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Publisher Herausgeber Editeur	Editor-in-chief Chefredaktor Rédacteur en chef	Editors Redaktoren Rédacteurs	Assistant Editor Redaktions-Assistent Rédacteur assistant
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Ich bedanke mich bei den unten aufgeführten Kolleginnen und Kollegen für ihre wertvolle Mitarbeit, die sie in den vergangenen zwei Jahren geleistet haben.

Adrian Lussi

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SWISS DENTAL JOURNAL SSO 124:
 1170–1183 (2014)
 Accepted for publication:
 11 December 2013

SADMFR Guidelines for the Use of Cone-Beam Computed Tomography/ Digital Volume Tomography

Oral and maxillofacial surgery, temporomandibular joint disorders
 and orthodontics

A consensus workshop organized by the Swiss Association
 of Dentomaxillofacial Radiology

KEYWORDS

Cone-beam computed tomography,
 three-dimensional imaging,
 Swiss Guidelines,
 guidelines

SUMMARY

Cone-Beam Computed Tomography (CBCT) has been introduced in 1998. This radiological imaging procedure has been provided for dentistry and is comparable to computed tomography (CT) in medicine. It is expected that CBCT will have the same success in dental diagnostic imaging as computed tomography had in medicine. Just as CT is responsible for a significant rise in radiation dose to the population from medical X-ray diagnostics, CBCT studies will be accompanied by a significant increase of the dose to our patients by dentistry.

Because of the growing concern for an uncritical and consequently rapidly increasing use of CBCT the Swiss Society of Dentomaxillofacial Radiology convened a first consensus conference in 2011 to

formulate indications for CBCT, which can be used as guidelines.

In this meeting, oral and maxillofacial surgery, orthodontics and temporomandibular joint disorders and diseases were treated and the most important and most experienced users of DVT in these areas were asked to participate. In general, a highly restrictive use of CBCT is required. Justifying main criterion for CBCT application is that additional, therapy-relevant information is expected that should lead to a significant benefit in patient care. All users of CBCT should have completed a structured, high-level training, just like that offered by the Swiss Society of Dentomaxillofacial Radiology.

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Introduction

It is standard accepted practice that dentists produce, read and diagnose their own radiographs. However, in medical radiology this is considered a comprehensive process performed by different specialists. For intraoral radiography, fixed exposure settings have been introduced for most of the X-ray machines, assuring facilitated use, image quality and radiation protection. In panoramic radiographs and lateral cephalograms, exposure parameters are variable. Therefore, knowledge about the effect of different exposure settings on image quality is required. In cone-beam computed tomography (CBCT, *MOZZO ET AL. 1998*) dental radiology becomes more complex, because the user is confronted with a system similar to computed tomography (CT, *HOUNSFIELD 1973*). This imaging technique is not a basic radiographic examination, since it applies a much higher radiation dose compared to other dental X-ray imaging modalities, which makes proper indication and justification much more sensitive. The choice of exposure values, optimization of device-specific image quality and measures for radiation protection must be determined by the dentist, whereas in general radiology and, particularly in CT, this responsibility is transferred to a specially trained medical-technical radiographer. As cross-sectional images are provided, image reading, interpretation and diagnosis must be based on intensive, repeated training and highly skilled experience. The additional help of a computer scientist may also be required to address problems of hard disk space and image archiving. Finally, it is imperative to write a report of the findings for all studied patients. The operator of a CBCT device must be aware that this cannot be performed simultaneously with any other treatment of patients. The time required for this task must be explicitly kept free during working hours, otherwise this work must be carried out during free time. Considering all these points it is clear that with the introduction of CBCT dental radiology has finally matured to dentomaxillofacial radiology, which must be considered as a specialty for which a special education must be created.

However, a specialization in dentomaxillofacial radiology has only been established in a few countries. Therefore, it is not feasible at this time to permit only dentists with a specialization to operate a CBCT device. For these reasons, the Board of the Swiss Association of Dentomaxillofacial Radiology (SADMFR) is concerned that the rapid and uncontrolled adoption of CBCT into routine practice might lead to an uncritical, unjustified and incorrect use and to a significant increase in the radiation burden of patients. This probable development must be expected in light of the fact that the radiation burden in medicine is already heavily increasing throughout the world because of the rapid increase in CT examinations (*HALL & BRENNER 2008; SCHAUER & LINTON 2009*). Considering that, depending on the volume and the region chosen, a CBCT examination may deliver up to one-third to half of the dose of a standard CT examination (*LUDLOW & IVANOVIC 2008; PAUWELS ET AL. 2012*), CBCT will contribute considerably to the ever increasing collective dose to our patients. Although guidelines for the use of CBCT have been established from different groups as a form of regulatory measure (*LEITLINIE DER DGZMK 2009; HEALTH PROTECTION AGENCY 2010A, 2010B; ADVIES VAN DE HOGE GEZONDHEIDSRaad 2011; EUROPEAN COMMISSION RADIATION PROTECTION 2012*), the field is under discussion. Therefore, the SADMFR feels encouraged to contribute to the discussion by reviewing the current literature, establishing evidence-based guidelines and promoting high-level education with adherence to these guidelines for a justified and ethical application of CBCT in dentistry.

Material and Methods

On January 24th and 25th, 2011 the SADMFR convened for the first consensus workshop to establish indications and contraindications for CBCT in dental medicine. This first consensus workshop focused on oral and maxillofacial surgery, disorders of the temporomandibular joints (TMJs) and orthodontics. A follow-up conference (scheduled for 2014) will deal with the topics of periodontology, fixed and removable prostheses, endodontology, and operative and pediatric dentistry.

For the first consensus workshop, a core group of eleven members was appointed, all of whom have been working intensively for years with CBCT and with expert knowledge in dentomaxillofacial radiology. All members were dentists with a doctor's degree and most of them with one or more specialty degrees: two maxillofacial surgeons, seven oral surgeons, two orthodontists and two colleagues working solely in the fields of temporomandibular disorders (TMDs) and orofacial pain. In addition, there was one Master of Science in dentomaxillofacial radiology (London), one dentomaxillofacial radiologist without a specialty degree and one physicist. All of them were recognized colleagues with long and highly skilled experience in their field. For some specialties, a specialist title is not available at the moment in Switzerland.

Ten of the eleven participants were working in one of Switzerland's universities; seven of the eleven as chair or head of a department, division or section. Five of the eleven were assistant or associate professors or scientific associates. One was working in a private practice as Master of Science in dentomaxillofacial radiology.

The workshop was organized from 9:00 a.m. to 10:00 p.m. on January 24th and from 9:00 a.m. to 2:00 p.m. on January 25th, 2011, with a rigid timetable. Prior to the meeting, in subgroups of two, the participants had to prepare an opinion and indication list for CBCT in their respective working field according to items on the agenda established from one member of the group who had prepared and lead the meeting. Each group presented their proposals, which were then discussed and adopted in a consensus in plenary. A draft document was later presented to another peer of the respective specialty for review and then sent by email to all members for final revision. Three of these peers contributed so much to the discussion that they are coauthors of the present article. It represents the SADMFR guidelines for the use of CBCT with the principle authors of each chapter.

Results

Basic considerations for cone-beam computed tomography

(D. Dagassan-Berndt)

Justification of CBCT

X-rays may cause harm. Prior to any radiograph, the benefit from the specific exposure has to be weighed against the risk for the patient (*DULA ET AL. 2001*). Strict indications must be respected, with highest attention to the ALARA principle (as low as reasonably achievable, *MOUNTFORD & TEMPERTON 1992*).

The person responsible for CBCT examinations must start the process of justification by taking into account the medical history of the patient, the results of the clinical findings and all previously performed imaging procedures in the region of interest. He must decide whether the application of CBCT is really justified or whether alternative imaging at a lower dose (other X-rays) or even without dose (magnetic resonance imaging,

ultrasound) are also suitable or even better suited for obtaining the necessary information.

If careful assessment of these points reveals that CBCT is justified, exposure should be carried out while abiding by the following recommendations: selection of the smallest possible scan volume, of appropriate exposure settings (kV and mA) and resolution and proper adjustment of the field of view (FoV) (FARMAN 2005). The responsible person will then document the procedure and do the mandatory reporting (EUROPEAN COMMISSION ON RADIATION PROTECTION N° 172, 2012).

When patients are referred, the referring clinician must provide the person responsible for the CBCT examination with all the necessary information to start the process of justification. In case of any doubt, the responsible person must consult the referring colleague and finally decide whether there is enough justification for the required exposure. For the mandatory reporting and image transmission, it must be assured that patient data are handled in accordance with the applicable data protection provisions.

Setting Parameters

For each justified CBCT exposure there are different parameters that need to be chosen. In general, the following guidelines apply: the kV settings must be selected individually according to the patient size and to the volume to be imaged. Increased tube current increases patient dose, whereby penetration and image contrast remain the same. Therefore, the exposure values should be kept as low as possible for mA, while the kV settings should be maintained (DULA ET AL. 1998). The size of the FoV is associated with the effective dose and the image quality (HIRSCH ET AL. 2008; OKANO ET AL. 2009; ROBERTS ET AL. 2009). The FoV is defined by the area to be imaged and by the individual indication. Large FoV sizes result in a higher patient dose and should only be chosen when larger areas need to be studied.

The voxel size varies from 0.1 (0.08) to 0.42 (HASHIMOTO ET AL. 2003; LIEDKE ET AL. 2009; LOUBELE ET AL. 2008). In general, the smaller the voxel size, the higher the spatial resolution and greater the image quality. However, small voxel sizes (high resolution) result in more noise in the image and in a higher patient dose. Serious consideration should be given to the central idea that the voxel size meets the required spatial resolution. Furthermore, higher voxel size prolongs the exposure time, which may result in a higher probability of the emergence of movement artifacts. Thus, small voxel sizes should only be chosen if a high resolution is really needed (DA SILVEIRA ET AL. 2013).

The use of an X-ray apron and thyroid shielding is recommended when producing CBCT images (QU ET AL. 2012). Yet, care must be taken to ensure good adaptation in order to provide effective protection. In particular, the shielding must not extend into the radiation field, since this could lead to a considerable increase in dose by the system-specific automatic adjustment of exposure and contrast.

These recommendations cannot be implemented by all CBCT devices since only limited parameters are available in most machines. The ideal CBCT device should be equipped with all essential parameter-setting options. This includes free choice of mA and kV settings, choice of the FoV (continuously variable volume with a minimum of 3 apertures), voxel size and scan time. The data should be produced in accordance with the established standards in medicine, i.e. DICOM data should be automatically exported. For image analysis of the CBCT scans,

an unlimited number of freely customizable reconstruction planes should be available.

Avoidance of Artifacts

With CBCT technology, movement artifacts and beam-hardening artifacts caused by foreign bodies can arise during image production. Beam-hardening artifacts are caused by materials of very high density, located either extra- or intraorally within the beam path (NACKAERTS ET AL. 2011).

Patient motion affects the spatial resolution and the distinction between different structures. Movement artifacts can be seen particularly in CBCT images with longer scan times (HOLBERG ET AL. 2005). Consequently, the following point should be observed: the scan time for CBCT should be as short as possible. Particularly with respect to children, the shortest possible scan time should be selected if the device in use allows this option.

All foreign objects located in the CBCT beam path (extraoral: glasses, jewelry, piercings, hair clips, etc.; intraoral: dentures, piercings and all kinds of jewelry) must be removed. When radiopaque objects cannot be removed, the image quality may be compromised (PAUWELS ET AL. 2011).

