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Diagnostic Reference Levels for Dental Cone-beam Computed Tomography: Current State and Way Forward

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ABSTRACT

This study provides a comprehensive overview of Diagnostic Reference Levels (DRLs) for dental Cone Beam Computed Tomography (CBCT), addressing the current variability and challenges associated with their implementation. Data were collected through a survey conducted among members of the Dental Imaging Special Interest Group of the European Federation of Organizations for Medical Physics, encompassing 33 countries, not limited to Europe. The focus was on official DRL documentation issued by regulatory or authorized bodies and peer-reviewed publications based on data from more than ten CBCT units.

Official DRLs were identified in Finland, Germany, Ireland, Italy, the United Kingdom, Sweden, Japan, Switzerland, and Estonia. DRLs were analyzed using two primary classification schemes: by field of view (FOV) dimensions and by clinical application or indication. The application of differing methodologies across countries was a key finding. In the clinical application-based group DRLs ranged from 200 mGy·cm² for imaging a single jaw quadrant in Sweden to 1150 mGy·cm² for paranasal

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sinus imaging in Finland. The United Kingdom was the only country to establish pediatric-specific DRLs. For FOV-based DRLs, values ranged from 500 mGy·cm² for FOVs ≤ 25 cm², in Germany, to 1960 mGy·cm² for a > 100 cm² FOVs, in Japan. The variability in exposure parameters and data reporting practices complicates cross-country comparisons.

To improve radiation safety, the harmonization of DRLs is essential. Increased international collaboration, the standardization of dose metrics, and enhanced training for dental professionals are critical steps toward the implementation of evidence-based DRLs and the optimization of CBCT practices worldwide.

Keywords

Dental radiography; cone-beam computed tomography; dentistry; radiation protection; radiation dosimetry

Highlights

- Most countries presented in this study (both inside and outside Europe) have not yet established national DRLs.
- The majority of DRLs consider small Field of Views (FOVs) and/or specific tasks, and do not cover the entire clinical application range for CBCT
- For harmonization, DRLs for CBCT should try to adhere to a standardized classification scheme
- DRL 'groups' can be divided by: patient (adult/pediatric), FOV dimensions, beam energy and image quality

1) INTRODUCTION

Cone Beam Computed Tomography (CBCT) has emerged over the past two decades as a transformative imaging technology in dental and maxillofacial radiology, due to its ability to generate high-resolution three-dimensional volumetric images of the dentomaxillofacial region. Originally introduced in the late 1990s, CBCT is now considered essential for a variety of clinical applications, particularly in procedures such

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as implant planning, assessment of impacted teeth, endodontic evaluations, and orthognathic surgery. As such, the utilization of CBCT in dental imaging is rising globally. [1-4]. This trend is driven by the growing availability of compact, cost-effective CBCT units and the increasing number of dental clinics adopting three-dimensional imaging for routine care.

However, this broader adoption brings new challenges. CBCT examinations can deliver radiation doses 5 to 40 times higher than conventional panoramic radiography, depending on the field of view (FOV) and exposure parameters [5]. The increasing number of CBCT units, often in dental practices outside of conventional radiology departments and governance, contributes significantly to collective radiation exposure [6][7]. This underscores the urgent need for up-to-date and comprehensive dose data, particularly concerning the frequency of CBCT examinations and variability in clinical practice.

Diagnostic Reference Levels (DRLs) serve as essential benchmarks in medical imaging. They are not dose limits but indicative values that help clinicians evaluate and optimize radiation exposure in routine procedures. The European RP 162 [8] report recommends using DRLs for CBCT, even suggesting they be used to define “suspension levels” where corrective action is needed. Furthermore, the International Commission on Radiological Protection (ICRP) [9] advises that DRLs be reviewed every 3–5 years—especially for rapidly evolving technologies such as CBCT.

Despite these recommendations, establishing DRLs in CBCT remains challenging. The literature shows considerable variability in DRL values due to inconsistencies in exposure parameters, non-standardized FOV classifications, and a general lack of data specific to clinical indications and patient groups [10]. This lack of harmonization complicates meaningful comparisons across studies and regions. Dose-Area Product (DAP) can serve as a basis for setting DRLs, but only when collected consistently under clinical conditions with rigorous data extraction.

