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TECHNICAL NOTE

RADIATION EXPOSURE AND DOSE EVALUATION IN INTRAORAL DENTAL RADIOLOGY

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In this study, dose area product measurements have been performed to propose diagnostic reference levels (DRLs) in intraoral dental radiology. Measurements were carried out at 60 X-ray units for all types of intraoral examinations performed in clinical routine. The third quartile values calculated range from 26.2 to 87.0 mGy cm^2. The results showed that there exists a large difference between the patient exposures among different dental facilities. It was also observed that dentists working with faster film type or higher tube voltage are not always associated with lower exposure. The study demonstrated the necessity to have the DRLs laid out as guidelines in dental radiology.

INTRODUCTION

Diagnostic reference levels (DRLs) have been introduced by the European Union in the Medical Exposure Directive (MED) (97/43/Euratom)(1). The directive requires the member states to promote the establishment and the use of DRLs and to ensure that implementation guidance is available. These values should not be exceeded if good practice is performed. They are helpful in identifying inadequate techniques or machine malfunctions in the case where they are consistently exceeded so that appropriate corrective action could be undertaken. Since then, DRLs have been implemented by different organisations(2,3) and countries(4,5) for standard procedures in diagnostic radiology. Dental radiological procedures are sporadically included only in these studies. The explanation might be that the dose incurred by patients is considered to be low and has not been given the same degree of importance as other procedures in diagnostic radiology. However, when taking into account that dental radiology is the most frequent X-ray examinations performed(3), its significance should not be overlooked. In addition to that, the majority of dental radiology investigations is performed in dental clinics where no routine quality assurance programme is present or no proper operator training may be given(6). Patients may be subjected to unnecessarily high-radiation doses due to unsatisfactory equipment or inadequate techniques.

Entrance surface dose (ESD), dose area product (DAP) or other dose-related quantities may be used to establish DRLs(2). In this work, DAP has been chosen as the measurement quantity as it could be measured without the patient in place. Moreover, the field size of the beam is directly reflected on the measured value. Although most X-ray units are still equipped with cylindrical collimators, there is an increasing trend that a rectangular collimator which better matches the size and the shape of the film is being used. Helmrot and Alm Carlsson(7) have also proposed DAP as the dose quantity in establishing reference levels in dental radiology.

This work has been carried out as part of a study (StSch 4436) initiated by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to establish DRLs for dental radiology in Germany. Therefore, a representative number of introral X-ray units were selected from a database containing 2000 Northern German dentists. DAP measurements were carried out without the patient in place for standard intraoral examinations performed in clinical routine.

MATERIALS AND METHODS

Overall 60 intraoral X-ray units were selected randomly from a database of 2000 dentists in the Lower Saxony region, Germany. Out of the 60 X-ray units, 9 were equipped with a digital image receptor system. Six of the digital systems used storage phosphor plates and three used charge-coupled device sensor chips. Out of the measured X-ray units, there are

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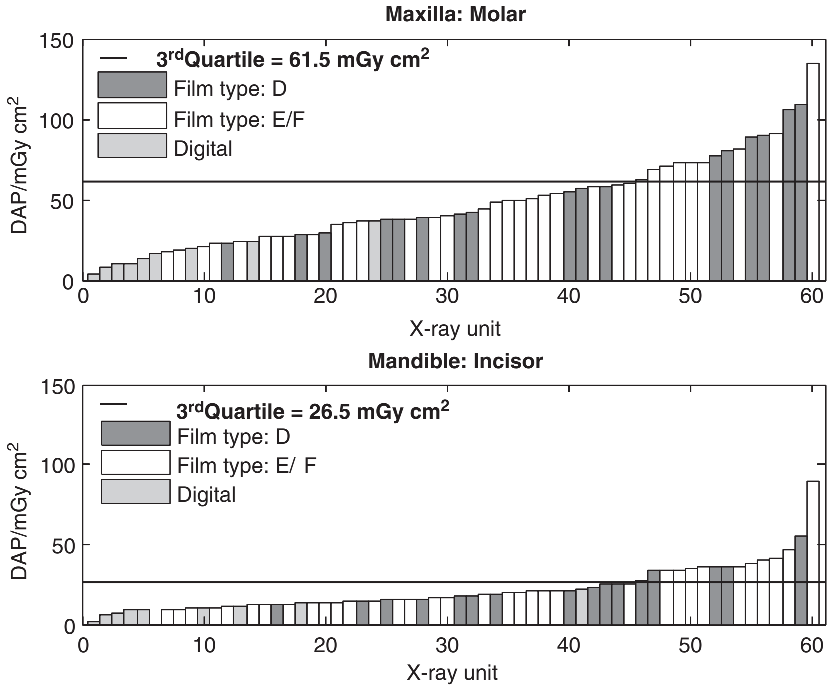

