Review article

DIAGNOSTIC REFERENCE LEVELS IN DENTAL RADIOLOGY: A SYSTEMATIC REVIEW

Diagnostične referenčne ravni v dentalni radiologiji - Sistematični pregled literature

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ABSTRACT

Purpose: The purpose of this work was to review published articles in the field of diagnostic reference levels in dental radiology, and to determine which areas have not been covered yet and require further scientific studies. The aim was also to determine if there are any dose optimization procedures suggested after DRL establishment.

Materials and methods: A systematic review was performed using the Science Direct, PubMed, CINAHL (via EBSCOhost) and Dentistry & Oral Sciences Source (via EBSCOhost) databases, following the Cochrane Network study design guidelines. Articles were analysed and presented by author, year of publication, country of origin, technology (e.g. digital radiography, computed radiography and film-screen), radiographic type (e.g. intraoral, panoramic and CBCT), units of measurement and main conclusions for each study.

Results: Thirteen scientific articles on dose reference values in dental radiology were evaluated. Full-access articles published between 2001 and 2021 were used, and both reviews and original research articles were included. The studies address the definition or analysis of DRLs in intraoral and panoramic dental imaging and in dental CBCT imaging. Many studies report results based on different image-receiving systems (e.g. DR, CR and film-screen). The film-screen system yielded the highest dose values of all three systems. All studies reviewed describe DRLs for the adult population, while only four also describe paediatric DRLs.

Conclusion: Most EU countries have not yet set national DRLs for dental radiology. Most studies set or revise DRLs at the national level and compare them with guidelines from literature and from similar studies conducted in other countries. Most of these studies observed DRLs in the adult population. DRLs should also be set in the field of dental CBCT imaging, as the use of this technology is rapidly increasing and the dose levels are incomparably higher than in general dental radiography.

Keywords: dental radiography, diagnostic reference levels, intraoral imaging, panoramic dental imaging.

IZVLEČEK

Namen: Namen tega dela je pregledati objavljene članke s področja diagnostičnih referenčnih ravni v dentalni radiologiji, določiti področja znotraj slednje, ki še niso bila obravnavana in ki zahtevajo nadaljnje raziskave, pa tudi raziskati, ali po vzpostavitvi diagnostičnih referenčnih ravni študije predlagajo katero od oblik optimizacije doze.

Materiali in metode: Izvedli smo sistematični pregled literature z uporabo podatkovnih baz Science Direct, PubMed, CINAHL (preko EBSCOhost) ter Dentistry & Oral Sciences (preko EBSCOhost). Pri zasnovi študije smo delno sledili smernicam Cochrane omrežja. Članke smo analizirali in razvrstili glede na avtorje, leto objave, državo nastanka, tehnologijo (digitalna radiografija, računalniška radiografija, sistem folija-film), vrsto slikanja (intraoralno, panoramsko, CBCT) in uporabljene merske enote, za vsako študijo pa smo zapisali glavne ugotovitve.

Rezultati: Trinajst znanstvenih člankov, ki obravnavajo diagnostične referenčne ravni v dentalni radiografiji, smo analizirali in ocenili. Uporabili smo članke s polnim dostopom, objavljene med leti 2001 in 2021. Upoštevali smo tako izvirne kot pregledne znanstvene članke. Raziskave obravnavajo vzpostavitev ali analizo DRR-jev pri intraoralnem, panoramskem in zobnem CBCT slikanju. Velik delež raziskav poroča in ločuje rezultate glede na slikovni sprejemnik (DR, CR, folija-film). Sistem folija-film se je izkazal kot sistem z najvišjimi doznimi vrednostmi. Vse analizirane raziskave obravnavajo odraslo populacijo, le 4 opisujejo tudi DRR-je za pediatrijo.

Zaključek: Večina držav Evropske unije še nima vzpostavljenih DRR-jev na nacionalnih ravneh za področje dentalne radiologije. Večina obravnavanih raziskav vzpostavlja DRR-je na nacionalni ravni in jih primerja s smernicami iz literature ali s podobnimi študijami, izvedenimi v drugih državah. Večina raziskav obravnava odrasle paciente. Pojavlja se pomanjkanje raziskav s področja DRR-jev za dentalno CBCT slikanje, saj je uporaba te tehnologije v strmem porastu, dozne ravni zanjo pa so občutno višje v primerjavi s splošno dentalno radiologijo.

