Dentomaxillofacial Radiology (2020) 49, 20190468

birpublications.org/dmfr

RESEARCH ARTICLE

Establishment of national diagnostic reference levels in dental cone beam computed tomography in Switzerland

[1,2]Marine Deleu, [3]Dorothea Dagassan, [4]Isabelle Berg, [1]Julie Bize, [5]Karl Dula, [2]Vincent Lenoir, [6]Barbara Ott, [7]Julien G. Ott, [1]Francis R. Verdun, [8]Robert Weber, [9]Panagiotis Ziglinas, [2]Cesare Zingariello and [2]Marta Sans Merce

[1]Institute of Radiation Physics, Lausanne University Hospital, Lausanne, Switzerland; [2]Department of Radiology, University Hospital of Geneva, Geneva, Switzerland; [3]University Center of Dental Medicine Basel, Center for Dental Imaging, University of Basel, Basel, Switzerland; [4]University hospital of Basel, Basel, Switzerland; [5]University of Bern, Bern, Switzerland; [6]Radiation Protection Division, Federal office of Public Health, Bern, Switzerland; [7]HNO-Zentrum, Bern, Switzerland; [8]Division of Medical Radiation Physics, Inselspital, Bern, Switzerland; [9]Praxisklinik, Basel, Switzerland

Objectives: The aim of this study was to establish diagnostic reference levels (DRLs) in the field of dental maxillofacial and ear-nose-throat (ENT) practices using cone beam CT (CBCT) in Switzerland.
Methods: A questionnaire was sent to owners of CBCTs in Switzerland; to a total of 612 institutions. The answers were analyzed for each indication, provided that enough data were available. The DRLs were defined as the 75th percentile of air kerma product distribution (P_{KA}).
Results: 227 answers were collected (38% of all centers). Third quartile of P_{KA} values were obtained for five dental indications: 662 mGy cm² for wisdom tooth, 683 mGy cm² for single tooth implant treatment, 542 mGy cm² for tooth position anomalies, 569 mGy cm² for pathological dentoalveolar modifications, and 639 mGy cm² for endodontics. The standard field of view (FOV) size of 5 cm in diameter x 5 cm in height was proposed.
Conclusions: Large ranges of FOV and P_{KA} were found for a given indication, demonstrating the importance of establishing DRLs as well as FOV recommendations in view of optimizing the present practice. For now, only DRLs for dental and maxillofacial could be defined; because of a lack of ENT data, no DRL values for ENT practices could be derived from this survey.
Dentomaxillofacial Radiology (2020) **49**, 20190468. doi: 10.1259/dmfr.20190468

Cite this article as: Deleu M, Dagassan D, Berg I, Bize J, Dula K, Lenoir V, et al. Establishment of national diagnostic reference levels in dental cone beam computed tomography in Switzerland. *Dentomaxillofac Radiol* 2020; **49**: 20190468.

Keywords: Diagnostic reference level; Cone beam computed tomography; Dental Radiography; Dose area product; Clinical DRL

Introduction

Over the last 10 years, the number of cone beam CT (CBCT) devices used in dental practices or head and neck examinations has noticeably increased[1] (Figure 1). Concretely, there were about 700 installed devices in Switzerland at the beginning of 2019 (612 at the time of the survey, which translates to about 1.2 units per 10,000 inhabitants) and new devices are continually being installed.

Technical progress in dentistry and in CBCT-technologies, as well as the availability of CBCT scans, has led to an increase of the latter's use and in which large variations of patient exposure have been reported.[2] This means that even when the added value of using CBCT is clearly stated, the variety of image quality levels available (due in particular to the wide range of

Correspondence to: Dr Marta Sans Merce, E-mail: marta.sansmerce@hcuge.ch
Received 20 November 2019; revised 30 March 2020; accepted 01 April 2020

