Finally, sometimes it is impossible to wait till adult age for replacing the particular tooth (eg esthetic demand in absence of upper lateral incisor), in that case a protocol for stereolithographic based tooth autotransplantation may be considered a valuable treatment option. Although the use and benefit of rapid prototyping models has already been documented (35), it is often claimed that a major drawback – especially in children – is the radiation burden. Yet when using a low-dose CBCT, with an exposure equivalent to 2 panoramic radiographs, approximating 1 day of background radiation, this drawback could be easily justified. Autotranplantation may thus become a more reliable treatment method for tooth replacement when using 3D CBCT-based pre-surgical planning with transfer by stereolithographic surgical guidance. The final outcome of the autotransplantation may benefit from a significantly reduced extra-oral time, a more accurate recipient site preparation, and a better position of the donor tooth (35).

Cleft lip and palate and maxillofacial surgery in general

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. However, the amount and quality of available bone cannot be accurately assessed on a panoramic radiograph. The same applies to the complicated tooth eruption scheme. It is obvious, that diagnosis and management may gain from a true 3D imaging approach. Yet, considering the repeated use in children and the relatively low dose, CBCT is rapidly replacing medical CT for this task (36) (Fig. 11). 3D CBCT reconstructions of nose and facial skin are also possible. These principles, advantages and drawbacks surely also apply for maxillofacial surgery in general. The possibilities of CBCT to deliver integrated 3D information beyond diagnostics may surely help maxillofacial surgeons in preparing or preoperatively transferring the surgical demands. The availability of digital impressions for a refined occlusal surface and the use of CBCT devices with a concomitant facial scan may surely add to to the possibilities of an optimized transfer of the preoperative planning phase to the surgical theatre.

Maxillofacial trauma

Although plain radiographs are useful in the initial evaluation of suspected facial fractures, CT is advised for detecting radiographically occult fractures, or fractures suspected on the basis of secondary signs, such as a sinus air–fluid level, and for defining fracture displacements of fractures prior to surgical reduction and fixation. One could assume that CBCT might also suit that purpose, which can be partly confirmed. Yet in complex maxillofacial and head trauma, the suspected presence of

Fig. 12. — An intra-oral radiograph does not always reveal the true lesion extent (A). The present case indicates a palatal lesion, around an horizontal tooth root trauma.

other than bony defects, might push towards spiral CT imaging.

Diagnosis of dental trauma and endodontic treatment failure

Root canal treatment of molars and other teeth presenting with complex root canal configurations can be diagnostically and technically challenging. The use of CBCT imaging in endodontically challenging cases can facilitate a better understanding of the complex root canal anatomy, which ultimately enables the clinician to explore the root canal system and clean, shape, and obturate it more efficiently. Besides, various studies have indicated a superiority in detection internal and external root resorption lesions in the teeth. It has also been shown that trauma of teeth can be better assessed in three dimensions (Fig. 12). Taken together, CBCT imaging may allow an assessment of tooth prognosis when clinical signs and symptoms indicate an unexplained endodontic treatment failure and with assumed tooth trauma. CBCT findings may modify treatment planning, as well as the techniques employed during both non-surgical and surgical endodontic treatment (1).

Bone-related TMJ problems

Bony pathology of the TMJ including cysts, tumors or joint morphology changes as well as TMJ trauma may be diagnosed using CBCT. In temporomandibular joint osteoarthritis, discrete changes in joint morphology may help in early diagnosis or in assessment of disease progression or treatment effects. Else and most often TMJ related pain problems are not found in bony tissue defects, necessitating the use of MRI.

Diagnostic and/or therapeutic approach of benign jaw bone tumors and cysts

Most cystic lesions occurring in the jaws are related to teeth (odontogenic); some are non-odontogenic, and others are not true cysts, but are conveniently considered within this category because of cyst-like radiographic appearances. Some neoplasms, notably ameloblastoma, can appear cystic, and must be considered in the differential diagnosis of a cyst.

Cone-beam CT has excellent spatial and high contrast resolution and may allow for the production of panoramic, axial and cross-sectional 2D reconstructions (1). The extent of a lesion's relationship to teeth, root resorption, internal structure, cortical expansion and erosion, the boundary of a lesion and the presence of multiple lesions can all be evaluated. This surely aids diagnosis yet also surgical treatment planning, by using the 3D information.

Conclusions

CBCT offers numerous potentials in both the diagnostic and dental therapeutic field. Yet, it is obvious that the latter should not be done without proper optimisation strategies. The EADMFR basic principles on the use of Cone Beam CT published by Horner et al. (12) are a useful guidance for the justification and optimization. It is clear that to maintain a proper balance (optimisation) between on one hand costs and radiation dose and on the other hand information required. Also, the scanned area should not exceed the area of interest. This will limit the dose substantially, thus justifying its use for preparing implant surgery. Furthermore, such strategy would also prevent that areas are visualised that cannot be properly scanned and diagnostically interpreted. Considering that dental CBCT enables volumetric imaging of the craniofacial complex at reasonable costs and doses, numerous diagnostic potentials are opened. These challenges may also have an impact on disease management, therapy planning and even aid therapeutic approaches. Development of procedures for surgical template and CAD/CAM procedures as well as surgical navigation go hand in hand with procedures for cone beam CT scanning. These concomitant developments will probably alter the treatment strategies in oral health care. Yet, more clinical research is needed to validate the outcome of various applications in this particular field.

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