Ključne besede: dentalna radiografija, diagnostične referenčne ravni, intraoralno slikanje, panoramsko slikanje

Introduction

Technological development in dental radiology began after 1919, when adequate electrical insulation made it possible to safely perform intraoral imaging techniques. Panoramic dental imaging was developed and introduced for general use in the 1960s, while computed tomography has been used since the 1970s (1).

The newest technology in dental radiology is cone beam computed tomography (CBCT), the use of which is rapidly increasing. It was developed for the maxillofacial region in 1995 and has been available for commercial use since 1999. Its use is popular primarily because it is a low-cost diagnostic technology that enables treatment planning and image-guided surgical and operative procedures (2).

Ionizing radiation exposure in dental radiology contributes to approximately 2.5% of the effective dose received during medical examinations. The average adult effective dose for intraoral radiographs is 0.005 mSv for panoramic radiographs 0.01 mSv, and 0.011 to 1.073 mSv for dental computed tomography (3).

According to the European guidelines for radiation protection in dental radiology, 96 to 449 dental radiological examinations are performed per 1,000 inhabitants in the countries of the European Union that have provided such data (4). Because of the large number of professionals performing such procedures and because many examinations in dentistry involve the use of ionizing radiation, certain radiation protection measures must be considered for patients exposed to a certain dose of ionizing radiation during these imaging examinations. One way to ensure optimal performance by a healthcare provider when using ionizing radiation is to determine diagnostic reference levels (DRLs)

DRLs are usually easy to measure and are directly related to the radiation dose received by the patient (5). DRLs are the dose levels for ionizing radiation in diagnostic radiologic procedures that should not be exceeded if the procedure is optimized. They are determined using measured dose levels for patients undergoing a specific diagnostic examination. It is recommended that they be measured on as many x-ray machines as possible. The DRL is determined by the value of the third quartile of all doses received (6).

Diagnostic reference values for radiological procedures in adults have been established for 72% of the 36 European countries. According to the European Commission report, the specific DRL values for dental radiology have only been applied at the national level in Finland and France (7). The European guidelines for radiation protection in dental radiology also state that few countries have conducted national or similar studies to determine DRLs and that there are no published DRLs for dental radiography at the European level (4). The establishment of national and local DRLs is proposed by the International Atomic Energy Agency for all medical examinations and procedures, for all clinical indications and for all patient groups (adults and size-dependent groups of children) (8).

Because of the aforementioned large number of radiologic procedures performed annually in dentistry, the establishment of DRLs for this profession is of great importance. Specifically, for CBCT imaging, there is also a great need to establish DRLs, as the doses of ionizing radiation received in this technology are considerably higher than those received in intraoral or panoramic dental imaging and are comparable to those received by the patient during radiographs of the pelvis or abdomen (7).

We use different units of measurement to determine DRL values. In general radiography, air kerma product (KAP or PKA) and entrance surface air kerma (Ke) are commonly used. CTDIvol (computed tomography dose index) or dose length product (DLP) are used in computed tomography, while the received dose is considered in terms of activity delivered to the patient or activity per kilogram of body weight in nuclear medicine. Literature recommends using incident air kerma (Ki) for intraoral dental imaging and PKA for dental panoramic imaging (8).

The authors of the articles discussed in this paper also use the unit PED (patient entrance dose) instead of ESD (entrance skin/surface dose). It is defined as the absorbed dose in air measured at the end of the spacer 'cone' for typical examinations without backscatter from the patient (9).

Aim of the study

The aim of this systematic review was to investigate how many countries, health facilities or radiology departments have already established diagnostic reference values for dental radiology. The aim was also to determine which areas of dental radiology (intraoral, panoramic or CBCT imaging) these DRLs cover and whether their establishment has suggested dose optimization for patients.

Methods

We performed a systematic review of literature. We relied in part on the guidelines of the Cochrane network when designing our study (10).

Sources

The Science Direct, PubMed in CINAHL (via EBSCOhost) and Dentistry & Oral Sciences Source (via EBSCOhost) scientific databases (11–14) were used to perform the search via the University of Ljubljana's and Central Medical Library's remote access.