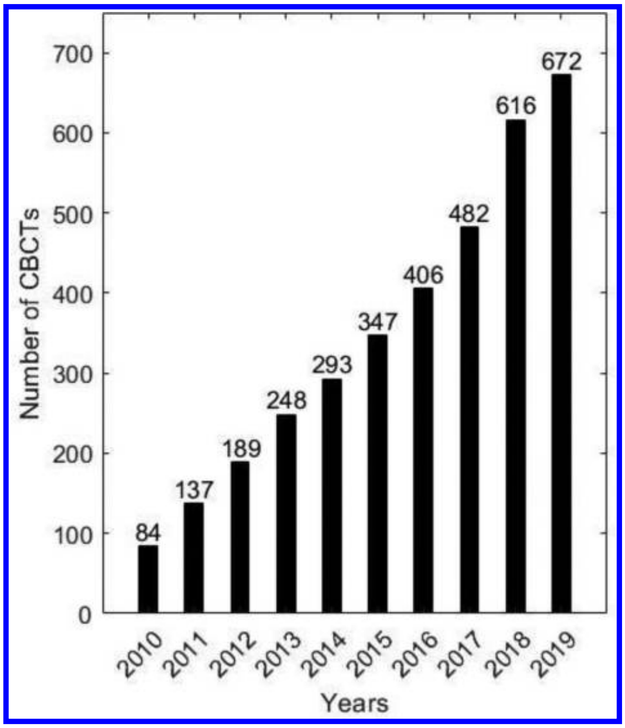

Figure 1 Evolution of the number of CBCTs in dental, maxilla, and ENT in Switzerland between 2010 and 2019

the available voxel sizes and detector doses) and the variability of the chosen field of view (FOV) sizes has led to heterogeneous patient exposure levels. This situation has prompted some countries to organize surveys meant to help introduce a few diagnostic reference levels (DRL) as defined by the International Commission on Radiological Protection (ICRP)[3] for the most commonly performed indications. At the moment, only two countries have proposed a set of DRL for dental CBCT. Both countries published using the global dose indicator air kerma product (P_{KA}), with only one considering the FOV used.[4–6] It is worth mentioning that the introduction of DRL is also supported by the ESR EuroSafe imaging initiative to promote optimal patient exposures.

In addition, although some CBCT indications do present certain advantages for the patient, there is still no medical consensus among practitioners for some other indications.

In this context, an optimization strategy has to be established involving all interested parties and considering all the parameters that influence image quality (in particular voxel size and detector dose) and patient exposure (that is the previous parameters and the size of the FOV).

The aim of this study was to propose a set of DRLs intended to help practitioners optimize their practices with data that not only focus on the dose indicator itself but also give some hint about the volume of data acquisition. In this way, practitioners should get a comparable level of image quality for a given clinical indication.

To reach this objective, a working group involving dentists, medical physicists, and radiology technicians was established to define the most frequent indications and prepare a questionnaire that was then sent to all centers within Switzerland using a CBCT for the head and neck regions.

Methods and materials

Questionnaire

A peer-group of experts in CBCT of the head and neck area in Switzerland—including dentists, medical physicists and radiology technicians—was created with the aim of proposing a set of clinical indications in order to then establish DRLs related to the practice. After several meetings, the group of experts accepted a final version of the questionnaire with discipline-specific indications of dentistry, maxillofacial surgery, and otorhinolaryngology. The questionnaire contained the following information: general information about the practice, number of CBCT and panoramic X-ray examinations performed per year, if examinations were performed for other referring physicians, and if examinations on patients under age 18 were performed. A list of 19 dental and maxillofacial indications (Table 1), and 20 ENT indications (Table 2), was proposed to enable physicians to then choose the 5 most frequent indications used in their practices (dental/ENT practice or hospital). For each of these five indications, the following questions had to be answered: the FOV (expressed as: diameter x height, in cm x cm) used; the frequency of examinations (per week, month, or year); the indicated exposure parameters (air kerma product (P_{KA}) and/or the volume CT dose index ($CTDI_{vol}$) expressed in mGy cm², mGy respectively) and if possible the tube high voltage (kVp) and the total tube current exposure time product (mAs) used for the acquisition.

Data analysis

Data were analyzed using Matlab software v. R2017b. First, general questions about the practice were analyzed, such as the number of centers conducting examinations for other physicians, the number of centers conducting examinations on pediatric patients, as well as a comparison between the number of CBCTs *vs* panoramic X-rays per year. The dosimetric quantities displayed by the different devices were then analyzed in order to choose which should be considered for establishing the DRLs.

The answers concerning the five most frequent examinations reported by the users were analyzed in terms of number of responses for each indication and frequency of examination. This allowed us to define the indications where enough statistics could be obtained (Tables 1 and 2).