Figure 1. DAP values of maxillary molar and mandibular incisor examinations. *x*-axis indicates the measured X-ray units. The image receptors employed are marked in different shades of grey.

6 units operating at 50 kV, 6 units at 60 kV, 32 units at 65 kV, and 16 units either operating at 70 kV or with adjustable tube voltage between 60 and 70 kV.

DAP values for all standard exposure programmes used in daily clinical routine by different dentists were measured (periapicals maxillary and mandibular molar, premolar, canine and incisor radiography, bitewing radiography, and occlusal radiography) using a translucent transmission ionisation chamber connected to a DAP meter (DIAMENTOR M4, PTW-Freiburg, Germany). The calibration was performed by the manufacturer in the energy range of 50–150 kV. A maximum uncertainty of 5% is expected due to the variation in tube voltage of the intraoral X-ray units investigated in this study. A discrepancy of our results due to the calibration process is therefore negligible in this context. The ionisation chamber was attached to the end of the exit cone of the X-ray unit. To eliminate dose contribution from backscatter radiation, the exit cone was pointed towards the centre of the examination room. For each X-ray unit, the DAP value of one chosen programme was measured three times to check the stability of the X-ray unit. The exposure parameters such as tube voltage, tube current and exposure time were documented for each measurement. For references, the types of X-ray units along with the manufacturers, film speed and film developer were also recorded. Around 30% of the clinics equipped with conventional systems are still using D-speed film whereas others have switched to faster E/F-speed film which could reduce exposure up to 50%[8].

The third quartile value (proposed DRL) was calculated alongside with the mean and standard deviation for each type of examination. In order to compare our results with the published data, proposed DRLs in terms of cone end dose (CED) and ESD are estimated from the results of this study using the DAP third quartile values. CED measured in air was calculated by dividing the DAP value by the field size. For a general comparison, a field size of 28.3 cm^2 has been used which corresponds to a cylindrical collimation with 6 cm diameter representing the most common type of collimation used in clinical practices. ESD was calculated as above using a backscatter factor of 1.2[9] and a mass attenuation coefficient ratio of 1.05[10] from human tissue to air.

RESULTS

Measured DAP values of the 60 X-ray units examined are given in Figure 1 for maxillary molar and

Table 1. Third quartile (proposed DRL), mean and standard deviation of the DAP values together with the proposed DRLs in terms of CED measured in air and ESD for each type of intraoral X-ray examinations.

Examination	Third quartile (mGy cm^2)	Mean (mGy cm^2)	Standard deviation (mGy cm^2)	CED measured in air (mGy)	ESD (mGy)
Maxillary molar	61.5	47.1	27.5	2.2	2.7
Maxillary premolar	44.1	32.7	17.9	1.6	2.0
Maxillary canine	36.2	28.6	16.4	1.3	1.6
Maxillary incisor	37.9	29.1	17.7	1.3	1.7
Mandibular molar	41.2	31.2	18.8	1.5	1.8
Mandibular premolar	31.8	23.9	13.2	1.1	1.4
Mandibular canine	31.8	23.4	13.2	1.1	1.4
Mandibular incisor	26.2	21.5	14.3	0.9	1.2
BTW: Front	46.1	35.0	20.0	1.6	2.1
BTW: Back	47.3	36.8	20.7	1.7	2.1
OCC: Maxilla	87.0	72.2	34.7	3.1	3.9
OCC: Mandible	71.2	55.6	26.3	2.5	3.2

BTW: bitewing; OCC: occlusal.