Inclusion and exclusion criteria

A search algorithm based on a combination of keywords and logical operators was used in this review and is described in Table 1. No exclusion criteria in the first search (for example the use of logical operator NOT) were applied.

In the next step of the process, other conditions were set: full access articles, not older than 10 years (published between 2001 and 2021), and the inclusion of reviews as well as original research articles. After the initial search, which yielded 134 documents, exclusion criteria were applied and, at the end of the process, 13 articles were considered for inclusion in this review. The step-by-step process of document selection is shown in Figure 1.

The results of the review were then presented in Table 2. Studies were listed by author, year of publication, country of origin, technology (e.g. digital radiography, computed

Table 1: Keywords and logical operators

1st keyword	Logical operator	2nd keyword	Logical operator	3rd keyword
dental	OR	dentistry	OR	oral
Logical operator: AND				
x- ray	OR	radiology	OR	radiography
Logical operator: AND				
DRL	OR	diagnostic reference levels		

radiography and film-screen), type of radiography (e.g. intraoral, panoramic and CBCT), units of measurement, and main conclusions for each study.

Results

By using search terms and exclusion criteria described earlier and after further analysis of titles and abstracts, 13 studies were eligible for inclusion in this systematic review and are presented in Table 2.

This systematic review analysed 13 scientific articles from 10 different countries that address the area of diagnostic reference values in dental radiology. Most of them deal with the establishment and/or analysis of DRLs in general radiography (intraoral and panoramic dental imaging), while only two studies deal with CBCT imaging (17, 21). The DRLs are considered at the national level, while the authors performed comparisons between institutions and a larger number of radiographic units. Only Izawa et al (20) specify local DRLs and a comparison of three units at an institution with the aim of optimising and standardising the institution's imaging protocols.

The authors of studies also frequently reported results on different image-receiving systems (e.g. DR, CR and film-screen). In all studies that made such a comparison, the film-screen system was found to have the highest dose levels of all three systems.

All studies reviewed describe DRL values for the adult population, while only four studies (9, 19, 22, 25) also describe paediatric DRL values. The importance of the latter is particularly emphasised in Holroyd's study, as it describes cephalometric imaging and the associated dose burden. Since cephalometric imaging is most commonly used in orthodontics and the patients are mostly children, special attention should be paid to optimal (as low as possible) dose exposure in this type of dental radiology, since children are more sensitive to ionising radiation, which can cause more damage in children than in adults (19).

Discussion

All articles studied report specific DRL values, i.e. the value of the 3rd quartile of measured doses from their data. The values are then compared with literature, with guidelines or, as in the study by Manousaridis et al. (23), with previous studies from the same country. This shows the importance of national DRL facilities everywhere, including Slovenia.

Some authors emphasise the legal reasons for conducting these types of studies. For example, Alcaraz et al (15) mention the legal status of mandatory annual DRL reviews as part of the quality assurance programme in Spain. This may serve as a reason for conducting such studies. These reviews are mandatory in most European countries, but not all countries specify the time frame for their implementation. For example, Slovenian legislation does not specify how often a DRL review should be performed, but does states that the institution responsible for radiation protection should set DRL values based on systematic reviews of patient exposure and that it should follow European and other international recommendations in this area (27).

Considering the small number of studies performed in CBCT imaging DRLs, this area of radiology seems very suitable for further research. The use of this technology is rapidly increasing, but dose levels can be up to 26 times higher than in dental panoramic imaging (18).

Dose optimization for specific imaging modalities should always be considered. This applies to exposure parameters for general radiography, as well as FOV and resolution (these two can be controlled by the user) for CBCT imaging. It is especially important to establish and regularly revise DRLs, as they are one of the key factors that guide all parties involved in the process (dentists, radiographers, radiologists, medical physicists and service technicians) toward a high-quality work process that causes the least possible harm to patients.