DRL values are defined by the International Commission on Radiological Protection (ICRP)[3] as

Table 1 Dental and maxilla indications associated with the number of response (percentage of centre it represents) and the number of examinations per year (percentage of the practice it represents)

Indications	*Number of responses (percentage)*	*Annual frequencies (percentage)*
Wisdom teeth	176 (18)	5869 (24)
Implant on maxilla or mandible	170 (18)	5140 (21)
Implant on maxilla with sinuslift (unilateral/bilateral)	152 (16)	3097 (13)
Form and position anomalies of tooth and their relations with surrounding structures	106 (11)	1980 (8)
Modification of dentoalveolar pathologies (*e.g.* cyst, periodontal and periapical lesions)	90 (9)	1748 (7)
Virtual planning of prosthetic implant's restoration	65 (7)	1867 (8)
Endodontic	53 (5)	1002 (4)
Odontogenic tumor, bone pathologies, lesions: cysts, maxilla bone tumor	30 (3)	327 (1)
Orthodontics	24 (2)	832 (3)
Sinus pathologies	24 (2)	752 (3)
Dental and maxillofacial traumatology (zygomatic bone, mandible, frontal sinus, orbits, nose, maxilla sinus (pre- or post-op))	19 (2)	436 (2)
Periodontology	16 (2)	94 (0)
Bone damage of temporomandibular joint (arthrosis)	14 (1)	870 (4)
Foreign body localization at face and jaw level	10 (1)	274 (1)
Diagnostic and operating planning of complex cranial malformations (cleft palate: alveoplasty planning, dental germs localization, osteotomy)	9 (1)	354 (1)
Osteitis, osteomyelitis, necrosis, osteoporosis	7 (1)	91 (0)
Diagnostic of superior airway	1 (0)	10 (0)
Salivary lithiasis	No response	
Representation of the lachrymal duct with contrast agent		

the 75th percentile of the dose indicator distribution. Thus, after deciding which was the most common dose indicator used, the first, median, and third quartiles were evaluated using all the data available without considering the number of acquisitions made in the centers.

In order to orient any users willing to optimize his/her practice, it was also decided to analyze the FOV distribution for each selected indication. Thus, not only the global dose indicator would be available but also some hint about the median FOV used. These data would enable the user to determine the reason behind his/her noncompliance with the DRL. For example, if the FOV is adequate then the noncompliance might be a result of an inadequate level of image quality or a problem with image detector performance. This is similar to the philosophy used when dealing with CT imaging since the analysis of the $CTDI_{vol}$/DLP (dose–length product) makes it possible to verify the adequacy of the scanned length.

Among the many small, medium, or large FOV available there are variations among the various units used in data acquisition and voxel sizes. In order to correct for the differences of FOV available, the third quartile P_{KA} values were normalized to the most used FOV according to the following relationship:

$$P_{KA_{Adpated}} = P_{KA_{Displayed}} \times \frac{FOV_{Most\ used}}{FOV_{Acquisition}}$$

Where the $P_{KA_{Displayed}}$ is the P_{KA} given by the device, the $FOV_{Acquisition}$ is the FOV used by the physician for the examination and the $FOV_{Most\ used}$ is the FOV chosen to normalize the P_{KA} to the most used FOV.

Results

Despite several contact attempts, only 227 (38%) institutes out of the 612 contacted answered the questionnaire.

Almost half of the responding centers perform examinations for other referring physicians [107/110 (yes/no)] and most institutes do pediatric examinations [121/96 (yes/no)].

The total number of annual panoramic X-rays (approximately 51,000) is higher than CBCT examinations (23,000) in those centers functioning with both devices.

The analysis of the data showed that 7 indications of the 39 proposed in the list represented 76.4% of the total examinations number (20,703/27,109), dental, maxillofacial and ENT indications confounded. Each of these 7 indications represented more than 1000 examinations per year.

The following seven proposed indications appeared to be particularly relevant:

- Wisdom teeth,

Table 2 Ear, nose & throat indications associated with the number of response (percentage of center it represents) and the number of examinations per year (percentage of the practice it represents)

Indications	*Number of responses (percentage)*	*Annual frequency (percentage)*
Anterior skull base		
Refractory or recurrent rhinosinusitis (with or without nasal polyps)	6 (18)	700 (30)
Sinonasal disease of dental origin	5 (15)	154 (7)
Pre-operative work-up	5 (15)	145 (6)
Nasal obstruction, rhinorrhea, hyposmia or facial pain without clinical correlation	4 (12)	700 (30)
Sinonasal and skull base masses/tumors	3 (9)	27 (1)
Nasal fractures	2 (6)	3 (0)
Radiopaque foreign bodies	1 (3)	1 (0)
CSF leak	No response	
Congenital anomalies of the nose		
Nasolacrimal duct disease (local application of contrast medium)		
Lateral skull base		
Post-cochlear implant control	3 (9)	60 (3)
Pre-operative work-up	2 (6)	408 (17)
Cholesteatoma	2 (6)	168 (7)
Chronic suppurative otitis media	No response	
Otosclerosis		
Petrous apex disease		
Temporal bone tumors		
Temporal bone fractures		
CSF leak		
Congenital anomalies of the temporal bone		
Radiopaque foreign bodies		
Conductive hearing loss of unknown origin		

CSF, cerebrospinal fluid.