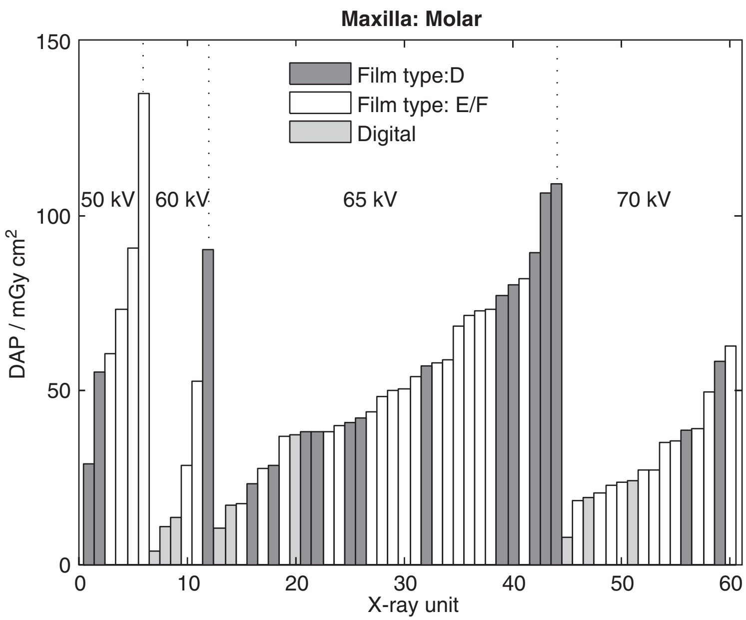

Figure 2. DAP values of maxillary molar examinations grouped according to the tube voltage of the X-ray units.

mandibular incisor examinations. The third quartile values of the measurements are marked in the figure. Alongside with the DAP values the image receptors used are also shown in the graphs. There is a large difference between the doses of different X-ray units for the same examination. As an example, the measured DAP values for maxillary molar examinations range from 3.8 to 134.8 mGy cm^2. The minimum dose measured for non-digital systems was 17.4 mGy cm^2 and the maximum value measured was 134.8 mGy cm^2.

Third quartile (proposed DRL), mean and standard deviation for each type of intraoral examinations together with the proposed DRLs in terms of CED measured in air and ESD are summarised in Table 1. The highest third quartile value was calculated for occlusal examinations, whereas the lowest value was calculated for mandibular incisor examination.

Figure 2 shows the DAP values for maxillary molar examinations grouped according to the tube voltage. It was observed that the use of a higher

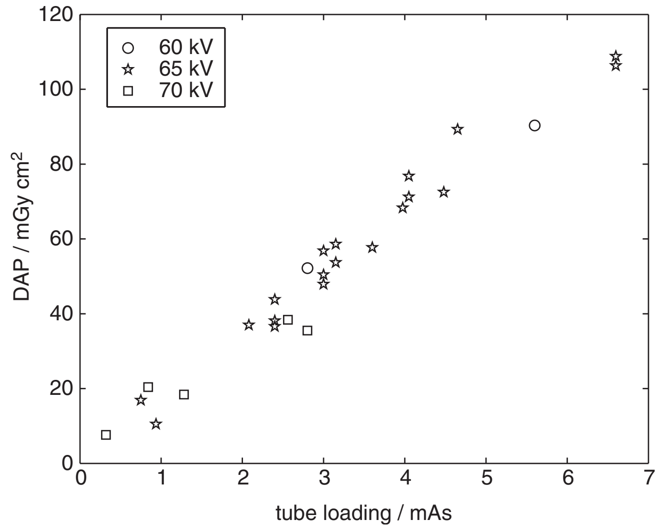

Figure 3. DAP values for X-ray units operating at 60, 65 and 70 kV equipped with 2 mm aluminium filtering and cylindrical collimation with 6 cm diameter plotted against the tube loading (mA s).

speed film does not always lead to dose reduction. It also shows that digital system generally requires less exposure than conventional film radiology.

