Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Radiation protection in dental radiology – Recent advances and future directions

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A R T I C L E I N F O

Article history:
Received 31 March 2017
Received in Revised form 21 July 2017
Accepted 22 July 2017
Available online xxxx

Keywords:
Dental
Radiation protection
Optimization

A B S T R A C T

Dental radiology uses X-ray technology to diagnose and design treatment of various clinical problems related to the oral cavity and surrounding tissues. As technology quickly evolves, there are numerous X-ray modalities using different tools in the attempt to best image and treat efficiently these diseases, disorders or other related clinical conditions. The reported numbers of dental X-rays, the fact that these may be under-reported in many countries and because dental X-rays are performed more on younger individuals, whose teeth and dentition are still developing, calls for increased need on radiation protection. The objectives of this paper are to report on the latest technology updates and related radiation protection issues, to present future directions and define gaps. Most of existing radiation protection national and international guidelines are more than a decade old. Update is needed to account for newer technologies such as cone beam computed tomography (CBCT) and digital imaging. Diagnostic Reference Levels (DRLs), a well established method for dose optimization, are not yet defined for CBCT and have to be set for various clinical indications. As far as shielding is concerned, recent data confirm that use of lead apron, even in pregnant patients, or gonadal shielding are not recommended, due to negligible radiation dose reduction. Thyroid lead shielding should be used in case the organ is in or close to the primary beam. Specifically for CBCT, leaded glasses, thyroid collars and collimation (smaller field of view (FOV) especially for paediatric patients) minimize the dose to organs outside the FOV.

1. Introduction

Radiation protection is a fundamental issue addressed numerous times in many organization standards, codes of practice and/or safety guides, the most recent of which being the European [1] and the International Basic Safety Standards [2]. Both of these documents are based on the most recent scientific evidence on the effects of ionizing radiation in the attempt to protect workers, members of the public and patients against the dangers arising from ionizing radiation. Dental radiology uses X-ray technology to address various clinical problems that cannot be treated efficiently, by conventional dental examination, solely. Currently, dentists, dental surgeons and other medical professionals have a variety of X-ray systems that they can use, depending on the clinical problem, starting from the most straightforward such as the periapical or bitewing radiography, to panoramic, cephalometric or cone beam computed tomography (CBCT) [3,4]. These technologies can be also combined for the best treatment of the patient.

According to the latest United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 Report, the annual frequency of dental diagnostic examinations has remained fairly constant for health-care level I countries (275 dental examinations per 1000 population), whereas there has been a substantial increase in healthcare level II countries, from the corresponding UNSCEAR survey in 1980–1984 (0.8 per 1000 population in 1980–1984 to 16 per 1000 population in the latest survey), reaching a global value of 74 dental examinations per 1000 population [5]. The UNSCEAR 2008 Report also states that 480 million diagnostic dental examinations are performed worldwide annually, almost all of them undertaken in level I countries. Despite the fact that the annual per caput or collective effective dose contribution is very small (much less than 1%), the enormous numbers of dental X-rays and the fact that these may be under-reported in many countries calls for increased need for radiation protection. As there is a survey to compile updated data from medical exposures currently undergoing by UNSCEAR, it would be interesting to see the results in the near future [6]. Another important issue is that dental X-ray examinations tend to be performed more on younger individuals, whose teeth and dentition are still developing [5,7].

Due to all these reasons, a number of national organizations have produced guidelines of the safe use of X-ray radiation in dental radiology [8–12]. The most recent European report related

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http://dx.doi.org/10.1016/j.ejmp.2017.07.018
1120-1797/

to the subject is the document entitled "European guidelines on radiation protection in dental radiology", that is practically a guide to radiation protection for professional groups of dentists and staff [11]. The document takes into account all relevant knowledge and available technology and gives guidance on the application of radiation protection principles in dental radiology to patients, staff and public. Although providing clear and comprehensive information it is more than a decade old and relates to older European directives [13,14].

The objective of the paper is to present an overview of the radiation protection in dental radiology, specially focusing on the new X-ray technology and techniques introduced the recent years. Part of this work was presented at the International Conference on Medical Physics held in Bangkok, Thailand in December 2016.

2. X-ray technology and radiation dose in dental radiology

There are many types of X-ray machines using either two-dimensional (2D) or three-dimensional (3D) technology used in dental radiology which are briefly described below.

2.1. Intraoral radiography

This is the most common type of 2D radiography during which an image receptor such as direct exposure film (without the use of any intensifying screen), photostimulable phosphor (PSP), charge-coupled device (CCD), or complementary metal oxide semiconductor (CMOS) is placed in the patient mouth. Depending on the region of the mouth to be investigated it can be 1) bitewing radiography, imaging the crown of a tooth and the adjacent alveolar crests, 2) periapical radiography, imaging all the tooth and surrounding bone, or 3) occlusal radiography, which images a larger area of the mouth. The same X-ray machine is used which can be either mounted on the wall or is portable [4].