- Implant on maxilla or mandible,
- Tooth form and position anomalies and their relationship to surrounding structures,
- Modification of dentoalveolar pathologies (*e.g.* cyst, periodontal, and periapical lesions),
- Endodontics,
- Implant on maxilla with sinuslift (unilateral/bilateral),
- Virtual planning of restoration of prosthetic implant.

From our results and as found in the literature,[7,8] P_{KA} is displayed by most of the devices. The choice of P_{KA} as a dosimetric quantity was consistent with actual tendencies and necessary to keep the maximum amount of data. 39 centers had to be excluded because P_{KA} values were not provided.

For each of the indications studied, we established a frequency distribution of the P_{KA} values. See Table 3, leading to the following third quartile values: wisdom teeth (662 mGy cm^2), implant on maxilla or mandible (683 mGy cm^2), tooth form and position anomalies and their relationship to surrounding structures (542 mGy cm^2), modification of dentoalveolar pathologies (*e.g.* cyst, periodontal, and periapical lesions) (569 mGy cm^2), endodontics (639 mGy cm^2).

For each of the indications studied, we also established a frequency distribution of the FOV size, as shown

Table 3 P_{KA} (*mGy.cm*^{2}) values obtained for the five indications chosen

Indications	*First quartile*	*Second quartile*	*Third quartile*
Wisdom tooth	215	421	662
Implant on maxilla or mandible	218	442	683
Form and position anomalies of tooth and their relations with surrounding structures	203	342	542
Modification of dentoalveolar pathologies (*e.g.* cyst, periodontal and periapical lesions)	259	421	569
Endodontics	297	421	639

P_{KA}, air kerma product.

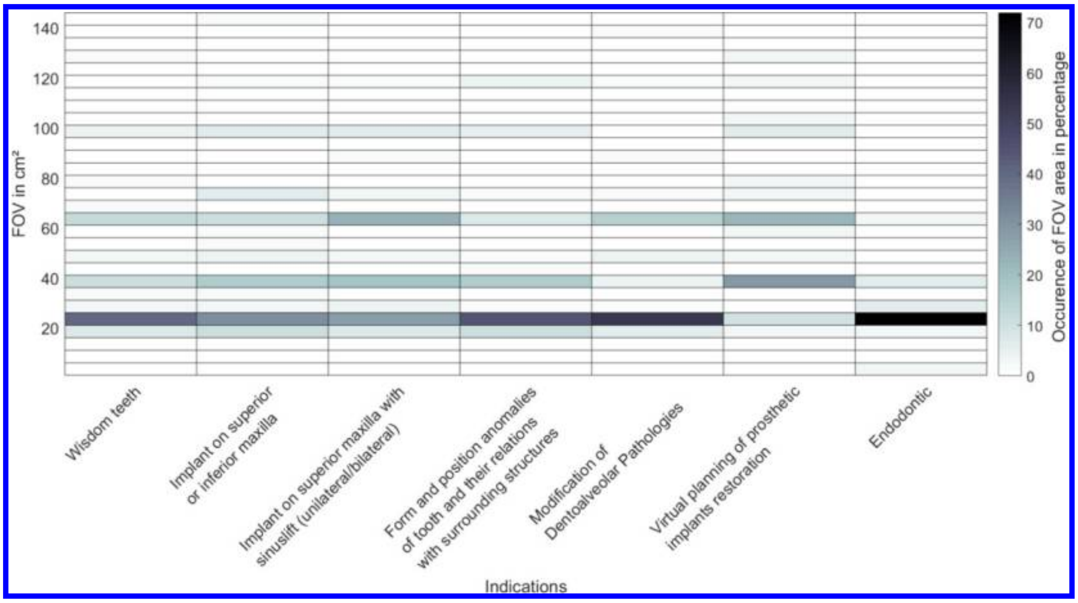

Figure 2 Field of view area (in cm²) occurrence for each of the 7 indications studied.

in Figure 2. The most used FOV in practice was 25 cm² (comprising values of FOV between 20 and 25 cm²) (n = 159, 40.6%), except for the indications of implant planning on maxilla or mandible with sinuslift (unilateral/bilateral) which had an FOV larger than 25 cm² in 64.2% (n = 43/67) of the cases and virtual planning of prosthetic implant restoration which had an FOV larger than 25 cm² in 86.2% (n = 25/29) of the cases.