Diagnostic principles in cross-sectional images (A. Filippi)

Prior to image analysis, it is mandatory to focus on all three planes in the region of interest and to adjust for the best brightness and contrast for the specific imaging and diagnostic task. The object of interest should then be rectangularly positioned with respect to the viewing angle. Only after having prepared the images in this way should the response to the core question be addressed. By scrolling meticulously the proportion of the volume where the structure to be examined is located, all relevant findings must be precisely described. Then, the whole volume must be examined to search for (additional) relevant findings in the field of view. With regard to the procedure, it is important to scroll the entire volume in one plane, with preference to the axial plane. If relevant findings are detected, then the remaining two planes need to be meticulously browsed.

Application of CBCT for preoperative analysis of partially retained, fully retained and impacted teeth (R. Lauber and K. Dula)

Mandibular Third Molars

During surgical removal of mandibular third molars, possible damage to the inferior alveolar nerve (IAN) is a concern when close proximity of the roots to the inferior alveolar canal is observed in two-dimensional images. In several studies, the following signs have been identified in panoramic radiographs that indicate an augmented risk of nerve damage (BLAESER ET AL. 2003): close proximity of the roots to the inferior alveolar canal with darkening of at least one of the roots, diversion of the inferior alveolar canal and discontinuity of the cortical line of the inferior alveolar canal.

More certainty about the anatomical relationship between the inferior alveolar canal and mandibular third molar roots can surely be obtained by three-dimensional (3-D) imaging. However, the reliance on CBCT images seems to give the surgeon a false sense of security. GUERRERO ET AL. (2012), for instance, found no significant differences in postoperative sensory disturbances in patients preoperatively examined with panoramic radiography or with CBCT. SUOMALAINEN ET AL. (2012) analyzed three national registers in Finland and found that the availabili-

ty of CBCT devices had no significant influence on the number of IAN injuries related to mandibular third molar removals. ROEDER ET AL. (2012) found that it is almost impossible to conduct a clinical study to prove a potential benefit from CBCT scans prior to surgical removal of mandibular wisdom teeth with respect to the most important parameters, i.e., IAN damage, due to the very large sample sizes required. They concluded that CBCT scans should only be performed for high-risk wisdom tooth removals.

Generally, the incidence of IAN injury is low and decreases with the increasing experience of the surgeon (BATAINEH 2001; JERJES ET AL. 2006). As a result, the more experienced a surgeon is, the less likely he requires confirmation by 3-D imaging. Thus, SADMFR emphasizes that only highly experienced colleagues should perform surgery on difficult mandibular third molars since they will also perform the radiological assessment based on proper routine practice. If 3-D imaging is required, CBCT should be preferred to CT because of its better image sharpness and lower dose (LIANG ET AL. 2010; PAUWELS ET AL. 2012). Table I illustrates the SADMFR recommendations for the use of CBCT in preoperative analysis of partially retained, fully retained and impacted mandibular third molars.

Maxillary Molars, Canines, Premolars

Mere localization of impacted canines or premolars can often still be achieved with perspective displacement in two periapical films (parallax view). For impacted maxillary wisdom teeth, canines or premolars, the SADMFR emphasizes that a radiographic evaluation with CBCT should be performed only when information about pathological changes or for surgical removal is needed that cannot be obtained from standard radiographs.

Supernumerary Teeth

These teeth are generally impacted and show a close relationship to the roots of adjacent teeth, to the nasal floor, the maxillary sinus or to vital structures in the maxilla or mandible. In complex situations where precise information is required, particularly with regard to related pathologies, such as cystic lesions, resorption of adjacent roots or multiple retention with crowding, a CBCT is indicated prior to the removal of these teeth (HANEY ET AL. 2010).

Application of CBCT for apical surgery (R. Lauber and K. Dula)

A prerequisite for successful apical surgery is a sufficient root canal treatment and a proper coronal seal. Further radiological investigations should not be performed before these requirements are fulfilled (VON ARX ET AL. 2010).

Due to the complexity of the root canals, standard radiographs cannot sufficiently image the respective condition (IOANNIDIS ET AL. 2011; KFIR ET AL. 2012). Persistent complaints and pain in the absence of pathology found by clinical and radiological examination with periapical and panoramic radiography justify the use of CBCT (BORNSTEIN ET AL. 2011; LOW ET AL. 2008). In 3-D radiographs, endodontically treated teeth often reveal chronic periapical inflammation. This applies especially for the maxillary premolar and molar regions because of the superimposing maxillary sinus. Furthermore, CBCT may provide detailed information of a possible furcation involvement, thus serving as a reliable basis for therapeutic decisions. However, it is considered justifiable as an additional diagnostic measure only when major invasive therapies are planned (WALTER ET AL. 2012; WALTER ET AL. 2010). Table II illustrates the SADMFR recommendations for the use of CBCT in the preoperative analysis for apical surgery.

Application of CBCT in the evaluation of cysts and cyst-like lesions of the jaws (M. M. Bornstein)

True Jaw Cysts

The WHO classification of odontogenic tumors (KRAMER ET AL. 1992) divides jaw cysts into two categories: developmental and inflammatory cysts (Tab. III).

Odontogenic cysts are derived from structures of the tooth germ, for example from remnants of the dental lamina, whereas non-odontogenic cysts arise from epithelial remnants from other tissues. The most frequently occurring jaw cysts are the radicular cysts (78% of all cysts) and follicular cysts (12%) (MORGENROTH & PHILIPPOU 1998), followed by the odontogenic keratocysts. This parakeratinized form of the cysts was re-grouped by the current WHO classification of head and neck tumors from 2005 and classified as a true benign neoplasm (PHILIPSEN & REICHART 2006; REICHART ET AL. 2006; THOMPSON 2006)

Tab. I General recommendations of the Swiss Association of Dentomaxillofacial Radiology (SADMFR) for the use of CBCT prior to necessary removal of mandibular third molars

CBCT indicated	CBCT not indicated
Apparently high-risk situation in standard radiographs. In case of superimposition of the tooth roots with the mandibular canal, with diversion or interruption of the cortical line or with darkening of at least one of the roots.	No proximity of the tooth roots to the mandibular canal.
Third molar with further pathologies: – Complication-prone cystic lesions – Signs of resorption of neighboring teeth.	Germ of wisdom teeth.

Tab. II SADMFR general recommendations for the use of CBCT prior to apical surgery

CBCT indicated	CBCT not indicated
Molars: – Prior to apical surgery of maxillary molars – Prior to apical surgery of mandibular molars with difficult anatomy or pathology.	Obviously insufficient root canal treatment and/or reconstruction of the crown.
All teeth: – Clinical signs of a periapical problem with no signs of periapical pathology in the intraoral radiograph – Sensitive anatomical structures near the apex – Difficult pathology.	

Tab. III Classification of “true” jaw cysts with epithelial lining (KRAMER ET AL. 1992)

Developmental (dysontogenic) cysts	Inflammatory cysts
1. <i>Odontogenic cysts</i> Gingival cyst of infants Odontogenic keratocyst* Dentigerous cyst Eruption cyst Gingival cyst of adults Lateral periodontal cyst Botryoid odontogenic cyst Glandular odontogenic cyst Calcifying odontogenic cyst	Radicular cyst – Apical and lateral radicular cyst – Residual radicular cyst Paradental cyst Inflammatory collateral cyst
2. <i>Non-odontogenic cysts</i> Midpalatal raphé cyst of infants Nasopalatine duct cyst Nasolabial cyst	
*According to the most recent classification provided by the WHO (PHILIPSEN & REICHART 2006; REICHART ET AL. 2006), the parakeratinized variant of the odontogenic keratocyst has to be considered as a true odontogenic tumor and is called the keratocystic odontogenic tumor (KCOT). The orthokeratinized form behaves like a cystic lesion.	

and referred to as a keratocystic odontogenic tumor (KCOT). Typical for almost all jaw cysts is an often clearly defined radiolucent area that is slowly expansile, resulting in a displacement of adjacent structures rather than resorption. Generally, they are asymptomatic (non-inflammatory jaw cysts are frequently coincidental radiographic findings) and of a bluish color and fluctuate in the case of expansion into the soft tissues (CAWSON & ODELL 2002).

Most jaw cysts may be radiographically depicted using periapical or occlusal films or panoramic radiography. In most cases, these radiological techniques are even sufficient for making therapeutic assessments. However, CBCT may be indicated for a more exact localization and for a better evaluation of the position and the dimension of the cyst in relationship to other important anatomic structures (LOFTHAG-HANSEN ET AL. 2007; STAVROPOULOS & WENZEL 2007).

Generally, the extent of apical pathologies is underestimated in two-dimensional imaging techniques or even not visible at all (BORNSTEIN ET AL. 2011). When applying CBCT, the differentiation of granulomas and cysts is not possible and must be accomplished histopathologically (DE PAULA-SILVA ET AL. 2009; LAUX ET AL. 2000).

In periapical films, the differentiation between a nasopalatine (incisive canal) cyst and a radicular cyst of the maxillary central incisors may be difficult and in films with lateral projection may even be confusing. It is widely known among clinicians that a heart-shaped radiolucency is the typical sign of a nasopalatine cyst (SUTER ET AL. 2007). When a nasopalatine cyst is suspected, a radiographic evaluation should be carried out with at least two projections using periapical film and an occlusal view. In unclear cases and for larger pathological processes, 3-D radiographic examinations are indicated, preferably executed with CBCT (VON ARX & BORNSTEIN 2009; LEMKAMP ET AL. 2006). In 3-D images, the nasopalatine cyst presents itself typically as a cylindrical-shaped extension of the nasopalatine canal (SUTER ET AL. 2011A, 2011B). With the remaining jaw cysts, 3-D imaging

using CBCT may provide important additional information relating to diagnosis, methods of treatment and, in special circumstances, prognosis.

Cyst-Like Lesions

Cyst-like lesions are characterized by a lack of an epithelial lining. They are commonly referred to as pseudocysts. As a rule, these anomalies are also asymptomatic, radiologically well defined (cortical and non-cortical), often discovered incidentally during a routine radiographic examination taken for another purpose (coincidental findings), and they often have an unclear, controversial etiology and pathogenesis (REICHART & PHILIPSEN 2004). Typical lesions as representatives of this group are the aneurysmal bone cyst, Stafne's cyst (lingual mandibular bone cavity) and the solitary bone cyst (simple/traumatic/hemorrhagic/idiopathic bone cyst). If with panoramic radiography a classic kind of Stafne's cyst is shown, no additional 3-D imaging is necessary to elucidate the findings. However, in the case of an anomalous lesion, the use of magnetic resonance imaging (MRI) should be considered, because MRI allows for the visualization and assessment of the soft tissues within a defect. Thus, an exploratory opening can often be avoided (BORNSTEIN ET AL. 2009A; SMITH ET AL. 1985). For all other lesions of this type, a CBCT may provide important information on the exact position of the lesion and its association to adjacent structures. MRI can be used here as a second imaging technique to provide additional information to CBCT.

Application of CBCT in dentoalveolar trauma and root resorptions (A. Filippi and G. Krastl)

Basic Considerations

Tooth injuries in the permanent dentition as well as most post-traumatic complications require a radiographic diagnosis adjunctive to the clinical examination. Generally, panoramic radiography does not adequately display the primarily involved anterior tooth region. Accidents involving the teeth most commonly occur in young children and teenagers. This segment of the population also has an increased biologic risk after exposure to ionizing radiation. For this reason, the indication for CBCT must be taken into much stricter consideration. If considered to be necessary, the size of the FoV should be reduced to an absolute minimum since often only single anterior teeth are involved. Thus, the main criterion for using CBCT is whether the course of therapy is influenced by the outcome and whether the patient is likely to have a clear benefit through the exposure (HARRIS ET AL. 2002; HARRIS ET AL. 2012).