2.2. Panoramic radiography

The panoramic X-ray machine utilizes an X-ray tube and an image receptor which rotate around the patient imaging the mandible and maxilla as well as the supporting structures. The 2D X-ray image is produced using an image receptor which can be either a film with an intensifying screen, a PSP, a CCD or a direct conversion sensor providing a curved-plane tomogram of the teeth and jaws. Panoramic radiography has a lower spatial resolution than intraoral radiography. It is usually applied in cases of treatment planning or for postoperative control [4].

2.3. Cephalometric radiography

Usually a cephalometric unit is incorporated in a panoramic machine and uses a head positioning device to produce a 2D extra-oral radiograph with a special head handling device. The image receptor is most often the same as the one used for panoramic radiography. Cephalometric radiography is applied to evaluate the head and neck as well as the whole facial symmetry and also in orthodontic diagnosis and treatment planning [4].

2.4. Cone-beam CT (CBCT)

Due to the fact that the maxillofacial region includes fairly complex 3D anatomy, often traditional imaging fails to address the patient clinical problem. The evolution of the X-ray technology has succeeded in introducing new imaging methods that can help overcome these problems. One example is dental CBCT that uses a cone- or pyramid-shaped X-ray beam directed on the pursued maxillofacial field-of-view (FOV). The image receptor in this X-ray system is either a flat panel detector (FPD) or a CMOS detector. The machine is similar to a panoramic unit that, apart from the digital detector, has sophisticated software to produce 3D images. The patient is standing or seating in most cases. The C-arm of the X-ray unit rotates around the patient, taking multiple aquisitions (starting from 200 reaching up to 600 images depending on the acquisition time and the extent of the revolution pathway), that are used to produce the 3D images. The particular technology, developed the last 15 years has revolutioned the practice of dentistry [3,15,16] at the expense though of higher radiation dose.

2.5. Multi-detector CT (MDCT)

This imaging procedure involves a conventional MDCT scanner that has special dental software to image the whole mouth area and surrounding tissues. The patient is not standing as in CBCT but he is lying on the CT bed exactly as if he would do for a CT scan. Modern MDCTs use a widened fan-shaped beam and a 2D detector that produces submillimeter images (as small as 0.5 mm) with sub-second rotation times. This technique gives in general higher doses than dental CBCT although there are studies in the recent literature that investigate various technical protocols and MDCT scanners technologies that could provide acceptable image quality at low radiation dose [17–19].

3. Patient dose assessment

Radiation dose measurement is a very important tool for optimization. There are various dose quantities that can be used to measure patient radiation dose, depending on the X-ray system. They are described in detail elsewhere [20] and outlined briefly in this section: 1) Incident Air Kerma (IAK) measured in Gray (Gy), 2) Entrance surface Air Kerma (ESAK) measured in Gy, 3) Air Kerma–Area product (KAP) measured in Gym^2, 4) Air Kerma–length product (KLP) or Dose–Width product (DWP) measured in Gym, 5) CT Air Kerma index ($CTDI_{air}$) measured in Gy and 6) Weighted CTDI ($CTDI_w$) measured in Gy. In some older X-ray machines instead of KAP we find the dose quantity called Dose Area Product (DAP). KAP is similar to DAP in diagnostic radiology. Table 1 shows main technical and dose parameters of all systems [20].

Another important dose quantity is Effective dose (E). It is used to assess the radiation risk from ionizing radiation. E is the weighted sum of each tissue equivalent dose (D_E) multiplied by the corresponding tissue weighting factor for tissue T (w_T). The unit of E is the Sv and can be used to compare modalities and techniques. The organs and/or tissues considered are those that are sensitive to the induction of stochastic effects including cancer and heritable effects. The w_T values were defined in International Commission on Radiological Protection (ICRP) Publication 60 in 1990 [21] and were revised in 2007 in ICRP Publication 103 [22]. As recently reported [23], E will rise by approximately 32–422% in dental radiology due to the inclusion of salivary gland, oral mucosa, muscle, lymphatic nodes and extra thoracic airway in the list of radiosensitive tissues in the ICRP 103 publication [22]. There are a number of studies that have measured doses of radiation for dental radiography, but only a few have estimated effective dose [11,24]. There are still a number of radiographic techniques for which no published data are available and some for which very different results have been reported [11]. Organ and effective doses in dental radiology are estimated using Monte Carlo computational methods such as the personal computer-based Monte Carlo (PCXMC) software [25] and the International Commission on Radiological Protection voxel adult male and female reference phan-

Please cite this article in press as: Tsapaki V. Radiation protection in dental radiology – Recent advances and future directions. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.07.018