Unfortunately, the survey did not gather enough information for subindications regarding implants on maxilla with sinuslift (unilateral/bilateral) or virtual planning of prosthetic implant restoration. Indeed, each subindication would imply the use of a different FOV. We therefore could not establish a reliable DRL value for these 2 indications, which represented 217 of the 999 responses.

Figure 3 (a) and (b) show the histograms and the box plots of the distribution of the P_{KA} values obtained for the wisdom tooth indication. Figure 3 (c) and (d) show the histograms and the box plots of the P_{KA} values normalized to the most used FOV. Similar histograms were established for each of the indications studied.

Discussion

Our survey results show that panoramic X-rays are still the reference examination in dental practice, indicating that Swiss dentists and maxillofacial surgeons are still favoring this imaging technique in which patient exposure is lower than in CBCT.[9,10] Due to the limited number of CBCT units compared to standard X-ray units (11,517 panoramic devices installed in Switzerland) used for dental care, it seems evident that there are more panoramic X-rays performed in Switzerland than CBCT examinations.

As mentioned previously, more than 40% of all CBCT acquisitions performed used a FOV of about 25 cm². We found this result quite encouraging since it showed that an optimization process concerning the choice of the acquisition volume was already being performed. Most indications contain the visualization of anatomical landmarks like wisdom teeth, especially their root tips, the mandibular canal, or the outer margin of the alveolar bone in the maxilla or mandible.

As CBCT systems are also used for pediatric examinations, it is interesting to note that some constructors add pediatric FOV such as 4 x 4 cm, as well as propose adapted mA values as recommended in the literature.[11–15] In our study, because the indication of CBCTs on wisdom teeth may also be used for pediatrics, this might be the reason why so many CBCT users responded that they acquire child CBCT scans. Nevertheless, pediatrics protocols still need to be standardized since smaller FOV and adapted protocol are not available on several devices.

The indications studied were all dental indications. For ENT imaging, the number of responding centers was very low (only six centers answered, and with incomplete data). The lack of data might come from the fact that the survey asked for the five indications most frequently used in dental and ENT confounded; the responses showed that dental applications were more frequent than ENT applications in the institutes, which were mostly centers specialized in dental indications. Nevertheless, since the number of annual ENT examinations reached 700 for those few institutes performing ENT examinations, it could be interesting to organize a similar survey focused only on specific ENT indications.

The obtained FOV were classified into different groups based on the literature[14,16,17]: small for FOV ≤40

