What the general dental practitioner should know about cone beam computed tomograph technology

Magdalena Marinescu Gava[1]

[1] D.D.S. Pirkanmaa Hospital District, Regional Imaging Centre, Tampere, Finland.

Abstract

Ionising radiation is used in health care for the diagnosis of diseases, for prevention (such as screening for breast cancer) and for treatment (radiotherapy). The aim of radiation protection is to ensure that radiation is used safely and that exposure of the patient is kept to a minimum. The principles of radiation protection are based on the recommendations of the International Commission on Radiological Protection (ICRP). To be acceptable, the use of ionising radiation must be justified, optimal, and limited. Dental radiography has been used since the beginning of radiology and now accounts for nearly one-third of the total number of radiological examinations in the European Union. Pantomography is widely used because in one exposure it records the jaws, temporomandibular joints, maxillary sinuses, and dentition. However, when this technique is used, superimposition of structures in the dentomaxillofacial area has been a limitation in making reliable diagnoses due to the complexity of the anatomy in this region. These shortcomings have led to development of three-dimensional techniques. One of these techniques, cone-beam computed tomography (CBCT), is now available for use in everyday general practice. The aim of this paper is to present CBCT's advantages and limitations when compared with alternative imaging techniques and to stress how it may be used safely in general dental practice.

Key Words: Medical Subjects, Radiation Protection, Dentistry, Cone-Beam Computed Tomography (CBCT)

Introduction

Although the doses of ionising radiation generated during dental examinations are in general relatively low, dental radiology accounts for nearly one-third of the total number of radiological examinations in the European Union and therefore deserves specific attention with regard to radiation protection [1].

In radiology, protection of patients requires that any investigation using ionising radiation is justified, optimised, and minimised for each patient. When seeking a diagnosis using ionising radiation, it is critical to keep the balance between the potential gain in information and the risk to the patient from exposure to ionising radiation. The rule known as 'ALARA' (as low as reasonably achievable) summarises this concept and implies the achievement of good diagnostic images with a minimum of exposure to radiation [2].

Imaging of the maxillofacial area is developing fast, evolving from the two-dimensional radiography (intra-oral film or pantomography), with its shortcomings due to superimposing of structures, to three-dimensional techniques that take into account the complicated human anatomy. Such three-dimensional techniques include magnetic resonance imaging (MRI), computed tomography (CT), and the newer CBCT, which includes cone-beam tomography, volumetric computed tomography, micro CT, and digital volume tomography (DVT) [3-5].

In head and neck examinations, MRI is a three-dimensional traditional/alternative technique, which does not use ionising radiation and is ideal for investigating soft tissues. However, it is not readily available, requires lots of space and expensive equipment, and is rather poor at evaluating hard tissues.

Technology using ionising radiation is cheaper, is more widely available, has good performance in hard-tissue imaging, but comes with biological risks: some effects of radiation are deterministic (depending on the quantity of radiation used) and some are stochastic (having no threshold, leading to changes in cellular structures, causing cancer and genetic modification in chromosomes, thus genetic modification in genome of offspring, etc.) [2].

Corresponding author: Magdalena Marinescu Gava, Pirkanmaa Hospital District, Regional Imaging Centre, Finnish Student Health Service, Tampere, Finland; e-mail: magdalena_gava@hotmail.com

Although the quantity of radiation absorbed in traditional intra-oral radiography in the dentomaxillofacial area is relatively small, the use of CT can result in far greater exposure to ionising radiation. In addition, classic CT is expensive and the equipment required takes up a lot of space. CBCT provides a complement to or a substitute for traditional CT, especially in dentistry [6-8]. Initially designed as experimental equipment, micro-CT involved long exposure and high radiation doses. With time, very compact scanners have been developed and nowadays CBCT equipment is more compact, much cheaper, and generates less ionising radiation than classic CT. The radiation beam is not fan-like as it is in CT; it is cone-shaped and the area of investigation can be limited to the area of interest.

In dentistry, the use of CBCT is becoming part of everyday general practice. In order to protect patients best against radiation, is important to know the correct indications for the use of this type of investigation and the right techniques. This will ensure that sufficient information for a reliable diagnosis is produced using the lowest possible dosage of ionising radiation.

Aim

Against this background, the aim of this paper is to present the indications for the use of CBCT and its advantages and limitations when compared with alternative imaging techniques, in the overall context of protecting patients from excessive use of ionising radiation.