Crown-Root Fractures

In unclear cases, the visualization of the fracture line and knowledge about its course serves to elucidate the possibilities of tooth conservation (BORNSTEIN ET AL. 2009B; COHENCA ET AL. 2007). In the literature, the application of CBCT has often been considered to be necessary in cases of root fractures (COTTON ET AL. 2007; NAIR & NAIR 2007; PATEL & DAWOOD 2007; TERAKADO ET AL. 2000). However, it is clinically important to depict the course of fracture in three dimensions only if the fracture has an intra-alveolar localization. In cervical fractures, a CBCT may help to determine whether the fracture line has a communication with the oral cavity, because this information has an impact on the treatment approach. In these cases, the information from CBCT, the degree of mobility or displacement of the coro-

nal fragment, and the pulp status in the coronal fragment determine the treatment of root fractures.

Root Resorptions

In all cases of replacement resorption, infection-related root resorption, invasive cervical resorption, and internal root resorption, a CBCT is indicated in order to evaluate the possibility of saving the involved tooth (COHENCA ET AL. 2007; COTTON ET AL. 2007; MAINI ET AL. 2008; PATEL & DAWOOD 2007; PATEL ET AL. 2007).

Application of CBCT in implant dentistry (K. Dula and D. Buser)

These guidelines utilize the SAC categorization of difficulty level in oral implantology originally proposed by the Swiss Society of Oral Implantology in 1999, illustrated by BUSER ET AL. (2004) and subsequently adopted by the International Team for Implantology (DAWSON & CHEN 2011). This SAC categorization stands for straightforward, advanced and complex cases and may be used to facilitate the decision-making process of implementing CBCT in implantology. In the opinion of the SADMFR, the classification of cases in the A or C category can generally be regarded as identical with the recommendation for the use of CBCT in the preoperative assessment.

Treatment Planning

Three-dimensional imaging may be necessary in all cases where clinical and standard radiographic findings are insufficient to assess the bone volume with required certainty. Generally, in complex cases, 3-D imaging is indicated if there is considerable risk of harm from the surgical intervention when performed following mere plain film imaging and when sound knowledge of the bone shape is required for an improved esthetic outcome. Whenever possible, CBCT should be preferred to multiple slice computed tomography (MSCT), because CBCT generally requires a lower dose for the same imaging task (CHAU & FUNG 2009; LUDLOW & IVANOVIC 2008; PAUWELS ET AL. 2012) and offers better image quality due to higher resolution (LIANG ET AL. 2010; LOUBELE ET AL. 2008). Its reliability for distance measurements has been demonstrated in several studies (LASCALA ET AL. 2004; LUND ET AL. 2009; MOREIRA ET AL. 2009; WANG ET AL. 2011; WATANABE ET AL. 2010). Treatment planning will, therefore, benefit from 3-D imaging for correct implant placement with regard to function and/or esthetics. It might also be helpful to use special software functions, such as surface-shaded display to visualize the bone structure (MARET ET AL. 2010) or a surgical stent/drilling guide to optimize the result (ALMOG ET AL. 2001; BEHNEKE ET AL. 2012; FORTIN ET AL. 2003; HORWITZ ET AL. 2009; MANDELARIS ET AL. 2010; NG ET AL. 2005; NICKENIG ET AL. 2012; SCHIROLI ET AL. 2011; SCHNITMAN ET AL. 2012; VAN ASSCHE & QUIRYNEN 2010).

Anterior Maxilla

After tooth loss in the anterior maxilla, the bone volume is reduced in most cases due to irregular atrophy in both lateral and vertical dimensions. CBCT may provide important information on the necessity and the possibility of improving the hard tissue situation in order to optimize the soft tissue structure for a better esthetic outcome (MOLEN 2010; TIMOCK ET AL. 2011). CBCT application is highly recommended in all advanced and complex cases. If implant placement is provided in the region of the central incisor, the extent and location of the nasopalatal canal must be known (DULA ET AL. 2001).

Posterior Maxilla

In cases where sinus floor elevation is necessary, CBCT is highly recommended. It is mandatory to obtain information on both bone height and width, on the condition of the Schneiderian membrane, and on the presence of septae and any other individual shape of the sinus floor to decide which surgical technique should be used (NEUGEBAUER ET AL. 2010). If circumstances require the lateral window technique, the lateral sinus wall must be visualized because it varies in size and thickness. Only with this information can the best place for a successful and tissue-sparing antrostomy be determined. In the case of a special sinus pathology, the entire sinus cavity, the natural ostium and the nasal septum must be visualized.

In some cases of a two-staged approach, success of the sinus floor elevation must be ascertained prior to implant placement. Measurements of the elevated bone volume may determine implant selection and position.

Anterior Mandible

In general, the alveolar process is delicate and only large enough to host the front teeth. After tooth loss, vertical and transverse bone atrophy progresses rapidly, leaving a defect which does not allow for immediate implant placement. If the vertical and transverse dimensions are not restored, an unfavorable situation may result for postoperative hygiene. Single- and multi-tooth gaps require an investigation with CBCT in those cases in which clinical findings and standard radiographs do not provide adequate information regarding atrophy and bone volume. In edentulous cases, degrees of atrophy corresponding to Cawood level V or VI (CAWOOD & HOWELL 1988) require 3-D imaging to obtain information on the bone volume in general, and in particular on the extent of the submental fossa and the mental spine (DULA ET AL. 2001).

Posterior Mandible

In patients with poor bone mineralization, high-quality CBCT of the mandible may help to visualize the mandibular canal (ANGELOPOULOS ET AL. 2008). There are cases where bone width in the premolar and molar region must be determined (FREI ET AL. 2004) because severe undercuts of the submandibular fossa may result in serious complications, such as severe bleeding (LABODA 1990; MASON ET AL. 1990; MORDENFELD ET AL. 1997). However, when well-exposed plain film radiographs are carefully studied, the mylohyoid line and the beginning of the submandibular fossa can often be identified.

Follow-up

Implant patients should not be routinely followed-up with CBCT. Metal artifacts are observed at the interface between implant and bone, mesially and distally to the implant, impeding the evaluation of osseointegration (SCHULZE ET AL. 2011; SCHULZE ET AL. 2010; SIEWERDSEN & JAFFRAY 2001). SADMFR states that CBCT should be specifically avoided for the purpose of peri-implantitis diagnosis.

On the buccal and oral parts of implants, the images are generally not or at least less destroyed by metal artifacts, which generally allows for the visualization of the bone adjacent to these implant surfaces. However, the buccal bone wall, which is of greater interest, is often only a more or less fine line, which is hardly represented (PATCAS ET AL. 2012). Distance measurements of thin bone structures depend on the spatial resolution and the linear accuracy of the CBCT machine involved (MOLEN 2010).

Consequently, erroneous measurements are likely for many machines. Due to the sufficient accuracy of measuring the buccal bone wall with the periodontal probe, the use of CBCT to study the buccal bone wall can generally not be justified in routine practice and should therefore be left for research purposes.

Application of CBCT for odontogenic and implantogenic sinus diseases (J.-Th. Lambrecht and K. Dula)

The diagnosis, treatment and evaluation of rhinosinusitis and odontogenic sinusitis are traditionally accompanied by visual examination and radiographic imaging.

Odontogenic sinusitis is for the most part caused by a bacterial infection and, less commonly, by mycosis. It forms through an infection transferred from the teeth, a perforation between the oral cavity and the sinuses or through a foreign body entering the sinus from the oral cavity. Connections between the mouth and the sinuses can be found with the aid of a sinus probe instrument, and foreign bodies can normally be discovered as a radiopacity on a radiograph.

The two-dimensional radiograph is inferior to the tomographic image for these purposes. Therefore, in otolaryngology CT has become the standard tool of imaging for sinus infections (CAMPBELL ET AL. 2009; MIRACLE & MUKHERJI 2009).

CBCT allows for new diagnostic possibilities in detecting odontogenic sinusitis (ZOUMLAN ET AL. 2009). Ease of positioning, decreased radiation exposure and simpler patient education are additional advantages of this tool.

Application of CBCT in Odontogenic Sinusitis

Not included in this discussion are infections involving cleft lip and palate (STUEHMER ET AL. 2008), previously operated sinuses after Caldwell-Luc, cysts in the sinus areas, and neoplasms or specific changes involving hereditary diseases or atypical post-operative anatomical malpositions. These cases often require hospitalization and, therefore, CT is warranted when CBCT is not available.

If the diagnosis of odontogenic sinusitis with CBCT is indicated, it must be carried out together with an assessment of the sinus mucosa (RITTER ET AL. 2011). Since CBCT does not work with a grey level value scale, such as the Hounsfield scale, only a general statement on the condition of a mucosal swelling can be made. Odontogenic sinusitis, however, always involves an inflammatory swelling of the Schneiderian membrane. Therefore, a differentiated soft tissue visualization, as it is possible in CT, is not required (PATEL ET AL. 2007). However, the non-specific soft tissue diagnosis of the CBCT does require a CBCT device with sufficient resolution. Relating to exposure technique, the following requirements must be fulfilled in sinus diagnosis: the FoV has to be set in order to fully represent the entire sinus with the natural ostium, the nasal septum, and the inferior and the middle turbinates of the nasal cavity. The image quality must allow for the evaluation of soft tissue swellings. In sinusitis caused by implants (implantogenic sinusitis), the perforation point into the maxillary sinus or the nasal cavity must be clearly visualized. In sinusitis of periodontal origin (periodontogenic sinusitis), the periodontal and periapical structures must also be clearly visible.

Application of CBCT in orthodontics (P. Pazera and Ch. Katsaros)

In orthodontics, 3-D imaging may be necessary for treatment planning. However, CBCT imaging is only justified if the ex-

pected additional information is therapeutically relevant compared with conventional orthodontic 2-D imaging. Most of the orthodontic patients are children, adolescents or young adults. To take maximum advantage of the ALARA principle it is, therefore, important to select the smallest field of view and to check the volume centering. After the exposure, the entire volume must be systematically screened for normal, pathological and incidental findings (PAZERA ET AL. 2011).

Thus, CBCT might be used in orthodontics (also as part of interdisciplinary treatment) after an individual risk-benefit assessment in specific cases, which include: retained, impacted, dysplastic, displaced or supernumerary teeth, root resorption, unfavourable dentoalveolar anatomy, craniofacial malformation, and bony asymmetries (BJERKLIN & ERICSON 2006; KAU ET AL. 2005; LAI ET AL. 2012; LIU ET AL. 2007; LIU ET AL. 2008; MOSSAZ ET AL. 2014; OHTANI ET AL. 2012; PAZERA ET AL. 2012; SUOMALAINEN ET AL. 2014).

Due to the higher radiation dose, CBCT should not currently be applied on a routine basis for the following purposes: as a standard imaging procedure replacing panoramic radiography and/or lateral cephalograms (HALAZONETIS 2012); for segmentation of digital 3-D models replacing dental cast impressions; bone volume and space evaluation for the placement of bone anchorage devices; 3-D cephalometry in standard orthodontic cases.

Whenever possible, CBCT should be chosen instead of MSCT because of the lower radiation dose.