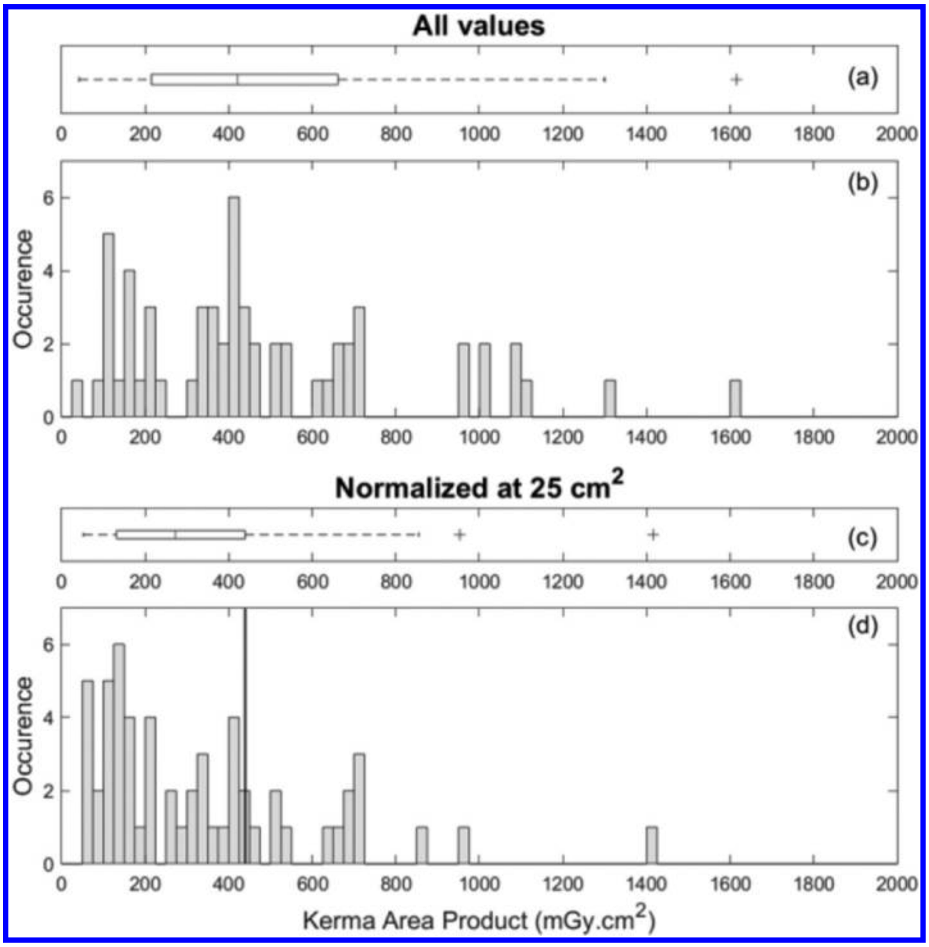

Figure 3 (a, b) show the histograms and the box plots of the distribution of the P_{KA} values obtained for the wisdom tooth indication. Figure 3 (c,d) show the histograms and the box plots of the P_{KA} values normalized to the most used FOV. Similar histograms were established for each of the indications studied. FOV, field of view; P_{KA}, air kerma product.

cm^2, medium for FOV between 40 and 100 cm^2, and large for FOV ≥ 00 cm^2; examples of FOVs for each category are available in Table 4. In our survey, since the indications were all dental, the small FOV category and the 5 x 5 cm FOV were the most used corresponding to a single tooth acquisition. The large FOV is not recommended in dental practice as the FOV must be limited to the region of interest.[14] This category is reserved for ENT practices where imaging the whole skull may be needed.

Table 4 FOVs examples for the three different categories

Categories	Common FOVs in cm Ø x cm height (size in cm^2)
S: Small	4 × 4 (16 cm^2) 5 × 5 (25 cm^2) 6 × 6 (36 cm^2) 8 × 5 (40 cm^2)
M: Medium	5 × 10 (50 cm^2) 8 × 8 (64 cm^2) 8 × 9 (72 cm^2)
L: Large	10 × 10 (100 cm^2) 15 × 15 (225 cm^2) 17 × 23 (391 cm^2)

FOV, field of view.

In spite of a certain FOV homogeneity, a large dose indicator distribution was obtained for all the indications studied. This mostly depends on the device used and on the parameters chosen.[11,18] It is important to mention that devices propose a limited choice of parameters and all users seem to use similar default values. For other devices, a wide range of exposure can be delivered (up to a factor of three) even when the FOV is kept constant by varying the kV, mA, and voxel size parameters.[16,19]

The outcome of this study is a set of DRL values for Switzerland. Moreover, third quartile P_{KA} values related to the most frequently used FOV have been derived. Indeed, in order to enable dentists to optimize their imaging techniques when dealing with CBCT examinations, third quartile P_{KA} values normalized to the recommended FOV following equation 1 as presented in Table 5 have been provided.

At the moment, national surveys on CBCT have only been done in the UK and Finland.[2,4–6] For the indication of a single implant, UK obtained a value

Table 5 Proposed DRLs and optimization values (third quartile normalized to the FOV) for Switzerland

Indications	*Third quartile values (mGy.cm²) normalized to a FOV of 5 cm Ø x 5 cm height*	*DRL proposal (mGy.cm²)*
Wisdom tooth	439	662
Single implant on maxilla and mandible	447	683
Form and position anomalies of tooth* and their relations with surrounding structures	451	542
Modification of dentoalveolar pathologies (*e.g.* cyst, periodontal and periapical lesions)	459	569
Endodontics	639	639

DRL, diagnostic reference level; FOV, field of view.