In this context, it is crucial to ensure that CBCT is used judiciously—optimizing image quality and minimizing unnecessary exposure. Particular attention must be paid to selecting the smallest possible FOV that adequately covers the region of interest, avoiding irradiation of adjacent, non-relevant tissues. Furthermore, as CBCT becomes increasingly

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integrated into routine dental workflows, there is a need for medical physicists to play a more active role in guiding optimization and ensuring patient safety, especially in private practices where their presence is limited. Medical physicists also play a crucial role in exploring alternative approaches for establishing DRLs and in addressing the challenges associated with their implementation (e.g. Esmailyfard et al.[11] . proposed a novel cloud-fog software architecture specifically designed for automated dental CBCT dose monitoring, utilizing DICOM structured reports).

The motivation for this study stems from the growing clinical reliance on CBCT imaging and the lack of harmonized DRLs tailored to dental CBCT. The considerable variability in equipment, exposure settings, and clinical protocols emphasizes the need for robust, evidence-based DRLs. This study aims to provide an overview of existing national DRLs for dental CBCT across multiple countries, evaluate the methodologies used for their determination, and highlight inconsistencies and best practices. By doing so, it seeks to contribute to the ongoing international effort to optimize CBCT imaging and promote radiation safety through more standardized and clinically relevant DRLs.

2) Methods

The data presented in this study were compiled through contributions from members of the ‘Dental Imaging’ Special Interest Group (SIG) of the European Federation of Organizations for Medical Physics (EFOMP). This targeted 58 professionals across 33 countries, not restricted to Europe, and focused on official DRL documentation issued by regulatory or authorized bodies, including legislation, technical guidelines, and scientific publications. The most represented countries are Germany, the United States, Belgium, Finland, Greece, Ireland, and Portugal, each with at least three active members. The interdisciplinary nature of the group is reflected in its composition, which includes medical physicists, dental practitioners, and industry representatives. Membership remains open and continues to grow. Only sources meeting predefined criteria were included—namely, official documents issued by regulatory or authorized bodies, or peer-reviewed publications based on measurements from more than ten CBCT units.

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To further contextualize the findings, countries were also categorized based on the existence of national DRLs (published in legislation or issued by competent authorities) specifically for dental CBCT. Table 1 summarizes the countries that have and have not established national DRLs for CBCT.

Table 1 - Countries of the SIG members with/without national DRLs

Countries Without DRLs	Belgium, Bosnia and Herzegovina, Canada, Costa Rica, Croatia, Denmark, France, Greece, Hong Kong (China), India, Israel, Kuwait, Malaysia, Malta, Netherlands, Norway, Portugal, Spain, Thailand, Turkey, USA, United Arab Emirates
Countries With DRLs	Finland, Germany, Ireland, Italy, UK, Sweden, Japan, Estonia, Switzerland

3) Results

a) Existing DRLs for CBCT

It was found that DRLs for CBCT are implemented inconsistently across the globe [12]. Germany, Switzerland, the UK, Finland, Japan, Estonia and Sweden have established DRLs for CBCT, with Ireland and Italy adopting the value determined in the UK. At the time of this paper, Malta, France and Denmark were in the process of implementation. Most of the data presented vary in their reporting format but can generally be categorized into two main approaches: clinical application, which stratifies DRLs by specific diagnostic purposes (e.g., implantology, endodontics), and FOV dimensions, where DRLs are determined based on the size of the imaging region (e.g. small, medium, or large).

b) DRLs by Clinical Application

Given the diverse clinical applications in dental and maxillofacial radiology, each requiring specific diagnostic image quality and FOV coverage, the International Atomic Energy Agency (IAEA) [13] recommends establishing DRLs tailored to each common clinical application, with a suggested categorization of clinical indications shown below.