Limitations

The fact that there are significantly fewer studies in the field of dental radiology compared to general radiography (X-ray or computed tomography) is the reason why this systematic review has limitations. When the sample is larger, the results are easier to interpret. In our case, we can only compare them in terms of their main results and derive some guidelines for possible further research, for example, the recommendation to extend the research to the field of CBCT imaging and the associated dose burden. Another problem that appears in our review is the problem of comparing the studies correctly because they do not all use the same units of measurement. Some even suggest the use of new units of measurement, although literature recommends using Ki for intraoral and PKA for panoramic images.

Table 2: Review of studies

Author	Year	Country	Sample	Technology	Radiography type	Units of measurement	Main conclusions
Alcaraz et al. (15)	2012	Spain	16175 official reports, gathered between 2002 and 2009	DR, CR, film-screen	Intraoral	ESD	Eight-year-long observation (2002–2009). DRL value in 2009 was 3.1 mGy (which is 35.4 % less than in 2002 when the value was 4.8 mGy). EU guidelines for intraoral imaging in 2004 recommended a value of 4 mGy; 83.4 % of institutions are below this value. DRL values also change which each system used (DR has the lowest, while film-screen has the highest one). Regular revisions are suggested, at least every three years (Spanish legislation even requires them every year) as part of the QA programme in dental offices. Limitation: there is no data on how many expositions were repeated.
Alcaraz et al. (16)	2015	Spain	34143 official reports gathered between 1997 and 2014	DR, CR, film-screen	Intraoral	ESD	DRR observation from 2002–2014. In 2014, the value was 2.8 mGy (41.7 % less than in 2002 when the value was 4.8 mGy). In the last three years since their last study, DRL values stabilised. It is assumed that this happened because of the stabilisation in technology system changes and the establishment of digital systems. For every x-ray machine, 10 exposures were made, measured in mGy, for upper second molar.
Christofides et al. (9)	2016	Cyprus	20 machines	Film-screen	Intraoral	DAP	They stress the importance of DRL establishment for all age groups (this study also included children) and the calculation of PED value. DRLs are between 7.23 mGy (upper molar, adults) and 1.88 mGy (lower incisor, children). The DRLs are slightly higher than those of EU guidelines, although those are expressed as ESD values, while the ones from this study are in PED value, which does not include backscatter radiation. There are significant differences between the 20 locations (x-ray machines). Dose value standardisation and reduction are supposed to be achieved in the future, primarily by transitioning to digital receivers.
Deleu et al. (17)	2020	Switzerland	227 machines	DR	CBCT	P_{KA}, $CTDI_{vol}$	Besides DRL establishment, the study also suggests the establishment of certain guidelines and recommendations on FOV (field of view) sizes, even though their results showed that mostly small size FOV are used (average area 25 cm^2, which means this aspect of dose reduction is already considered and in use). The suggested DRLs in this study are normalized to the FOV dimension. Head and neck CBCTs were also considered in this study, not only dental, although the indications still mostly require dental CBCTs, so the establishment of DRLs in this area is especially important.

Author	Year	Country	Sample	Technology	Radiography type	Units of measurement	Main conclusions
Han et al. (18)	2011	South Korea	129 machines	DR	Intraoral, panoramic, cephalometric, CBCT	DAP	The measured values for intraoral examinations are 55.5; 46 and 36.5 mGy*cm^2 (for upper molar, premolar and incisor, respectively) and 120.3; 146 and 3,203 mGy*cm^2 for extraoral examinations (for panoramic, cephalometric and CBCT imaging, respectively). In intraoral dental imaging, the DAP value relates to tube current and exposure time product (mAs), while the CBCT imaging's DAP is more closely linked to the FOV. There are some differences in the measured dose values between private clinics and university hospitals.
Holroyd et al. (19)	2011	Great Britain	42 machines	DR, CR, film-screen	Cephalometric	DAP	A phantom study. DAP values for adults: 40 mGy*cm^2 for digital systems and 42 mGy*cm^2 for screen-film. For children: 25 mGy*cm^2.
Izawa et al. (20)	2017	Japan	3 machines (local DRLs)	Film-screen	Intraoral	P_{KA}, PED	Local DRLs were established taking into account a possible difference between genders. The dose values are slightly lower in women, which is supposed to be a consequence of the difference in size, since women ae usually smaller, so the operator should adjust exposure parameters. PED values are 1.56 ± 0.27, 1.09 ± 0.31, 1.92 ± 0.38, mGy for upper incisors, premolars and molars, respectively, and 1.27 ± 0.22, 2.42 ± 0.33 in 1.59 ± 0.20 mGy for lower incisors, premolars and molars, respectively.
Kim et al. (21)	2012	South Korea	126 (104 considered in the study) machines	DR, CR, film-screen	intraoral	DAP, PED	The study recommends DRL values for South Korea: 3.1 mGy (PED) and 87.4 mGy*cm^2 (DAP) for lower molar for adults. This study also shows lower dose values in digital systems compared to those in film-screen systems. They also considered the installation duration of the machine (<5 years in >6 years) and the type of dental x-ray machine (e.g. wall-mounted fixed type and hand-held portable type). There were no statistically significant differences with respect to equipment installation duration and type of dental X-ray system.
Manousaridis et al.(22)	2015	Greece	519 machines	DR, CR film-screen	panoramic	K_i	Three categories were analysed: children, petite adults and average adults. Recommended DRLs were 2.2; 3.3 and 4.1 mGy, respectively. Three systems were compared as well (DR, CR and film-screen), with dose values at the 3rd quartile of 3.5; 4.2 and 3.7 mGy, respectively. As we can see, the highest dose value is recorded with the CR system.