of 265 mGy cm² for adults with an average FOV area of 67 cm². Both countries decided to use the data without adapting the values to the most used FOV. Historically, the UK provided a value of 250 mGy cm[26] for a recommended FOV of 4 x 4 cm. This value was deduced from the 75th percentile of the data distribution from 41 devices normalized to a FOV of 4 x 4 cm. They named this value an achievable dose since they used the normalized value. Finnish DRL[4] values are based on the Turnbull-Smith master thesis.[2] They published DRLs for four indications; from these four indications, only two are common to our study. The proposed Swiss DRLs are slightly higher than the Finnish ones: Wisdom tooth—662 mGy cm² for Switzerland (439 mGy cm² normalized to the most common FOV) compared to 380 mGy cm² for Finland; Single implant on maxilla or mandible—683 mGy cm² for Switzerland (447 mGy cm² normalized to the most common FOV) compared to 360 mGy cm² for Finland. When comparing the Swiss value for a single implant 683 mGy cm² with the UK value of 265 mGy cm² for 75th percentile and 458 for the 95th percentile, we can conclude that protocols in Switzerland need to be optimized. One of the reasons why the Swiss values are higher than the UK or Finnish values could be the use of high-quality images when it is sometimes not necessary. The values used for the comparison among different countries have been summarized in Table 6.

The obtained values for P_{KA} should be used with caution if conversion factors between P_{KA} and effective dose are used to obtain an estimation of the effective dose. Indeed, kVp values range from 50 kV till almost 100 kV and different filtrations might be used, making it almost impossible to convert P_{KA} to effective dose in a straightforward, linear manner.

Unlike other devices, dental CBCT provide P_{KA} values predetermined by the manufacturers instead of measured ones by a built in P_{KA} meter. Therefore, the P_{KA} values provided in this study might differ from the real measured values; this is a source of uncertainty that has not been considered in our analysis.

Conclusion

The use of CBCT in dental, maxillae, and ENT practices has increased over recent years in line with the increasing exposure of the Swiss population to medical examinations, which represented 1.4 mSv/year in 2013 compared to 1.0 mSv/year in 1998.[20] DRLs are a valuable tool for physicians to optimize their practice. Indeed, the choices of parameters like FOV, voxel size, and mAs have a strong influence on the dose delivered to the patient and on image quality. Yet, until now, no values were available in the field of CBCT for dental, maxillae, and ENT examinations. This first survey of dose in dental, maxilla, and ENT CBCT gave us a good initial view on how CBCT is being used in dental practice in Switzerland and will be helpful in an approach of future optimization.

The DRLs in this field are quite new and a second iteration will most probably be needed. Nevertheless, Swiss DRLs are in good agreement to other existing values. For ENT, a new survey was launched in mid-2019.

Table 6 Comparison of DRLs proposal and optimization values (third quartile normalized to the FOV) with other countries DRLs (mGy cm²)

Indications	*Swiss third quartile values normalized to the recommended FOV recommended FOV)*	*Swiss DRL*	*Finnish DRL (4)*	*UK achievable dose (recommended FOV) (2)*	*UK DRL (5)*
Wisdom tooth	439 (5 cm Ø x 5 cm)	662	380		
Single implant on maxilla or mandible	447 (5 cm Ø x 5 cm)	683	360	250 (4 cm Ø x 4 cm)	265

DRL, diagnostic reference level; FOV, field of view.

Acknowledgment

For introducing and advertising the questionnaire to their members, we thank: the Swiss association of dentomaxillofacial radiology, the Swiss Society of Otorhinolaryngology Cervical and Facial Surgery, the Swiss Society of Oral and Maxillofacial Surgery, the Swiss Society of Radiobiology and Medical Physics and the Swiss Society of Radiology.

Funding

No financial support or benefits have been received by me or any co-author, by any member of my (our) immediate family or any individual or entity with whom or with which I (we) have a relationship from any commercial source which is related directly or indirectly to the scientific work which is reported on in the article.