General Principles

Due to the considerably higher radiation dose required, CBCT is not recommended as a routine investigation and there should always be a strong indication for its use. All those working with ionising radiation should receive adequate theoretical and practical training for radiation safety issues. Continuing education and training following qualification are required, particularly when new equipment or techniques are adopted. Mastering the technique and a justifiable indication for its use protects the patient from excessive or unjustified ionising radiation. The efficacy, benefits and risks of available alternative techniques, having the same objective but involving no or less exposure to ionising radiation, should also be taken into account by practitioners, who can make informed, responsible, and thus sensible choices when investigating their patients.

CBCT Techniques

The ionising radiation emitted during CBCT is not in a linear or fan-like beam, but is a cone-shaped beam. The name of tomography comes from ‘tomos’ (slices, in Greek) and ‘graph’ (to draw). During exposure to produce a CBCT image, the information is sent to a computer throughout a 180-360 degree rotation on a two-dimensional sensor (digital detector). The field of view (FOV) varies with the scanner from one device to another. FOV has a cylindrical shape, is a few centimetres high and has a diameter of 3-20 cm. The FOV can be chosen with respect to the investigative needs. The time needed to obtain the images is divided into scanning time and recording time, and the computer reconstructs three-dimensional structures using complex algorithms. There is excellent fidelity of the image in all dimensions and the resolution is very high. The thickness of slices varies between 0.125 and 2 mm, depending on device and operator’s choice.

The operator can choose the axial, coronal or sagittal view and acquire information from the appropriate direction. For example, in devices with a big FOV, images for cephalometric analysis are recorded from lateral and postero-anterior directions. The information is stored in voxels. A voxel (a combination of volume and pixel) is a unit for measuring the volume of stored information. One voxel is a cube with 0.08-4 mm edges [7-9]. The exposure time depends on the machine’s FOV and the desired resolution of the image.

Makes and Types of CBCT Machine (Devices)

CBCT machines (devices) may vary in relation to:

- The size of structure to be imaged.
- Geometrical resolution.
- Contrast.
- Slice thickness.
- Ionising radiation dose.

When this paper was written, there were more than 20 different devices available, some of which can be attached to pantomographic machines. They included: 3DX Accuitomo (Morita), NewTom9000 and NewTom 3G (AFP Imaging), Siremobil ISO-C-3D (Siemens Medical Solutions), I-CAT (ISI) and CB MercuRay (Hitachi), Scanora 3D (Soredex), Promax 3D (Planmeca), Kodak 9500 (Kodak), Picasso Master (E-WOO), Galileos (Sirona) *(Figure 1)*.

Figure 1. *Cone-beam computed technology (CBCT) machine.*

In the majority of devices, the patient either stands up or sits in a chair while the tube and the detector rotate around him/her. Some companies offer modified versions, with a bigger FOV (13-20 cm), or those that can be used while the patient is lying down. This option is very useful when obtaining images for patients with traumatic injuries. There are modified versions with a big FOV that are especially useful for cephalostatic imaging. There are also devices for intra-operator use and some have a C-arm (e.g., Siremobil ISO-C-3D; Siemens Medical Solutions).

Effective Doses

The doses of ionising radiation generated during imaging [7] are set out in *Table 1.* It is advantageous for devices to be adjustable for features such as FOV, voltage, amperage, exposure time and image resolution so that the operator is able to customise the settings for each individual patient, to obtain good quality diagnostic image consistent with the need to minimise the radiation dose (ALARA) [10].

Indications

As CBCT develops, it is possible that a number of further indications will come to light. Gröndahl (2007) [11] reported that in Sweden in 2007 the relative frequency in the use of CBCT between different oral specialties was:

- Implantology: 40%
- Oral surgery: 19%
- Orthodontics: 19%
- Endodontics: 17%
- Temporomandibular joint (TMJ): 1%
- Oto-rhino-laryngology: (ENT) 2%
- Other investigations 2% (periodontology, forensic dentistry, research).

These figures may or may not be replicated by findings from other studies but do give some indication of the possible current use of CBCT for oral purposes by specialty. Specific uses for CBCT by specialty have been reported and are listed below.