Application of CBCT in the evaluation of the temporomandibular joints (D. Ettlin and J. Türp)

CBCT allows for the imaging of the bony components of the temporomandibular joints (TMJs) without superimposition and distortion (BARGHAN ET AL. 2010). Compared with panoramic radiography and (linear/spiral) tomography of the TMJs, CBCT offers a significantly higher diagnostic accuracy (HONEY ET AL. 2007). Therefore, its strength lies in the detection of bony changes of the articular condyle, the temporal fossa, and the articular eminence, such as destructive-erosive remodeling, deformations, flattening of the articular surfaces, osteophyte formation, subchondral sclerosis and ankylosis (ALEXIOU ET AL. 2009; ALKHADER ET AL. 2010). From a clinical-diagnostic viewpoint, however, a critical disadvantage of CBCT is the lack of intra- and peri-articular soft tissue visualization, such as articular disc, joint fluids or capsule. MRI is more suitable for this purpose, and usually it also depicts calcified tissues with sufficient diagnostic detail (KAEPLER 2010).

The main pillars of TMJ diagnosis are (a) a comprehensive patient history, which considers both somatic and psychosocial aspects, and (b) the clinical examination. With the few exceptions specified below, additional information obtained by CBCT images does not result in the modification of therapeutic decisions in patients with TMJ problems (PETERSSON 2010). Hence, CBCT is not indicated for TMJ-related routine diagnosis in daily practice. It should be noted that other radiological methods, such as panoramic radiography, are similarly inappropriate for a meaningful therapy-oriented assessment (CROW ET AL. 2005; SCHMITTER ET AL. 2006).

If a TMJ tumor or fracture related to craniocervical trauma is suspected, the decision to obtain a CBCT or MRI is to be made in a setting that can offer adequate therapy (KAEPLER 2010).

TMJ-related complaints that are resistant to therapy (continuously limited mandibular mobility, persistent TMJ pain,

loud TMJ noises that disturb the patient's quality of life) warrant a referral to a clinical setting capable of offering comprehensive therapy that includes addressing psychosocial aspects. In cases of clinical diagnostic uncertainty, the decision to obtain a CBCT or other imaging modality (e.g. MRI) is to be made there.

Application of CBCT in maxillofacial traumatology (H.-Th. Luebbbers)

CBCT has such a broad indication in cranio-maxillofacial traumatology that indications given here can only be very general (Tab. IV).

In traumas where soft tissues must not be analyzed in detail, CBCT must be preferred (a) to MSCT because of the lower radiation dose and (b) to MRI because of better visualization of the bone (KAEPLER 2010; SHINTAKU ET AL. 2009). These situations generally apply to complex midfacial and mandibular traumas with no signs of intracerebral hemorrhage. In the future, planning datasets for intraoperative surgery and postoperative control will probably become very promising applications for CBCT for exactly the same reasons. If radiopaque foreign bodies must be diagnosed, such as in gunshot wounds, the CBCT may be superior to MSCT due to less artifacts (STÜHMER ET AL. 2008). How-

ever, acute bullet wounds regularly require soft tissue imaging with detailed information with regard to major vessels, which CBCT cannot reveal since CBCT in combination with angiography (AngioCBCT) is not yet established.

Application of CBCT in benign and malignant tumors (H.-Th. Luebbbers)

CBCT can nowadays be considered as the method of choice for examining benign tumors of the jaws because of the excellent representation of hard tissues and low radiation dose. Since, in most cases, benign bone tumors of the jaws are of circumscribed size, CBCT can be applied with smaller volumes adapted to the size of the tumor.

For the diagnosis of malignant bone tumors of the jaw region, MSCT must be applied instead in order to assess possible soft tissue infiltration and lymph node involvement. In particular for tumor staging based on X-ray images, the use of MSCT with a contrast medium is imperative. Current diagnostic methods for malignant tumors are supplemented with MRI, especially for soft tissue diagnosis. Recently it has been proposed to use CBCT for patients with squamous cell carcinoma in order to assess the extent of bone infiltration (CLOSMANN & SCHMIDT 2007; MOMIN ET AL. 2009).

Tab. IV SADMFR general recommendations for the use of CBCT in cranio-maxillofacial trauma

General situation	CBCT indicated	CBCT not indicated
Isolated cranio-maxillofacial trauma with need for 3-D imaging	No suspicion of intracerebral lesion or any other indication for soft tissue imaging (e.g. suspected lesions to major vessels)	Suspicion of intracerebral lesion or other indication for soft tissue imaging (could be used in combination with MRI)
Prior to open reduction internal fixation	<ul style="list-style-type: none"> - Complex fractures of all kinds (POHLENZ ET AL. 2007, 2008; SCHOEN ET AL. 2008) - Collum fractures (SCHOEN ET AL. 2008) 	If conventional radiograph provides clear information (DRAGE & SIVARAJASINGAM 2009; SCHOEN ET AL. 2008; ZIZELMANN ET AL. 2007)
Orbital wall fractures	No suspicion of soft tissue trauma, e.g. muscle incarceration, ophthalmic nerve trauma or retrobulbar hemorrhage (DRAGE & SIVARAJASINGAM 2009; ZIZELMANN ET AL. 2007)	Suspicion of soft tissue trauma, e.g. muscle incarceration (DRAGE & SIVARAJASINGAM 2009), ophthalmic nerve trauma or retrobulbar hemorrhage (can be combined with MRI)
Clinical situation with inconclusive conventional radiographs	Only if an influence on treatment is expected	No influence on treatment expected
Foreign body	If radiopaque CBCT is suggested for identification of exact location (EGGERS ET AL. 2007; GROBE ET AL. 2009; POHLENZ ET AL. 2007, 2008; SADIQ ET AL. 2010; STUEHMER ET AL. 2008)	Foreign body is not radiopaque, use MRI (EGGERS ET AL. 2007)
Intraoperative imaging (3-D c-arm, CBCT)	<ul style="list-style-type: none"> - For immediate control and revision of reposition and retention of complex fractures (GROBE ET AL. 2009; POHLENZ ET AL. 2007) (instead of postoperative 3-D imaging) - To reduce use of anesthesia prior to 3-D imaging, e.g. in young children with clear indication for surgery based on 2-D imaging but requiring 3-D imaging in order to carry out the procedure (POHLENZ ET AL. 2007) 	If intraoperative surgical navigation is available, the need for intraoperative 3-D imaging may be reduced
Intraoperative computer navigation (LUEBBERS ET AL. 2008, 2010A, 2010B, 2011)	To obtain an extra dataset if needed	If an existing dataset of a different modality can be used
Patient-specific models or implants (FERNANDES & DIPASQUALE 2007; QUERESHY ET AL. 2008)	If an extra dataset is needed	If an existing dataset of different modality can be used

In the follow-up of benign bone tumors of the jaw, the use of CBCT has the same advantages as during the initial assessment of these tumors (NAKAGAWA ET AL. 2002). Because of the undifferentiated soft tissue representation in the CBCT, MSCT imaging must be applied for reevaluations of malignant bone tumors.

For planning reconstructive surgery after tumor surgery, CBCT may be considered. However, MSCT allows for the possibility of operative planning with a very precise surface-shaded display and model reconstruction through application of the Hounsfield scale, which is not yet achievable in CBCT technology. In general, CBCT can be considered in cases of malignant tumors whenever there is no doubt about the tumor (or its possible relapse) and questions of mere reconstructive surgery are addressed. Otherwise, the imperative soft tissue imaging has to be performed with another modality, preferably with MRI. Listed in Table V are indications and contraindications for CBCT as well as rationale for the implementation of MSCT and MRI in the assessment of maxillofacial tumors.

Discussion

Challenges facing the use of CBCT

CBCT is the first CT-like spatial imaging technique in three planes developed and intended for dental medicine (MOZZO ET AL. 1998). It has been accepted and rapidly integrated by the profession because the diagnosis of various conditions can be highly improved by better information and higher precision. For treatment planning in implantology, for instance, practitioners are increasingly disposed to apply 3-D imaging due to the supposed advantage of obtaining superior results in the final treatment outcome.

However, CBCT applies a considerable radiation dose to patients. Hence, patient safety is a compelling reason to seriously discuss how the future of CBCT should evolve in dentistry. In oral surgery, for instance, the frequency of implant surgeries is continuously rising. Because CBCT is used particularly in oral implantology, it may well be assumed that the frequency of CBCT images will increase with the increasing number of oral implant surgeries. For example, the website of the German

Association of Implantology specifies that in Germany the number of incorporated implants has increased by 40% since 2006 (<http://www.dginet.de/web/dgi/warum>). According to The Swiss Implant Foundation (<http://www.implantatstiftung.ch/index.html>), this development can equally be observed in Switzerland. Convincing numbers can best illustrate the hypothesis made above: in 2004, three CBCT machines were accredited in Switzerland, two of which were located in university dental schools and one in a private practice. By October 2013, 279 CBCT machines were accredited, six in university dental schools and 273 in private practice, which corresponds to a ratio of approximately 28,500 inhabitants to one CBCT machine.

By providing 3-D information, CBCT imaging is nowadays very often linked with the progress of research in the various specialties of dentistry. Mutual stimulation can best be seen in oral implantology, as problems can be studied and new surgical procedures can be realized through the application of this new technology. The transfer of this knowledge to everyday patient treatment led to a paradigm shift with regard to the answers to therapeutic problems. However, this paradigm shift implies more dose to the patient for two reasons: universities are increasingly applying CBCT technology during both daily work and research, and their representatives illustrate many cases with CBCT images in conferences, publications and continuing education courses. This in turn motivates the private practitioner to use the CBCT technology on their patients, but unfortunately often less critically in terms of justification than do the universities. A particularly critical point is that most users begin with insufficient or without any education in image reading and diagnosis, and far too few colleagues specialized in dentomaxillofacial radiology are available to provide adequate training.

Challenges in estimating the collective and the individual risk

In medicine, the effects of high and low doses of radiation are often discussed, whereby a low dose of radiation exposure is understood to be below 100 mSv. This value has been defined in a report from the National Academy of Sciences/National

Tab. V SADMFR general recommendations for the use of CBCT in head and neck oncology

General situation	CBCT indicated	CBCT not indicated
Bone invasion of soft tissue malignoma in dispute (CLOSMANN & SCHMIDT 2007; MOMIN ET AL. 2009; ZIEGLER ET AL. 2002)	Suspected invasion through inner cortical layer Suspected invasion of mandibular canal	Amount of bone invasion is cleared by other (necessary) imaging techniques, such as MRI or MDCT
Intraosseous tumors (NAKAGAWA ET AL. 2002)	– Structure and localization of lesion – Prior to biopsy (surgical access planning) – Follow-up controls of lesion size (e.g. central giant cell granuloma under systemic therapy)	Need for soft tissue evaluation (could however be used in combination with MRI)
CBCT in combination with angiography	Only in clinical studies	Clinical routine
Patient-positioning CBCT prior to radiotherapy session (OSMAN ET AL. 2009; XU ET AL. 2008)	Only in clinical studies	Clinical routine
Intraoperative computer navigation (LUEBBERS ET AL. 2008, 2010A, 2010B, 2011)	If an additional dataset is needed	If an existing dataset of different modality can be utilized, e.g. by surface laser registration
Patient-specific models or implants (FERNANDES & DIPASQUALE 2007; QUERESHY ET AL. 2008)	If an extra dataset is needed	If an existing dataset of a different modality can be utilized

Research Council on the “Biological Effects of Ionizing Radiation” (BEIR VII 2006, ROYAL 2008). The upper limit of 100 mSv was chosen, since at this value the expected incidence of radiation-induced cancers is equal to the overall incidence of cancer occurring in the general population. BEIR VII (2006) also confirms once again that the “linear-no-threshold” model is currently the best model for determining the risk of radiation exposure in the field of radiation protection. Using this model, it is assumed that there is no threshold dose for inducing biologic harm and that the curve describing the radiation damage increases linearly in direct relationship to the increased dose. Therefore, a consensus exists that even the smallest dose of radiation has the potential to cause cancer. Nonetheless, it is very difficult, if not impossible, to relate an incidence of cancer to a radiation exposure that falls under the value of 100 mSv.