REFERENCES

1. Berg I, Gertsch A, Zeilhofer H-F, SchwenzerZimmerer K, Berg S, Hassfeld S, et al. Cone beam computed tomography et exposition aux radiations. *Swiss Dent J* 2014; **124**: 427–33.
2. Turnbull-Smith S. Cone-Beam computed tomography examinations of the head and neck region in Finland: indications and patient radiation dose. *Tampere University of Technology* 2016;.
3. ICRP Diagnostic reference levels in medical imaging. ICRP publication 135. *Ann ICRP* 2017; **46**.
4. Strålsäkerhetscentralen S. Reference levels for patient radiation exposure in cone-beam computed tomography examinations of adults' head region. *Decision* 2016;12/3020/2016.
5. Public health England. Dose to patients from dental radiographic X-ray imaging procedures in the UK [Internet]. 2017. Available from: www.facebook.com/PublicHealthEngland.
6. Comission E. Radiation protection N ° 172 cone beam CT for dental and maxillofacial radiology. 2012;.
7. Kiljunen T, Kaasalainen T, Suomalainen A, Kortesniemi M. Dental cone beam CT: a review. *Phys Med* 2015; **31**: 844–60. doi: https://doi.org/10.1016/j.ejmp.2015.09.004
8. Nemtoi A, Czink C, Haba D, Gahleitner A. Cone beam CT: a current overview of devices. *Dentomaxillofac Radiol* 2013; **42**: 20120443. doi: https://doi.org/10.1259/dmfr.20120443
9. Batista WOG, Navarro MVT, Maia AF. Effective doses in panoramic images from conventional and CBCT equipment. *Radiat Prot Dosimetry* 2012; **151**: 67–75. doi: https://doi.org/10.1093/rpd/ncr454
10. Shin HS, Nam KC, Park H, Choi HU, Kim HY, Park CS. Effective doses from panoramic radiography and CBCT (cone beam CT) using dose area product (DAP) in dentistry. *Dentomaxillofac Radiol* 2014; **43**: 20130439. doi: https://doi.org/10.1259/dmfr.20130439
11. Pauwels R, Jacobs R, Bogaerts R, Bosmans H, Panmekiate S. Determination of size-specific exposure settings in dental cone-beam CT. *Eur Radiol* 2017; **27**: 279–85. doi: https://doi.org/10.1007/s00330-016-4353-z
12. Marcu M, Hedesiu M, Salmon B, Pauwels R, Stratis A, Oenning ACC, et al. Estimation of the radiation dose for pediatric CBCT indications: a prospective study on ProMax3D. *Int J Paediatr Dent* 2018; **28**: 300–9. doi: https://doi.org/10.1111/ipd.12355
13. Wahid MA, Choi E, MacDonald DS, Ford NL. Dosimetry analysis of panoramic-imaging devices in different-sized phantoms. *J Appl Clin Med Phys* 2017; **18**: 197–205. doi: https://doi.org/10.1002/acm2.12059
14. Bornstein MM, Scarfe WC, Vaughn VM, Jacobs R. Cone beam computed tomography in implant dentistry: a systematic review focusing on guidelines, indications, and radiation dose risks. *Int J Oral Maxillofac Implants* 2014; **29 Suppl**: 55–77. doi: https://doi.org/10.11607/jomi.2014suppl.g1.4
15. Oenning AC, Jacobs R, Pauwels R, Stratis A, Hedesiu M, Salmon B, et al. Cone-Beam CT in paediatric dentistry: DIMITRA project position statement. *Pediatr Radiol* 2018; **48**: 308–16. doi: https://doi.org/10.1007/s00247-017-4012-9
16. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT-a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol* 2015; **44**: 20140197. doi: https://doi.org/10.1259/dmfr.20140197
17. American Academy of oral and maxillofacial radiology. clinical recommendations regarding use of cone beam computed tomography in orthodontic treatment. position statement by the American Academy of oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013; **116**: 238–57.
18. Pauwels R, Silkosessak O, Jacobs R, Bogaerts R, Bosmans H, Panmekiate S. A pragmatic approach to determine the optimal kVp in cone beam CT: balancing contrast-to-noise ratio and radiation dose. *Dentomaxillofac Radiol* 2014; **43**: 20140059. doi: https://doi.org/10.1259/dmfr.20140059
19. Endo A, Katoh T, Vasudeva SB, Kobayashi I, Okano T. A preliminary study to determine the diagnostic reference level using dose-area product for limited-area cone beam CT. *Dentomaxillofac Radiol* 2013; **42**: 20120097. doi: https://doi.org/10.1259/dmfr.20120097
20. Federal Office of Public Health. Exposition de la population suisse aux rayonnements [Internet]. 2018. Available from: https://www.bag.admin.ch/bag/fr/home/gesund-leben/umwelt-und-gesundheit/strahlung-radioaktivitaet-schall/strahlung-gesundheit/strahlenexposition-der-schweizer-bevoelkerung.html [cited 2019 Jul 4].