Implantology [12, 13]

- To assess the quantity and quality of bone in edentulous ridges.
- To assess the relation of planned implants to neighbouring structures.
- To assess the success of implant-osseointegration.
- To provide information on correct placement of implants *(Figure 2).*
- Before ridge augmentation in anodontia.
- Before bone reconstruction and sinus lifting.
- During planning and in designing a surgical guidance template.

Dentoalveolar and maxillofacial surgery [9,12-14]

To assess:

- The presence or absence of tumours.
- Lower molars and relationship with mandible canal.
- Impacted teeth, residual roots *(Figure 3).*

Table 1. *Typical Doses of Ionising Radiation Generated During Exposure for Panoramic and CBCT Images*

Examination	Effective patient dose (µSv)	Dose as the multiple of the dose from a typical panoramic exam
Panoramic	24	1
Small FOV CBCT	48-652	2-27
Large FOV CBCT	68-1073	3-45
CT scan (dental programme)	534[7]-2100	22-88

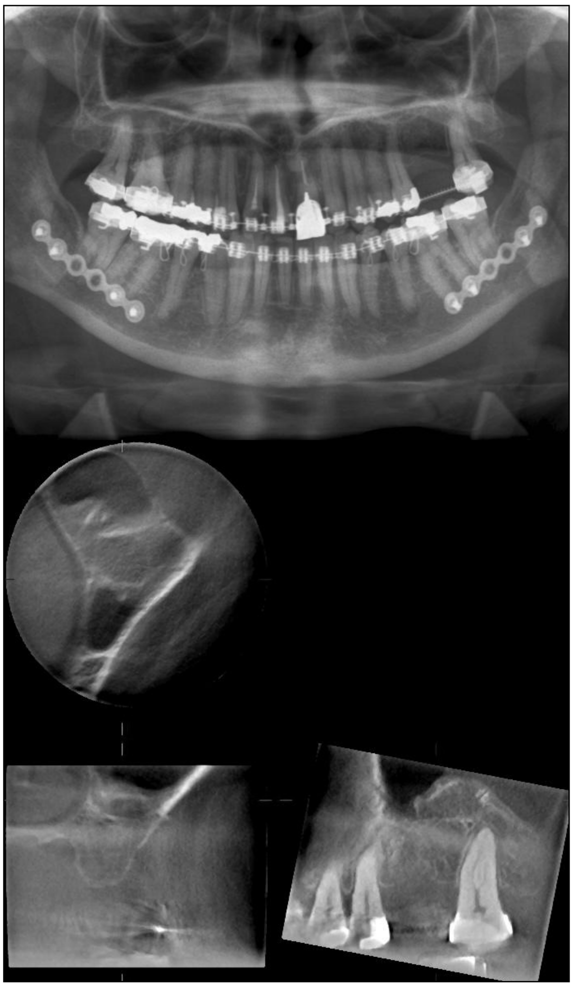

Figure 2. *Use of CBCT in sinus lifting and planning.*

- Superior teeth and position of the roots in respect to the maxillary sinus.
- Peri-oral abscesses, facial pain, trismus, differential diagnostic (presence or absence, source, and precise localisation in maxillofacial area).
- Foreign bodies.
- Cystic lesions and their delimitation *(Figure 4).*
- Osteomyelitis.

In trauma cases, CBCT is able to show a larger number of fracture lines and fractures when compared with conventional images, depicting precisely the position and orientation of displaced fragments in a reasonably short time interval. Such cases include:

- Dentoalveolar fractures *(Figures 8* and *9):*

- Tooth fractures (a fracture line is easier to visualise in an intact tooth rather than in a tooth that has been restored, due to artefacts).

- Avulsion.

- Dislocation.

- Luxation.

- Orbital fractures: MRI is more sensitive but CBCT can assess high-contrast structures such as lateral and median walls or search for foreign bodies.
- Condylar fractures.
- Mid-face fractures: larger-volume CBCT scanners acquire the entire maxillofacial region within a FOV up to 20 cm in diameter.