The largest contribution to the collective dose of the population not emanating from natural radiation sources is caused by medical X-ray diagnosis. This in turn is essentially due to the use of CT, which seems to have exponentially increased in the last 20 years. This can be shown with numbers from different countries (AROUA ET AL. 2007; BRENNER 2010; CATUZZO ET AL. 2010; SCHAUER & LINTON 2009). In the United States of America, for instance, the per capita dose for medical exposures (not including dental or radiotherapy) has increased from 0.53 mSv in 1982 to approximately 3.0 mSv in 2006, with 1.46 mSv from CT alone (METTLER ET AL. 2008). For Switzerland the per capita dose for medical exposures (not including dental or radiotherapy) was 1.0 mSv in 1998 (AROUA ET AL. 2002) and 1.2 mSv in 2008 (SAMARA ET AL. 2012). For Germany, this value was 1.5 mSv in 1996 and 1.8 mSv in 2010 (<http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeIdent=2459>).

The radiation burden as well as the biological risk of a single radiological examination is generally measured with and on the basis of the effective dose. However, questions relating to the use of the effective dose are complex. In particular, the applicability of said basis in determining the individual risk of an exposure to ionizing radiation is considered to be very limited. It has been introduced by the INTERNATIONAL COMMISSION OF RADIOLOGICAL PROTECTION (ICRP 1978) in order to estimate the radiation exposure from external and internal radiation sources to the whole body on the basis of summed organ doses and to determine appropriate limits in radiation protection. Therefore, it is considered a tool for risk management or control, but not for risk assessment. Value assessments for the effective dose are based on the utilization of referenced data of populations, exposure parameters and evaluation factors, averaged over the entire population. This explains why the effective dose is not suitable for conducting individual risk assessment (BRENNER 2008; MARTIN 2007; MCCOLLOUGH ET AL. 2010). In dentistry, for instance, only small radiation fields are used, which is why only a very small part of the body is exposed to a significant dose. Using the example of dentistry, it becomes quite clear that the effective dose, which is based on a whole body concept, is really of limited value. This is true not only for dentomaxillofacial radiology, but also for practically all areas of diagnostic radiology. It leads in all probability to an underestimation of the biological risk particularly in dentomaxillofacial radiology since only a relatively small portion of radiosensitive organs or tissues reside within the exposed field. Thus, when calculations are made with the effective dose in dentomaxillofacial radiology, the local dose, which is in part a very high dose and quite comparable with local doses applied in medicine, is distributed mathemati-

cally over the whole body and, therefore, minimized. Nonetheless, the effective dose can be usefully applied when different diagnostic procedures need to be compared, since differences in radiation exposure between different procedures can be relatively well determined in this way.

Up to now, there has been a commonly held perception that CBCT – as well as dental radiography in general – delivers only a small radiation dose. This relates to the problem in the way the effective dose is calculated. The different values for the effective dose reported in the study of LUDLOW & IVANOVIC (2008) arise, precisely, because of the different way of calculating according to the recommendations of ICRP 60 (1991) or ICRP 103 (2007). The values for the effective dose calculated with ICRP 103 are much higher because ICRP 103 takes into account an organ dose to and a weighting factor attributed to the salivary glands and the brain, and it includes the oral mucosa in the remainder tissues (tissues which had not been considered in ICRP 60). For the same reason, Pauwels (PAUWELS ET AL. 2012) found such a high contribution to the effective dose from the remainder tissues and the salivary glands.

LUDLOW & IVANOVIC (2008) measured in their study an effective dose in a spectrum between 0.068 mSv and 1.073 mSv, whereby most machines operated with values between 0.100 mSv and 0.600 mSv. In a study using current machines, PAUWELS ET AL. (2012) measured values between 0.019 mSv and 0.368 mSv, whereby devices with middle to large FoV lie between 0.028 and 0.368 mSv with a mean value of 0.106 mSv. By comparison, panoramic radiography has a dose value of about 0.025 mSv and CT of the jaw a value in the range of 0.500 mSv to 0.900 mSv (DULA ET AL. 2001; LUDLOW & IVANOVIC 2008). In computed tomography, if the problem is addressed by choosing adjusted exposition parameters, then the dose may be reduced to a level comparable to values of CBCT (DULA ET AL. 1996; KYRIAKOU ET AL. 2011). The large differences in the values of measured CBCT doses are a result of the large differences in the available devices and the differences in the size of the radiation field. The increasing frequency of exposures, the choice of larger exposure volumes and newer computation methods for determining the effective dose all lead to the fact that dentistry will play an ever-increasing role in the increasing radiation exposure of the population through medical X-ray examinations. It seems that the increase in reliability of diagnostics and the resulting increase in health today may lead to greater uncertainty regarding the origin and frequency of fatal diseases in the future.

As has been postulated several times by all authors of this publication, the SADMFR as a whole supports the concept that CBCT, based on its superior diagnostic qualities, should be applied in cases where it is warranted. However, the SADMFR stipulates emphatically that training at a high level and establishment of expertise with an emphasis on radiation protection be created. This framework would promote the motivation for all trained colleagues to avoid CBCT in cases where diagnosis and therapy are possible through simpler imaging methods. In order to strengthen the self-confidence of these colleagues on this point and to establish patient trust in a trained colleague, a confirmation should be added on the certificate of training that the attending dentist complies with and adheres to these guidelines and strives, whenever possible, to limit exposure to conventional radiographic diagnosis. This and, perhaps, even the deliberate renouncement to a CBCT machine could have the potential to establish a new kind of quality label for a private practice with regard to radiation protection.

Résumé

La tomographie volumique numérique (TVN) (en anglais *Cone Beam Computed Tomography*) est une technique tomographique introduite en 1998 et destinée à la médecine dentaire. À l'instar de la tomodensitométrie en médecine, on peut s'attendre à ce que la TVN s'imposera à son tour et avec le même succès dans le domaine du diagnostic dentaire. Tout comme le recours à la tomodensitométrie dans le diagnostic radiologique en médecine est responsable d'une exposition accrue de la population suisse aux rayons ionisants, la multiplication des examens à l'aide de la TVN est appelée à entraîner à son tour une forte augmentation de l'exposition subie par les patients en médecine dentaire.

Préoccupée par le recours croissant et indiscriminé à la TVN, la Société suisse de radiologie dentaire et maxillo-faciale a convoqué en 2011 une première conférence de consensus dans le but de formuler des indications en matière de tomographie volumique et d'en tirer des lignes directrices. Les domaines abordés lors de cette première conférence de consensus ont été la chirurgie orale et maxillaire, les dysfonctions et pathologies des articulations temporo-mandibulaires et l'orthodontie, principaux champs d'application de cette technique. La conférence s'adressait aux utilisateurs les plus massifs et les plus expérimentés.

Plus généralement, ces lignes directrices réclament une utilisation très restreinte de la tomographie volumique numérique. Le principal critère justifiant le recours à cette technique est l'acquisition d'un supplément d'information pertinent pour le traitement et d'une utilité directe et significative pour le patient. Elles stipulent que tous les utilisateurs doivent avoir suivi une formation structurée de haut niveau, telle que la propose d'ores et déjà la Société suisse de radiologie dentaire et maxillo-faciale.

Zusammenfassung

Die digitale Volumentomografie (DVT, engl. *Cone-Beam Computed Tomography*) ist ein erstmals 1998 vorgestelltes, für die Zahnmedizin gedachtes radiologisches Schnittbildverfahren, wie es in vergleichbarer Weise in der Medizin von der Computertomografie (CT) her bekannt ist. Es ist abzusehen, dass sich die DVT mit einem ebenfalls mit der CT vergleichbaren diagnostischen Erfolg durchsetzen wird. So wie die CT für eine stark ansteigende Strahlenbelastung der Bevölkerung durch medizinische Röntgendiagnostik verantwortlich gemacht werden muss, wird auch die Zunahme der DVT-Untersuchungen mit einer erheblich zunehmenden Dosisbelastung unserer Patienten seitens der Zahnmedizin einhergehen.

Aus der wachsenden Besorgnis über eine rasch und unkritisch zunehmende DVT-Anwendung berief die Schweizerische Gesellschaft für Dentomaxillofaziale Radiologie im Jahr 2011 eine Konsensuskonferenz ein, um Indikationen zur DVT zu formulieren, die als Leitlinien benutzt werden können. An dieser Zusammenkunft, zu der die zum damaligen Zeitpunkt wichtigsten und erfahrensten Anwender der DVT in der Schweiz gebeten wurden, wurden die Bereiche Oral- und Kieferchirurgie, die Dysfunktionen und Erkrankungen der Kiefergelenke und die Kieferorthopädie behandelt.

Generell wird ein betont restriktiver Einsatz der DVT gefordert. Rechtfertigendes Hauptkriterium für die DVT ist, dass eine therapierelevante Mehrinformation durch ihren Einsatz erwartet werden muss, sodass ein direkter, bedeutender Nutzen für den Patienten resultiert. Von allen Anwendern wird die Absolvierung einer strukturierten Ausbildung auf hohem Niveau gefordert, wie sie von der Schweizerischen Gesellschaft für Dentomaxillofaziale Radiologie angeboten wird.