Almost all types of intraoral X-ray units operate at fixed tube voltage. As recommended by Radiation Protection Document No. 136 by the European Commision[8], tube voltage of intraroal X-ray units should lie between 60 and 70 kV. Figure 3 shows the DAP values for three main categories of X-ray units operating at 60, 65 and 70 kV plotted against the tube loading (mA s) all equipped with 2 mm aluminium filtering and 6 cm diameter cylindrical collimation. The DAP values exhibit a linear relationship with the tube loading. It could be observed that units operating at higher (70 kV) tube voltages are associated with lower DAP values owing to the shorter exposure time.

DISCUSSION

From the measured DAP values, one can observe a large difference between patient exposures among different dental facilities. The differences are up to a factor of 35 for the same examination. This indicates inconsistencies of radiological practices performed in clinical routine. The main reasons may arise from the different X-ray units, exposure techniques, film speed or even inadequate exposure setting and film-developing procedures, and further demonstrates the necessity to have the DRLs laid out as guidelines. It is remarkable that several facilities using an E/F-speed film have higher doses than other facilities using the less sensitive D-speed films. For example, in the category of dentists using X-ray units operating at 65 kV, the lowest dose measured using D-speed film is ~3.5 times lower than the highest dose measured using E/F-speed film (Figure 2). It can be concluded that many dentists do not use dose-optimised programmes for the faster films. During interviews with the dentists, we realised that many times the transition to a more sensitive image receptor or film has been performed without careful adjustment of machine parameters such as the exposure time. The transition to faster film types should therefore always be accompanied by a reduction in exposure time, which was not always the case in our study. Technologists should be informed about the necessity of reducing exposure time when working with faster films.

The correlation between DAP and tube loading (Figure 3) may be used as a rule of thumb in determining the imparted dose on patients. The third quartile value for maxillary molar examination derived from this study corresponds to ~3.8 mA s. Using the most common tube current of intraoral X-ray units of 7 mA, one can easily compute the exposure time of 0.54 s in this case. X-ray units operating at different tube voltages did not show significant distinctive behaviour in our results.

Dose surveys for intraoral radiology have been carried out in a number of European countries[11–15]. Some of the results from these surveys and the proposed DRLs are summarised in Table 2. One could observe a decreasing trend in the dose values, which may be due to the transition to faster film-speed or digital techniques and the availability of modern

Table 2. Survey results and proposed DRLs of a number of European countries.

Country	Proposed DRL/survey result	Dose quantity	Examination
Denmark (1995)[11]	Third quartile: 3.5 mGy (E-speed), 6.3 mGy (D-speed)	CED measured in air	Mandibular incisor
Greece (1998)[12]	71% < 5 mGy	ESD	Mean exposure times
Greece (2005)[13]	Mean: 34–80 mGy cm^2	DAP	Not given
Spain (2001)[14]	DRL: 3.5 mGy	ESD	Averaged over all projections
UK (2002)[15]	DRL: 2.1 mGy	CED measured in air	Mandibular molar

X-ray units with high voltage multi-pulse generators. Our results are in general lower but still in the same range than the published values. One of the reasons for this is the fact that we have included a number of newer X-ray units partially equipped with digital image receptors in our study.

CONCLUSION

A comprehensive work has been carried out in an attempt to propose DRLs for intraoral radiology in Germany. This study involved a representative number of X-ray units and the reference levels derived from the data reflects the actual clinical practices in the country. A large dose variation between different X-ray units has been observed. Dentists working with faster film type or higher tube voltage are not always associated with lower exposure. Increased attention needs to be paid to dental radiology to minimise the dose imparted on patients. The proposed DRLs derived from this study are readily used as guidelines to identify improper practice in intraoral dental radiology. DRLs for panoramic radiology and paediatric intraoral dental radiology have been proposed and reported in previous studies[6,16]. Investigations were also carried out for other imaging techniques commonly used in dental radiology such as lateral cephalometric radiography, computed tomography and digital volume tomography (volumetric computed tomography). The results of these studies will be reported in separate works.

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