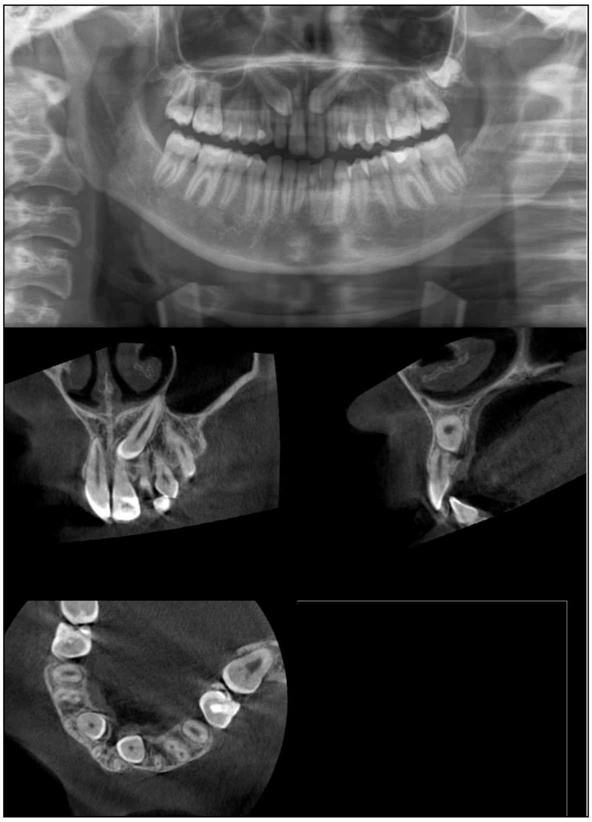

Figure 3. *Retained teeth, their relationship with neighbouring structures and resorption of other teeth.*

Orthodontics [14-17]

- In cases of anodontia.
- When planning orthognathic surgery.
- In obstructive sleep apnoea, evaluation of air space.
- Clefts of the palate:
  - Uni- or bilateral.
  - Positions of teeth *(Figure 5).*
  - Planning operations and orthodontic treatment, localisation of eventual bone.
  - Control of intervention.
  - Supernumerary teeth in palate cleft: position, angulations.
- Cephalometric analysis (special programs).

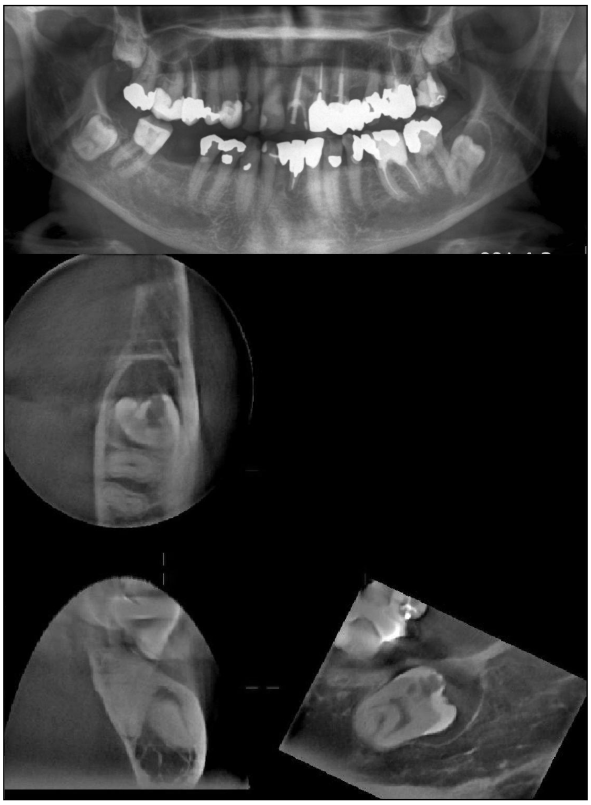

Figure 4. *Follicular cyst and impacted lower wisdom tooth, extension, relationship to the mandible nerve canal.*

Endodontics [18-20]

To assess:

- Upper molars where, because three or more root canals are present, they are frequently superimposed on two-dimensional images when using conventional radiographic techniques.
- Cysts, granulomas, periapical lesions.
- Endodontic surgery, evaluation of fractured instruments in canal.
- Unobturated, lateral or supernumerary root canals.
- Maxillary sinus involvement after apical infection.

CBCT, using limited quantities of ionising radiation, may be an alternative to intra-oral imaging of multi-rooted teeth when the latter does not allow each tooth to be viewed separately. For single-rooted teeth, conventional intra-oral imaging remains the technique of choice when evaluating the quality of root fillings.

Temporomandibular joint [21]

- Investigating bony structures of TMJ; the disc is best visualised by MRI.
- Osteoarthritis (bone destruction) and ankylosis.