References

- ADVIES VAN DE HOGE GEZONDHEIDSRaad NR. 8705: Dentale Cone Beam Computed Tomography (Belgian Guidelines). Brussel: Hoge Gezondheidsraad, www.hgr-css.be http://www.health.belgium.be/internet2Prd/groups/public/@public/@shc/documents/ie2divers/19068321.pdf (2011), [accessed on July 26, 2013]
- ALEXIOU K, STAMATAKIS H, TSIKLAKIS K: Evaluation of the severity of temporomandibular joint osteoarthritic changes related to age using cone beam computed tomography. *Dentomaxillofac Radiol* 38: 141–147 (2009)
- ALKHADER M, OHBAYASHI N, TETSUMURA A, NAKAMURA S, OKOCHI K: Diagnostic performance of magnetic resonance imaging for detecting osseous abnormalities of the temporomandibular joint and its correlation with cone beam computed tomography. *Dentomaxillofac Radiol* 39: 270–276 (2010)
- ALMGO D M, TORRADO E, MEITNER S W: Fabrication of imaging and surgical guides for dental implants. *Prosthet Dent* 85: 504–508 (2001)
- ANGELOPOULOS C, THOMAS S L, HECHLER S, PARISSIS N, HLAVACEK M: Comparison between digital panoramic radiography and cone-beam computed tomography for the identification of the mandibular canal as part of presurgical dental implant assessment. *J Oral Maxillofac Surg* 66: 2130–2135 (2008)
- AROUA A, BURNAND B, DECKA I, VADER J P, VALLEY J F: Nation-wide survey on radiation doses in diagnostic and interventional radiology in Switzerland in 1998. *Health Physics* 83: 46–55 (2002)
- AROUA A, TRUEB P, VADER J P, VALLEY J F, VERDUN F R: Exposure of the Swiss population by radiodiagnostics: 2003 review. *Health Physics* 92: 442–448 (2007)
- BARGHAN S, MERRILL R, TETRADIS S: Cone beam computed tomography imaging in the evaluation of the temporomandibular joint. *J Calif Dent Assoc* 38: 33–39 (2010).
- BATAINEH A B: Sensory nerve impairment following mandibular third molar surgery. *J Oral Maxillofac Surg* 59: 1012–1017 (2001)
- BEHNEKE A, BURWINKEL M, BEHNEKE N: Factors influencing transfer accuracy of cone beam CT-derived template-based implant placement. *Clin Oral Implants Res* 23: 416–423 (2012)
- BJERKLIN K, ERICSON S: How a computerized tomography examination changed the treatment plans of 80 children with retained and ectopically positioned maxillary canines. *Angle Orthod* 76: 43–51 (2006)
- BLAESER B F, AUGUST M A, DONOFF R B, KABAN L B, DODSON T B: Panoramic radiographic risk factors for inferior alveolar nerve injury after third molar extraction. *J Oral Maxillofac Surg* 61: 417–421 (2003).
- BORNSTEIN M M, LAUBER R, SENDI P, VON ARX T: Comparison of periapical radiography and limited cone-beam computed tomography in mandibular molars for analysis of anatomical landmarks before apical surgery. *J Endod* 37: 151–157 (2011)
- BORNSTEIN M M, WIEST R, BALSIGER R, REICHT P A: Anterior Stafne's bone cavity mimicking a periapical lesion of endodontic origin: report of two cases. *J Endod* 35: 1598–1602 (2009a)
- BORNSTEIN M M, WOLNER-HANSEN A B, SENDI P, VON ARX T: Comparison of intraoral radiography and limited cone beam computed tomography for the assessment of root-fractured permanent teeth. *Dental traumatol* 25: 571–577 (2009b)
- BRENNER D J: Effective dose: a flawed concept that could and should be replaced. *Br J Radiol* 81: 521–523 (2008)
- BRENNER D J: Should we be concerned about the rapid increase in CT usage? *Rev Environ Health* 25: 63–68 (2010)
- BUSER D, MARTIN W, BELSER U C: Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. *Int J Oral Maxillofac Implants* 19 Suppl: 43–61 (2004)
- CAMPBELL P D, JR., ZINREICH S J, AVGUN N: Imaging of the paranasal sinuses and in-office CT. *Otolaryngol Clin North Am* 42: 753–764 (2009)
- CATUZZO P, AIMONETTO S, ZENONE F, FANELLI G, MARCHISIO P, MELONI T, PASQUINO M, TOFANI S: Population exposure to ionising radiation from CT examinations in Aosta Valley between 2001 and 2008. *Br J Radiol* 83: 1042–1051 (2010)
- CAWOOD J I, HOWELL R A: A classification of the edentulous jaws. *Int J Oral Maxillofac Surg* 17: 232–236 (1988)

- CAWSON R A, ODELL E W:** *Cawson's Essentials of Oral Pathology and Oral Medicine*. Seventh Edition. Churchill Livingstone, Edinburgh, pp 102-120 (2002)
- CHAU A C, FUNG K:** Comparison of radiation dose for implant imaging using conventional spiral tomography, computed tomography, and cone-beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 107: 559-565 (2009)
- CLOSMANN J J, SCHMIDT B L:** The use of cone beam computed tomography as an aid in evaluating and treatment planning for mandibular cancer. *J Oral Maxillofac Surg* 65: 766-771 (2007)
- COHENCA N, SIMON J H, ROGES R, MORAG Y, MALFAZ J M:** Clinical indications for digital imaging in dentoalveolar trauma. Part 1: traumatic injuries. *Dental Traumatol* 23: 95-104 (2007)
- COMMITTEE TO ASSESS HEALTH RISKS FROM EXPOSURE TO LOW LEVELS OF IONIZING RADIATION: BEIR VII - Phase 2.** National Research Council. Washington D.C. (2006)
- COTTON T P, GEISLER T M, HOLDEN D T, SCHWARTZ S A, SCHINDLER W G:** Endodontic applications of cone-beam volumetric tomography. *J Endod* 33: 1121-1132 (2007)
- CROW H C, PARKS E, CAMPBELL J H, STUCKI D S, DAGGY J:** The utility of panoramic radiography in temporomandibular joint assessment. *Dentomaxillofac Radiol* 34: 91-95 (2005)
- DA SILVA P F, VIZZOTTO M B, LIECKE G S, DA SILVA H L, MONTAGNER F:** Detection of vertical root fractures by conventional radiographic examination and cone beam computed tomography - an in vitro analysis. *Dent Traumatol* 29: 41-46 (2013)
- DAWSON A, CHEN S:** *The SAC Classification in Implant Dentistry*. Quintessenz, Berlin (2011)
- DE PAULA-SILVA F W, WU M K, LEONARDO M R, DA SILVA L A, WESSELINK P R:** Accuracy of periapical radiography and cone-beam computed tomography scans in diagnosing apical periodontitis using histopathological findings as a gold standard. *J Endod* 35: 1009-1012 (2009)
- DRAGE N A, SIVARAJASINGAM V:** The use of cone beam computed tomography in the management of isolated orbital floor fractures. *Br J Oral Maxillofac Surg* 47: 65-66 (2009)
- DULA K, MINI R, VAN DER STELT P F, BUSER D:** The radiographic assessment of implant patients: decision-making criteria. *Int J Oral Maxillofac Implants* 16: 80-89 (2001)
- DULA K, MINI R, VAN DER STELT P F, LAMBRECHT J T, SCHNEEBERGER P, BUSER D:** Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible. *Eur J Oral Sci* 104: 503-510 (1996)
- DULA K, SANDERINK G, VAN DER STELT P F, MINI R, BUSER D:** Effects of dose reduction on the detectability of standardized radiolucent lesions in digital panoramic radiography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 86: 227-233 (1998)
- EGGERS G, WELZEL T, MUKHAMADIEV D, WORTCHE R, HASSFELD S, MUHLING J:** X-ray-based volumetric imaging of foreign bodies: a comparison of computed tomography and digital volume tomography. *J Oral Maxillofac Surg* 65: 1880-1885 (2007)
- EUROPEAN COMMISSION RADIATION PROTECTION N° 172:** Evidence Based Guidelines on Cone Beam CT for Dental and Maxillofacial Radiology. Luxembourg: Office for Official Publications of the European Communities (2012). Available at: http://ec.europa.eu/energy/nuclear/radiation_protection/publications_en.htm [accessed on July 26, 2013]
- FARMAN A G:** ALARA still applies. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 100: 395-397 (2005)
- FERNANDES R, DiPASQUALE J:** Computer-aided surgery using 3D rendering of maxillofacial pathology and trauma. *Int J Med Robot* 3: 203-206 (2007)
- FORTIN T, BOSSON J L, COUDERT J L, ISIDORI M:** Reliability of preoperative planning of an image-guided system for oral implant placement based on 3-dimensional images: an in vivo study. *Int J Oral Maxillofac Implants* 18: 886-893 (2003)
- FREI C, BUSER D, DULA K:** Study on the necessity for cross-section imaging of the posterior mandible for treatment planning of standard cases in implant dentistry. *Clin Oral Implants Res* 15: 490-497 (2004)
- GROBE A, WEBER C, SCHMELZLE R, HEILAND M, KLATT J, POHLENZ P:** The use of navigation (BrainLAB Vector vision 2) and intraoperative 3D imaging system (Siemens Arcadis Orbic 3D) in the treatment of gunshot wounds of the maxillofacial region. *Oral Maxillofac Surg* 13: 153-158 (2009)
- GUERRERO M E, NACKAERTS O, BEINSBERGER J, HORNER K, SCHOENAERS J, JACOBS R:** Inferior alveolar nerve sensory disturbance after impacted mandibular third molar evaluation using cone beam computed tomography and panoramic radiography: a pilot study. *J Oral Maxillofac Surg* 70: 2264-2270 (2012)
- HALAZONETIS D J:** Cone-beam computed tomography is not the imaging technique of choice for comprehensive orthodontic assessment. *Am J Orthod Dentofac Orthoped* 141: 403-407 (2012)
- HALL E J, BRENNER D J:** Cancer risks from diagnostic radiology. *Br J Radiol* 81: 362-378 (2008)
- HANEY E, GANSKY S A, LEE J S, JOHNSON E, MAKI K, MILLER A J, HUANG J C:** Comparative analysis of traditional radiographs and cone-beam computed tomography volumetric images in the diagnosis and treatment planning of maxillary impacted canines. *Am J Orthod Dentofac Orthoped* 137: 590-597 (2010)
- HARRIS D, BUSER D, DULA K, GRONDAHL K, HARIS D, JACOBS R, LEKHOLM U, NAKIELNY R, VAN STEENBERGHE D, VAN DER STELT P:** E.A.O. guidelines for the use of diagnostic imaging in implant dentistry. A consensus workshop organized by the European Association for Osseointegration in Trinity College, Dublin. *Clin Oral Implants Res* 13: 566-570 (2002)
- HARRIS D, HORNER K, GRONDAHL K, JACOBS R, HELMROT E, BENIC G I, BORNSTEIN M M, DAWOOD A, QUIRYNEN M:** E.A.O. guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the European Association for Osseointegration at the Medical University of Warsaw. *Clin Oral Implants Res* 23: 1243-1253 (2012)
- HASHIMOTO K, ARAI Y, IWAI K, ARAKI M, KAWASHIMA S, TERAKADO M:** A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 95: 371-377 (2003)
- HEALTH PROTECTION AGENCY:** Recommendations for the design of X-ray facilities and quality assurance of dental Cone Beam CT (Computed tomography) systems. HPA-RPD-065, Holroyd JR and Walker A (United Kingdom Guidelines). Chilton: Health Protection Agency (2010a)
- HEALTH PROTECTION AGENCY:** Guidance on the Safe Use of Dental Cone Beam CT (Computed Tomography) Equipment. HPA-CRCE-010. Chilton: Health Protection Agency, ISBN 978-0-85951-681-5 (2010b)
- HIRSCH E, WOLF U, HEINICKE F, SILVA M A:** Dosimetry of the cone beam computed tomography Veraviewepocs 3D compared with the 3D Accutomo in different fields of view. *Dentomaxillofac Radiol* 37: 268-273 (2008)
- HOLBERG C, STEINHAUSER S, GEIS P, RUDZKI-JANSON I:** Cone-beam computed tomography in orthodontics: benefits and limitations. *J Orofac Orthop* 66: 434-444 (2005)
- HONEY O B, SCARFE W C, HILGERS M J, KLUEBER K, SILVEIRA A M, HASKELL B S, FARMAN A G:** Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: comparisons with panoramic radiology and linear tomography. *Am J Orthod Dentofacial Orthop* 132: 429-438 (2007)
- HORWITZ J, ZUABI O, MACHTEI E E:** Accuracy of a computerized tomography-guided template-assisted implant placement system: an in vitro study. *Clin Oral Implants Res* 20: 1156-1162 (2009)
- HOUNSFIELD G:** Computerized transverse axial scanning. 1. Description of system. *Br J Radiol* 46: 1016-1022 (1973)
- INTERNATIONAL COMMITTEE ON RADIATION PROTECTION:** Principles for Handling Emergency and Accidental Exposures of Workers. Publication 28. Pergamon Press, Oxford (1978)
- IOANNIDIS K, LAMBRIANIDIS T, BELTES P, BESI E, MALLIARI M:** Endodontic management and cone-beam computed tomography evaluation of seven maxillary and mandibular molars with single roots and single canals in a patient. *J Endod* 37: 103-109 (2011)
- JERJES W, SWINSON B, MOLES D R, EL-MAAYTAH M, BANU B, UPILE T, KUMAR M, AL KHAWALDE M, VOORVACHIS M, HADI H:** Permanent sensory nerve impairment following third molar surgery: a prospective study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 102: e1-7 (2006)
- KAEPPLER G:** Applications of cone beam computed tomography in dental and oral medicine. *Int J Comput Dent* 13: 203-219 (2010)
- KAU C H, RICHMOND S, PALOMO J M, HANS M G:** Three-dimensional cone beam computerized tomography in orthodontics. *J Orthod* 32: 282-293 (2005)
- KFIR A, TELISHEVSKY-STAUBS Y, LEITNER A, METZGER Z:** The diagnosis and conservative treatment of a complex type 3 dens invaginatus using cone beam computed tomography (CBCT) and 3D plastic models. *Int Endod J* 14: 213-219 (2012)
- KRAMER I R, PINDBORG J J, SHEAR M:** The WHO Histological Typing of Odontogenic Tumours. A commentary on the Second Edition. *Cancer* 70: 2988-2994 (1992)
- KYRIAKOU Y, KOLDITZ D, LANGNER O, KRAUSE J, KALENDER W:** Digital volume tomography (DVT) and multislice spiral CT (MSCT): an objective examination of dose and image quality. *Rofo* 183: 144-153 (2011)
- LABODA G:** Life-threatening hemorrhage after placement of an endosseous implant: report of case. *J Am Dent Assoc* 121: 599-600 (1990)
- LAI C S, BORNSTEIN M M, MOCK L, HEUBERGER B M, DIETRICH T, KATSAROS C:** Impacted maxillary canines and root resorptions of neighbouring teeth: a radiographic analysis using cone-beam computed tomography. *Eur J Orthod* 35: 529-538 (2013)
- LASCALA C A, PANELLA J, MARQUES M M:** Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). *Dentomaxillofac Radiol* 33: 291-294 (2004)
- LAUX M, ABBOTT P V, PAJAROLA G, NAIR P N:** Apical inflammatory root resorption: a correlative radiographic and histological assessment. *Int Endod J* 33: 483-493 (2000)
- LEITLINIE DER DGZMK. DENTALE VOLUMENTOMOGRAPHIE (DVT): S1 - Empfehlung.** *Zahnärztl Z* 64: 490-496 (2009)