Author	Year	Country	Sample	Technology	Radiography type	Units of measurement	Main conclusions
Manousaridis et al. (23)	2013	Greece	529 machines	DR, CR, film-screen	Intraoral	K_i	DRL value for upper molar is set at 0.95 mGy for digital systems and 2.90 mGy for film-screen, which is comparable to or even lower than in those countries that at the time of this study provided such data (Spain, USA, Romania, Great Britain and previous studies in Greece).
Praskalo et al. (24)	2020	Bosnia and Herzegovina	41 machines	DR, film-screen	Intraoral	K_i, P_{KA}	New DRLs for the film-screen system (3.5 mGy) and for digital receivers (1.2 mGy) are recommended and are significantly lower than those established until now at the national level with a DRL value of 7 mGy. This value was taken from literature and not established as a result of a national study. There are considerably lower doses for digital receivers.
Suliman, Abdelgadir (25)	2018	Sudan	14 machines	DR, film-screen	Intraoral, panoramic	K_i, P_{KA}	The study recommends new DRLs for intraoral imaging: 1.45 mGy (DR), 4.45 mGy (film-screen) and 3.01 mGy (combined). For panoramic dental imaging, only average values are stated (and not the 3rd quartile, which is specific for DRLs): 70.4 mGy*cm^2 for children and 103.4 mGy*cm^2 for adults. The study describes significant differences between hospitals. This shows the there is a lot of room for protocol optimisation.
Walker et al. (26)	2010	Ireland	83 machines	*data unavailable*	Intraoral, panoramic	ESD, DWP (dose width product)	Suggested DRLs from this study are 2.4 mGy for lower molar for intraoral imaging and 60 mGy mm for panoramic imaging of adults. The study also recommends the introduction of a new reference quantity 1 mGy/mAs, which considers dose as well as exposure time. The recommended DRL for intraoral imaging with this new unit is 1.03 mGy/mAs. DRLs are comparable to literature, sometimes even lower due to new technologies.

Conclusion

As stated in the introduction from the European Commission Guidelines for Radiation Protection in Dental Radiology, most EU countries have not yet established national DRLs for dental radiology. In this systematic review, 13 original research articles on local or national DRLs in dental radiology for the EU and other countries were discussed. Most of these studies focus on intraoral and panoramic dental imaging, with only a few on CBCT imaging. This implies that there is room for further research in this area. Most studies set or revise DRLs at the national level and compare them with guidelines from literature and from similar studies conducted in other countries. Only one study is the result of local DRL establishment with the goal of protocol optimization. In our selection of articles, DRLs are mostly set for the adult population, and only in four cases for paediatric patients, although they require special consideration in terms of dose optimization.

In the future, DRLs should also be set in the field of dental CBCT imaging, as the use of this technology is rapidly increasing, and dose levels are incomparably higher than for general dental radiography. All EU countries should set DRLs for radiographs and for dental CBCT imaging, as suggested in guidelines or recommendations issued by European institutions responsible for radiation protection.

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