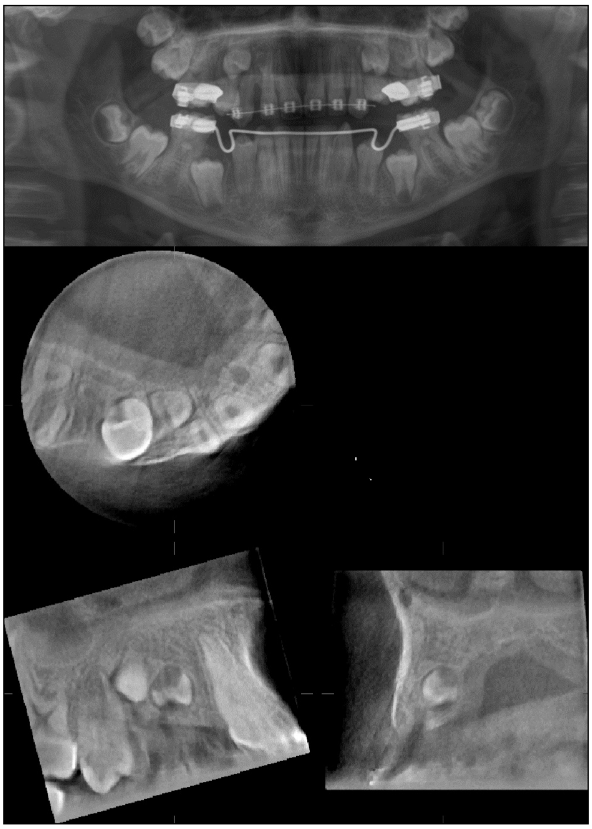

Figure 5. *Orthodontics.*

Figure 6. *Periapical lesions after root canal treatment.*

- Condylar fractures (localisation of fracture lines and dislocated fragments).
- Articular osteofytes.

- The relationship of the condylar head to the glenoid fossa.
- Bone erosions, malformations, condylar modifications *(Figure 7).*

Periodontology [22]

- Very accurate analysis of bone loss as well as bone healing after periodontal treatment or regenerative therapy. CBCT is a very sensitive method for imaging mineralised tissues *(Figure 10).*
- Periodontal complications arising from root fractures, which can be visualised with CBCT when a two-dimensional image fails to give any information.

Figure 7. *Condylar morphology.*

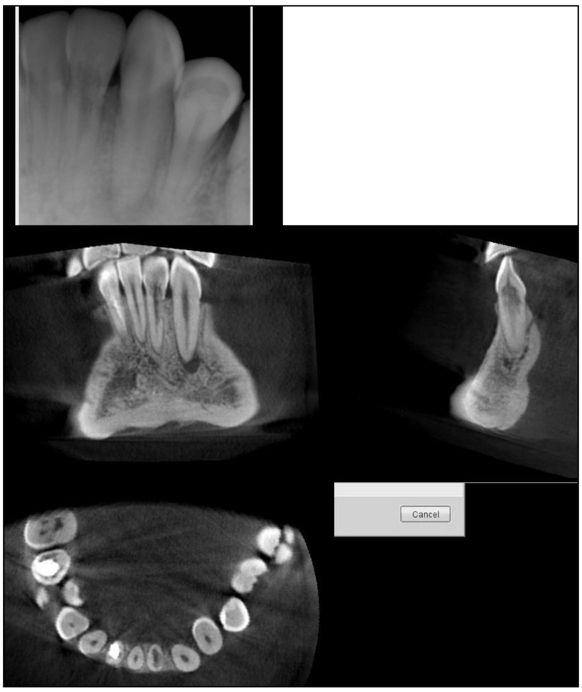

Figure 8. *Dentoalveolar trauma on traditional film and CBCT.*

Figure 9. *Follow-up of trauma treatment on pantomography and CBCT.*

Other investigations [11, 13]

- Imaging of the ear.
- Experimental use.
- Osteoporosis and bone healing after anti-osteoporotic medication.