- LEMKAMP M, FILIPPI A, BERNDT D, LAMBRECHT J T: Diagnostic possibilities of digital volume tomography. *Schweiz Monatsschr Zahnmed* 116: 645–653 (2006)
- LIANG X, JACOBS R, HASSAN B, LI L, PAUWELS R, CORPAS L, SOUZA P C, MARTENS W, SHAHBAZIAN M, ALONSO A: A comparative evaluation of Cone Beam Computed Tomography (CBCT) and Multi-Slice CT (MSCT) Part I. On subjective image quality. *Eur J Radiol* 75: 265–269 (2010)
- LIEDKE G S, DA SILVEIRA H E, DA SILVEIRA H L, DUTRA V, DE FIGUEIREDO J A: Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. *J Endod* 35: 233–235 (2009)
- LIU D G, ZHANG W L, ZHANG Z Y, WU Y T, MA X C: Three-dimensional evaluations of supernumerary teeth using cone-beam computed tomography for 487 cases. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 103: 403–411 (2007)
- LIU D G, ZHANG W L, ZHANG Z Y, WU Y T, MA X C: Localization of impacted maxillary canines and observation of adjacent incisor resorption with cone-beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 105: 91–98 (2008)
- LOFTHAG-HANSEN S, HUOMONEN S, GRONDAHL K, GRONDAHL H G: Limited cone-beam CT and intra-oral radiography for the diagnosis of periapical pathology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 103: 114–119 (2007)
- LOUBELE M, MAES F, JACOBS R, VAN STEENBERGHE D, WHITE S C, SUETENS P: Comparative study of image quality for MSCT and CBCT scanners for dentomaxillofacial radiology applications. *Radiat Prot Dosimetry* 129: 222–226 (2008)
- LOW K M, DULA K, BURGIN W, VON ARX T: Comparison of periapical radiography and limited cone-beam tomography in posterior maxillary teeth referred for apical surgery. *J Endod* 34: 557–562 (2008)
- LUDLOW J B, IVANOVIC M: Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 106: 106–114 (2008)
- LUEBBERS H T, JACOBSEN C, MATTHEWS F, GRATZ K W, KRUSE A, OBWEGESER J A: Surgical navigation in craniomaxillofacial surgery: expensive toy or useful tool? A classification of different indications. *J Oral Maxillofac Surg* 69: 300–308 (2011)
- LUEBBERS H T, MATTHEWS F, ZEMANN W, GRATZ K W, OBWEGESER J A, BREDELL M: Registration for computer-navigated surgery in edentulous patients: A problem-based decision concept. *J Cranio-maxillofac Surg* 48: 420–426 (2010)
- LUEBBERS H T, MESSMER P, OBWEGESER J A, ZWAHLEN R A, KIKINIS R, GRAETZ K W, MATTHEWS F: Comparison of different registration methods for surgical navigation in craniomaxillofacial surgery. *J Cranio-maxillofac Surg* 36: 109–116 (2008)
- LUEBBERS H T, OBWEGESER J A, MATTHEWS F, EYRICH G, GRATZ K W, KRUSE A: A Simple and Flexible Concept for Computer-Navigated Surgery of the Mandible. *J Oral Maxillofac Surg* 35: 25–31 (2010)
- LUND H, GRONDAHL K, GRONDAHL H G: Accuracy and precision of linear measurements in cone beam computed tomography Accutomo tomograms obtained with different reconstruction techniques. *Dentomaxillofac Radiol* 38: 379–386 (2009)
- MAINI A, DURNING P, DRAGE N: Resorption: within or without? The benefit of cone-beam computed tomography when diagnosing a case of an internal/external resorption defect. *Br Dent J* 204: 135–137 (2008)
- MANDELARIS G A, ROSENFELD A L, KING S D, NEVINS M L: Computer-guided implant dentistry for precise implant placement: combining specialized stereolithographically generated drilling guides and surgical implant instrumentation. *Int J Periodontics Restorative Dent* 30: 275–281 (2010)
- MARET D, MOLINIER F, BRAGA J, PETERS O A, TELMON N, TREIL J, INGLESE J M, COSSIE A, KAHN J L, SIXOU M: Accuracy of 3D reconstructions based on cone beam computed tomography. *J Dent Res* 89: 1465–1469 (2010)
- MARTIN C J: Effective dose: how should it be applied to medical exposures? *Br J Radiol* 80: 639–647 (2007)
- MASON M E, TRIPLETT R G, ALFONSO W F: Life-threatening hemorrhage from placement of a dental implant. *J Oral Maxillofac Surg* 48: 201–204 (1990)
- MCCOLLOUGH C H, CHRISTNER J A, KOFLER J M: How effective is effective dose as a predictor of radiation risk? *Am J Roentgenol* 194: 890–896 (2010)
- METTLER F A, THOMADSEN B R, BHARGAVAN M, GILLEY D B, GRAY J E, LIPOTI J A, MCCROHAN J, YOSHIZUMI T, MAHESH M: Medical radiation exposure in the U.S. in 2006: preliminary results. *Health Phys* 95: 502–507 (2008)
- MIRACLE A C, MUKHERJI S K: Conebeam CT of the head and neck, part 2: clinical applications. *AJNR Am J Neuroradiol* 30: 1285–1292 (2009)
- MOLEN A D: Considerations in the use of cone-beam computed tomography for buccal bone measurements. *Am J Orthod Dentofacial Orthop* 137: 130–135 (2010)
- MOMIN M A, OKOCHI K, WATANABE H, IMAIZUMI A, OMURA K, AMAGASA T, OKADA N, OHBAYASHI N, KURABAYASHI T: Diagnostic accuracy of cone-beam CT in the assessment of mandibular invasion of lower gingival carcinoma: comparison with conventional panoramic radiography. *Eur J Radiol* 72: 75–81 (2009)
- MORDENFELD A, ANDERSSON L, BERGSTROM B: Hemorrhage in the floor of the mouth during implant placement in the edentulous mandible: a case report. *Int J Oral Maxillofac Implants* 12: 558–561 (1997)
- MOREIRA C R, SALES M A, LOPES P M, CAVALCANTI M G: Assessment of linear and angular measurements on three-dimensional cone-beam computed tomographic images. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 108: 430–436 (2009)
- MORGENROTH K, PHILIPPOU S: *Oralpathologie II: Zahnsystem und Kiefer*. Springer-Verlag Berlin, Heidelberg, pp 60–105 (1998)
- MOSSAZ J, KLOUKOS D, PANDIS N, SUTER V G, KATSAROS C, BORNSTEIN M M: Morphologic characteristics, location, and associated complications of maxillary and mandibular supernumerary teeth as evaluated using cone beam computed tomography. *Eur J Orthod* in press (2014)
- MOUNTFORD P J, TEMPERTON D H: Recommendations of the International Commission on Radiological Protection (ICRP) 1990. *Eur J Nucl Med* 19: 77–79 (1992)
- MOZZO P, PROCACCI C, TACCONI A, MARTINI P T, ANDREIS I A: A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *Eur Radiol* 8: 1558–1564 (1998)
- NACKAERTS O, MAES F, YAN H, COUTO SOUZA P, PAUWELS R: Analysis of intensity variability in multislice and cone beam computed tomography. *Clin Oral Impl Res* 22: 873–879 (2011)
- NAIR M K, NAIR U P: Digital and advanced imaging in endodontics: a review. *J Endod* 33: 1–6 (2007)
- NAKAGAWA Y, KOBAYASHI K, ISHII H, MISHIMA A, ASADA K, ISHIBASHI K: Preoperative application of limited cone beam computerized tomography as an assessment tool before minor oral surgery. *Int J Oral Maxillofac Surg* 31: 322–326 (2002)
- NEUGEBAUER J, RITTER L, MISCHKOWSKI R A, DREISEIDLER T, SCHERER P, KETTERLE M, ROTHAMEL D, ZOLLER J E: Evaluation of maxillary sinus anatomy by cone-beam CT prior to sinus floor elevation. *Int J Oral Maxillofac Implants* 25: 258–265 (2010)
- NG F C, HO K H, WEXLER A: Computer-assisted navigational surgery enhances safety in dental implantology. *Ann Acad Med Singapore* 34: 383–388 (2005)
- NICKENIG H J, EITNER S, ROTHAMEL D, WICHMANN M, ZOLLER J E: Possibilities and limitations of implant placement by virtual planning data and surgical guide templates. *Int J Computerized Dent* 15: 9–21 (2012)
- OKANO T, HARATA Y, SUGIHARA Y, SAKAINO R, TSUCHIDA R, IWAI K, SEKI K, ARAKI K: Absorbed and effective doses from cone beam volumetric imaging for implant planning. *Dentomaxillofac Radiol* 38: 79–85 (2009)
- OSMAN S O, DE BOER H C, ASTREINIDOU E, GANGSAA S A, HEIJMEN B J, LEVENDAG P C: On-line cone beam CT image guidance for vocal cord tumor targeting. *Radiother Oncol* 93: 8–13 (2009)
- OHTANI J, HOFFMAN W Y, VARGERVIK K, OBEROI S: Team management and treatment outcomes for patients with hemifacial microsomia. *Am J Orthod Dentofacial Orthop* 141 (4 Suppl): 74–81 (2012)
- PATCAS R, MULLER L, ULLRICH O, PELTOMAKI T: Accuracy of cone-beam computed tomography at different resolutions assessed on the bony covering of the mandibular anterior teeth. *Am J Orthod Dentofac Orthoped* 141: 41–50 (2012)
- PATEL S, DAWOOD A: The use of cone beam computed tomography in the management of external cervical resorption lesions. *Int Endod J* 40: 730–737 (2007)
- PATEL S, DAWOOD A, FORD T P, WHAITES E: The potential applications of cone beam computed tomography in the management of endodontic problems. *Int Endod J* 40: 818–830 (2007)
- PAUWELS R, BEINSBERGER J, COLLAERT B, THEODORAKOU C, ROGERS J, WALKER A, COCKMARTIN L, BOSMANS H, JACOBS R, BOGAERTS R: Effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol* 81: 267–271 (2012)
- PAUWELS R, STAMATAKIS H, BOSMANS H, BOGAERTS R, JACOBS R, HORNER K, TSIKLAKIS K: Quantification of metal artifacts on cone beam computed tomography images. *Clin Oral Implants Res* 84: 214–229 (2011)
- PAZERA P, BORNSTEIN M M, PAZERA A, SENDI P, KATSAROS C: Incidental maxillary sinus findings in orthodontic patients: a radiographic analysis using cone-beam computed tomography (CBCT). *Orthod Craniofac Res* 14: 17–24 (2011)
- PAZERA P, FUDALEJ P, KATSAROS C: Severe complication of a bonded mandibular lingual retainer. *Am J Orthod Dentofacial Orthop* 142: 406–409 (2012)
- PETERSSON A: What you can and cannot see in TMJ imaging – an overview related to the RDC/TMD diagnostic system. *J Oral Rehabil* 37: 771–778 (2010)
- PHILIPSEN H P, REICHAERT P A: Classification of odontogenic tumours. A historical review. *J Oral Pathol Med* 35: 525–529 (2006)
- POHLENZ P, BLESSMANN M, BLAKE F, GBARA A, SCHMELZLE R, HEILAND M: Major mandibular surgical procedures as an indication for intraoperative imaging. *J Oral Maxillofac Surg* 66: 324–329 (2008)
- POHLENZ P, BLESSMANN M, BLAKE F, HEINRICH S, SCHMELZLE R, HEILAND M: Clinical indications and perspectives for intraoperative cone-beam computed tomography in oral and maxillofacial surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 103: 412–417 (2007)