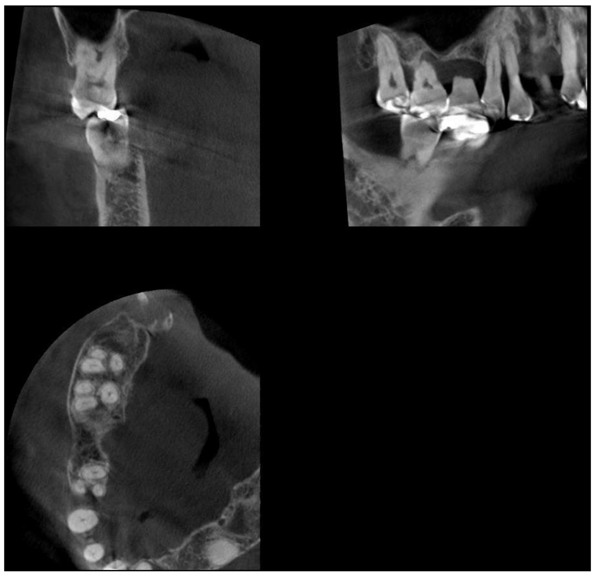

Figure 10. *True periodontal involvement.*

Advantages of CBCT

CBCT offers high quality in-office imaging, as the technique is easy to apply and has easy-to-use post-processing and viewing software. Compared with classic radiographs, measurements obtained by the use of CBCT are very exact, because the resulting images are actual size and high-resolution 3D. The resulting data have the potential for generating all 2D images in a single scan (e.g., dental panoramic tomogram, lateral cephalogram). It is the most accurate method for assessing the bony structures of the TMJ. Another major advantage of CBCT in head and neck region is the possibility of reducing the size of the area under investigation to the relevant field, for example a small unilateral area.

Compared to traditional CT, CBCT is cheaper, smaller, emits less ionising radiation, has a shorter exposure time and gives better image resolution.

Limitations and Disadvantages of CBCT

- It is definitely more expensive than classic two-dimensional radiologic investigations.
- The dose of ionising radiation generated is greater than in a pantomography investigation.
- As a new technology, it requires new competences from the clinician and the value of information obtained is interpretation-sensitive.
- Any movement artefacts affect the whole data set and the whole image rather than just one part.
- It provides limited resolution of deeper (inner) soft tissues, and MRI and classic CT are better for soft-tissue imaging.
- It has low contrast range (dependent on the type of x-ray detector).
- It has increased noise from scattered radiation and concomitant loss of contrast resolution.
- It cannot be used for estimation of Hounsfield Units (HU) [9].

Conclusions

Any x-ray exposure entails a risk to the patient. Under normal circumstances, the risk from dental radiography is very low, but can be high in neighbouring tissues: thyroid, salivary glands and brain.

CBCT offers high quality in-office imaging that can greatly improve patient care; on the down side, the radiation dose that the patients are exposed to is much greater than for traditional radiography.

The easy accessibility and handling of CBCT scanners could encourage the use of this technique in general practice. However, there is a risk that some practitioners may lack sufficient anatomical knowledge and experience to interpret the resulting images, which may have medicolegal consequences.

There should always be a very clear and strong indication for any tomographic investigation. The use of CBCT as routine substitute of pantomography is not recommended. It is essential that any radiographic examination should give a net benefit to the patient, weighing the total potential diagnostic benefits that it produces against the individual detriment that the exposure to ionising radiation might cause. The efficacy, benefits and risks of available alternative techniques having the same objective but involving no or less exposure to x-rays should always be taken into account.

Mastery of the technique protects patients from excessive or unjustified ionising radiation. Individual protection is most important in any method using ionising radiation (right indication, lead shielding, collimation, a quality control programme, special attention for children and pregnant women, etc.).

Users have to be aware of their responsibility to interpret the data thoroughly or to collaborate and work with trained professionals, such as specialised radiographers, who can help them to do so.

A core curriculum for training in the use of CBCT has yet to be developed. Recently, a set of 20 basic principles on the use of dental CBCT has been accepted by the European Academy of Dentomaxillofacial Radiology and, it is hoped, will be of value in national standard setting within Europe for dentists, dental specialists, and equipment manufacturers [23].

Acknowledgement

The author thanks Dr. Anni Suomalainen from the Department of Radiology, Helsinki University Central Hospital, for providing valuable help and iconography and Dr. Annukka Vuorinen, Chief Dentist at Finnish Student Health Service, Tampere, for her assistance and support.

References

1. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Annals of the ICRP* 2007; **38**: 1-242.

2. European Commission. Radiation Protection 136**.** *European Guidelines on Radiation Protection in Dental Radiology. The Safe Use of Radiographs in Dental Practice.*

Luxembourg: Office for Official Publications of the European Communities; 2004. Accessed (2009 Sept 18) at: http://ec.europa.eu/energy/nuclear/radioprotection/publication/doc/136_en.pdf

3. Roberts JA, Drage NA, Davies J, Thomas DW. Effective dose from cone beam CT examinations in dentistry. *British Journal of Radiology* 2009; **82**: 35-40.

4. Suomalainen A, Kiljunen T, Käser Y, Peltola J, Kortesniemi M. Dosimetry and image quality of four dental cone beam computed tomography scanners compared with multislice computed tomography scanners. *Dentomaxillofacial Radiology* 2009; **38:** 367-378.

5. Suomalainen AK, Salo A, Robinson S, Peltola JS. The 3DX multi image micro-CT device in clinical dental practice. *Dentomaxillofacial Radiology* 2007; **36**: 80-85.

6. Cohnen M, Kemper J, Möbes O, Pawelzik J, Mödder U. Radiation dose in dental radiology. *European Radiology* 2002; **12**: 634-637.

7. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone-beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofacial Radiology* 2003; **32**: 229-234.

8. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercury, NewTom 3G and i-CAT. *Dentomaxillofacial Radiology* 2006; **35**: 219-226.

9. Shintaku WH, Venturin JS, Azevedo B, Noujeim M. Applications of cone-beam computed tomography in fractures of the maxillofacial complex. *Dental Traumatology* 2009; **25**: 358-366.

10. Holroyd JR, Gulson AD. *The Radiation Protection Implications of the Use of Cone Beam Computed Tomography (CBCT) in Dentistry: What You Need to Know.* London: Health Protection Agency Radiation Protection Division; 2009: pp.1-10.

11. Gröndahl H-G. Jaw imaging with cone beam CT [oral presentation]. 20th meeting of the European Society of Head and Neck Radiology; 2007 Sept 8; Oslo, Norway.

12. De Vos W, Casselman J, Swennen G. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature; International Journal of Oral and Maxillofacial Surgery 2009; 38: 609-625.

13. Robinson S, Suomalainen A, Kortesniemi M. Micro-CT. *European Journal of Radiology* 2005; **56**: 185-191.

14. Cevidanes LH, Bailey LJ, Tucker SF, Styner MA, Mol A, Phillips CL, *et al.* Three-dimensional cone-beam computed tomography for assessment of mandibular changes after orthognathic surgery. *American Journal of Orthodontics and Dentofacial Orthopedics* 2007; **131**: 44-50.

15. Holberg C, Steinhäuser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. *Journal of Orofacial Orthopedics* 2005; **66**: 434-444.

16. Sakabe J, Kuroki Y, Fujimaki S, Nakajima I, Honda K. Reproducibility and accuracy of measuring unerupted teeth using limited cone beam X-ray CT. *Dentomaxillofacial Radiology* 2007; **36**: 2-6.

17. Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. *American Journal of Orthodontics and Dentofacial Orthopedics* 2008; **133**: 640.

18. Patel S, Horner K. The use of cone beam computed tomography in endodontics. *International Endodontic Journal* 2009; **42**: 755-756.

19. Soğur E, Baksi BG, Gröndahl HG. Imaging of root canal fillings: a comparison of subjective image quality between limited cone-beam CT, storage phosphor and film radiography. *International Endodontic Journal* 2007; **40**: 179-185.

20. Tsurumachi T, Honda K. A new cone beam computerized tomography system for use in endodontic surgery. *International Journal of Oral and Maxillofacial Surgery* 2007; **40**: 224-232.

21. Tsiklaklis K, Syriopouluos K, Stamatakis HC. Radiographic examination of TMJ using cone beam computed tomography. *Dentomaxillofacial Radiology* 2004; **33**: 196-201.

22. Park CH, Abramson ZR, Taba M Jr, Jin Q, Chang J, Kreider JM, *et al.* Three-dimensional micro-computed tomographic imaging of alveolar bone in experimental bone loss or repair. *Journal of Periodontology* 2007; **78**: 273-281.

23. Horner K, Islam M, Flygare L, Tsiklakis K, Whaites E. Basic principles for use of dental cone beam computed tomography: consensus guidelines of the European Academy of Dental and Maxillofacial Radiology. *Dentomaxillofacial Radiol*ogy 2009; **38**:187-195.