- QU X M, LI G, SANDERINK G C, ZHANG Z Y, MA X C: Dose reduction of cone beam CT scanning for the entire oral and maxillofacial regions with thyroid collars. *Dentomaxillofac Radiol* 41: 373–378 (2012)
- QUERESHY F A, SAVELL T A, PALOMO J M: Applications of cone beam computed tomography in the practice of oral and maxillofacial surgery. *J Oral Maxillofac Surg* 66: 791–796 (2008)
- REICHART P A, PHILIPSEN H P: *Odontogenic tumors and allied lesions*. Quintessence, London (2004)
- REICHART P A, PHILIPSEN H P, SCIUBBA J J: The new WHO classification of tumors of the head and neck. What has changed? *Mund Kiefer Gesichtschir* 10: 1–2 (2006)
- RITTER L, LUTZ J, NEUGEBAUER J, SCHEER M, DREISEIDLER T, ZINER M J, ROTHAMEL D, MISCHKOWSKI R A: Prevalence of pathologic findings in the maxillary sinus in cone-beam computerized tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 111: 634–640 (2011)
- ROBERTS J A, DRAGE N A, DAVIES J, THOMAS D W: Effective dose from cone beam CT examinations in dentistry. *Br J Radiol* 82: 35–40 (2009)
- ROEDER F, WACHTLIN D, SCHULZE R: Necessity of 3D visualization for the removal of lower wisdom teeth: required sample size to prove non-inferiority of panoramic radiography compared to CBCT. *Clin Oral Investig* 16: 699–706 (2012)
- ROYAL H D: Effects of low level radiation – what’s new? *Nuclear Med* 38: 392–402 (2008)
- SADIQ Z, BISASE B, COOMBS D M: Use of cone beam computed tomography in the management of glass injuries to the face. *Br J Oral Maxillofac Surg* 48: 308–309 (2010)
- SAMARA E T, AROUA A, BOCHUD F O, OTT B, THEILER T, TREIER R, TRUEB P R, VADER J P, VERDUN F R: Exposure of the Swiss population by medical x-rays: 2008 review. *Health Phys* 102: 263–270 (2012)
- SCHAUER D A, LINTON O W: NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States, medical exposure – are we doing less with more, and is there a role for health physicists? *Health Phys* 97: 1–5 (2009)
- SCHIROLI G, ANGIERO F, SILVESTRINI-BIAVATI A, BENEDICENTI S: Zygomatic implant placement with flapless computer-guided surgery: a proposed clinical protocol. *J Oral Maxillofac Surg* 69: 2979–2989 (2011)
- SCHMITTER M, GABBERT O, OHLMANN B, HASSEL A, WOLFF D, RAMMELSBURG P, KRESS B: Assessment of the reliability and validity of panoramic imaging for assessment of mandibular condyle morphology using both MRI and clinical examination as the gold standard. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 102: 220–224 (2006)
- SCHNITMAN P A, LEE S J, CAMPARD G J, DONA M: Guided flapless surgery with immediate loading for the high narrow ridge without grafting. *J Oral Implantol* 38: 279–288 (2012)
- SCHOEN R, FAKLER O, METZGER M C, WEYER N, SCHMELZEISEN R: Preliminary functional results of endoscope-assisted transoral treatment of displaced bilateral condylar mandible fractures. *Int J Oral Maxillofac Surg* 37: 111–116 (2008)
- SCHULZE R, HEIL U, GROSS D, BRUELLMANN D D, DRANISCHNIKOW E, SCHWANECKE U, SCHOEMER E: Artefacts in CBCT: a review. *Dentomaxillofac Radiol* 40: 265–273 (2011)
- SCHULZE R K, BERNDT D, D’HOEDT B: On cone-beam computed tomography artifacts induced by titanium implants. *Clin Oral Implants Res* 21: 100–107 (2010)
- SHINTAKU W H, VENTURIN J S, AZEVEDO B, NOUJEIM M: Applications of cone-beam computed tomography in fractures of the maxillofacial complex. *Dent Traumatol* 25: 358–366 (2009)
- SIEWERDSEN J H, JAFFRAY D A: Cone-beam computed tomography with a flat-panel imager: magnitude and effects of x-ray scatter. *Med Phys* 28: 220–231 (2001)
- SMITH N J, LOOH F C, TODD J M, WHAITES E J: Stafne’s bone cavity: a review of the literature and report of two cases. *Clin Radiol* 36: 297–299 (1985)
- STAVROPOULOS A, WENZEL A: Accuracy of cone beam dental CT, intraoral digital and conventional film radiography for the detection of periapical lesions. An ex vivo study in pig jaws. *Clin Oral Investig* 11: 101–106 (2007)
- STUEHMER C, ESSIG H, BORMANN K H, MAJDANI O, GELLRICH N C, RUCKER M: Cone beam CT imaging of airgun injuries to the craniomaxillofacial region. *Int J Oral Maxillofac Surg* 37: 903–906 (2008)
- SUOMALAINEN A, ABERG T, RAUTIO J, HURMERINTA K: Cone beam computed tomography in the assessment of alveolar bone grafting in children with unilateral cleft lip and palate. *Eur J Orthod* 36: 603–611 (2014)
- SUOMALAINEN A, APAJALAHTI S, VEHMAS T, VENTA I: Availability of CBCT and iatrogenic alveolar nerve injuries. *Acta Odontol Scand* 87: 45–52 (2012)
- SUTER V G, ALTERMATT H J, VOEGELIN T C, BORNSTEIN M M: The nasopalatine duct cyst – epidemiology, diagnosis and therapy. *Schweiz Monatsschr Zahnmed* 117: 824–839 (2007)
- SUTER V G, BUTTNER M, ALTERMATT H J, REICHART P A, BORNSTEIN M M: Expansive nasopalatine duct cysts with nasal involvement mimicking apical lesions of endodontic origin: a report of two cases. *J Endod* 37: 1320–1326 (2011)
- SUTER V G, SENDI P, REICHART P A, BORNSTEIN M M: The nasopalatine duct cyst: an analysis of the relation between clinical symptoms, cyst dimensions, and involvement of neighboring anatomical structures using cone beam computed tomography. *J Oral Maxillofac Surg* 69: 2595–2603 (2011)
- TERAKADO M, HASHIMOTO K, ARAI Y, HONDA M, SEKIWA T, SATO H: Diagnostic imaging with newly developed ortho cubic super-high resolution computed tomography (Ortho-CT). *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 89: 509–518 (2000)
- THE 1990 RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION: *Ann ICRP* 21: 1–201 (1991)
- THE 2007 RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION: ICRP publication 103. *Ann ICRP* 37: 1–332 (2007)
- THOMPSON L: World Health Organization classification of tumours: pathology and genetics of head and neck tumours. *J Ear, Nose, Throat* 85: 74 (2006)
- TIMOCK A M, COOK V, McDONALD T, LEO M C, CROWE J, BENNINGER B L, COVELL D A: Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. *Am J Orthod Dentofacial Orthop* 140: 734–744 (2011)
- VAN ASSCHE N, QUIRYNEN M: Tolerance within a surgical guide. *Clin Oral Implants Res* 21: 455–458 (2010)
- VON ARX T, BORNSTEIN M M: The patent nasopalatine duct. A rare anomaly and diagnostic pitfall. *Schweiz Monatsschr Zahnmed* 119: 379–389 (2009)
- VON ARX T, PENARROCHA M, JENSEN S: Prognostic factors in apical surgery with root-end filling: a meta-analysis. *J Endod* 36: 957–973 (2010)
- WALTER C, WEIGER R, DIETRICH T, LANG N P, ZITZMANN N U: Does three-dimensional imaging offer a financial benefit for treating maxillary molars with furcation involvement? A pilot clinical case series. *Clin Oral Implants Res* 23: 351–358 (2012)
- WALTER C, WEIGER R, ZITZMANN N U: Accuracy of three-dimensional imaging in assessing maxillary molar furcation involvement. *J Clin Periodontol* 37: 436–441 (2010)
- WANG Y, HE S, YU L, LI J, CHEN S: Accuracy of volumetric measurement of teeth in vivo based on cone beam computer tomography. *Orthod Craniofac Res* 14: 206–212 (2011)
- WATANABE H, HONDA E, KURABAYASHI T: Modulation transfer function evaluation of cone beam computed tomography for dental use with the oversampling method. *Dentomaxillofac Radiol* 39: 28–32 (2010)
- XU F, WANG J, BAI S, LI Y, SHEN Y, ZHONG R, JIANG X, XU Q: Detection of intrafractional tumour position error in radiotherapy utilizing cone beam computed tomography. *Radiother Oncol* 89: 311–319 (2008)
- ZIEGLER C M, WOERTCHE R, BRIEF J, HASSFELD S: Clinical indications for digital volume tomography in oral and maxillofacial surgery. *Dentomaxillofac Radiol* 31: 126–130 (2002)
- ZIZELMANN C, GELLRICH N C, METZGER M C, SCHOEN R, SCHMELZEISEN R, SCHRAMM A: Computer-assisted reconstruction of orbital floor based on cone beam tomography. *Br J Oral Maxillofac Surg* 45: 79–80 (2007)
- ZOUMALAN R A, LEBOWITZ R A, WANG E, YUNG K, BABB J S, JACOBS J B: Flat panel cone beam computed tomography of the sinuses. *Otolaryngol Head Neck Surg* 140: 841–844 (2009)