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For **adult patients**, clinical applications with low image quality needs include (the dimensions presented are the FOV height) :

- **Small FOV (<10 cm):** Ectopic teeth, single and multiple implants, periapical pathosis, bony pathosis and sinus assessment.
- **Medium FOV (10–15 cm):** Airway analysis.
- **Large FOV (>15 cm):** Facial trauma and orthognathic surgery.

Applications with high image quality needs for adults primarily use:

- **Small FOV (<10 cm):** Endodontics and dental trauma.

For **pediatric patients**, low image quality needs include:

- **Small FOV (<10 cm):** Ectopic teeth, periapical pathosis, and cleft surgery, bony pathosis
- **Large FOV (>15 cm):** Orthognathic surgery.

High image quality needs for children focus on:

- **Small FOV (<10 cm):** Endodontics and dental trauma (permanent dentition).

Although some countries adopt clinical indication-based diagnostic reference levels (DRLs), notable differences persist in how clinical indications are defined and applied, as summarized in Table 2. To the right of the table, a comparison with the IAEA classification, based on similar clinical indication — including field-of-view (FOV), imaging requirements, and procedure types — has been added ⁽¹⁾.

Table 2. Application-based diagnostic reference levels for CBCT

Country/Date of implementation	Clinical application	DRL Value	IAEA classification FOV	IAEA classification Image quality needs	IAEA Type of procedure

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Finland [14] -2019	Preoperative imaging for single implant	360 mGy·cm ²	Small FOV	Low	Single implant
	Assessing wisdom teeth relative to mandibular canal	380 mGy·cm ²	Small FOV	Low	Ectopic teeth
	Evaluating periapical areas or root canal morphology	550 mGy·cm ²	Small FOV	Low	Periapical pathosis
	Imaging for paranasal sinuses	1150 mGy·cm ²	Medium FOV	Low	Sinus assessment
Sweden [15] 2018	Imaging a single jaw quadrant (e.g., wisdom tooth extraction)	200 mGy·cm ²	Small FOV	Low	Ectopic teeth
	Imaging entire upper and lower jaw (e.g., multiple implants)	700 mGy·cm ²	Small FOV	Low	Multiple implants
UK [16] 2017	Maxillary implants (adult)	265 mGy·cm ²	Small FOV	Low	Multiple implants
	Impacted maxillary	170 mGy·cm ²	Small FOV	Low	Ectopic teeth

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	canines (12-year-old child)				
Switzerland [7] 2020	Wisdom teeth imaging	450 mGy·cm ²	Small FOV	Low	Ectopic teeth
	Maxillary or mandibular implants (1)	450 mGy·cm ²	Small FOV	Low	Multiple implants
	Dentoalveolar pathology	450 mGy·cm ²	Small FOV	Low	Periapical pathosis
	Tooth position anomalies (1)	450 mGy·cm ²	Small FOV	Low	Ectopic teeth
	Endodontics	650 mGy·cm ²	Small FOV (high image quality)	High	Endodontic

(1) Classifications reflect the interpretation of the task group of the IAEA guidelines.

(2) Normalized values for 5x5 FOV, see section 5.

Despite the lack of consistency in DRL data across countries, small FOV examinations predominate. Small FOVs are more representative because they are widely used, as illustrated by the Swiss study, which reported that 40% of CBCT exams were performed at a 25 cm² FOV (considering diameter x height). This prevalence makes it easier to collect and standardize data. Furthermore, implant planning and ectopic tooth localization are among the most common clinical indications for CBCT, which could be explained by the greater availability of dose data for these procedures.

Different methodologies emerge from the analysis of the table, confirming the lack of consistency in the establishment of DRLs across countries. For example, Finland and Switzerland have proposed multiple DRLs based on clinical indications, albeit for different types of indications; the United Kingdom stands out as the only country that

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included pediatric-specific DRLs; Sweden adopted a pragmatic approach by differentiating DRLs for single and multiple quadrants; and Switzerland was unique in providing normalized DRL values.

The inherent challenges of indication-based DRLs lies in the variability of FOV requirements within the same clinical indication. For example: while a small FOV may suffice for evaluating periapical areas or root canal morphology, more complex cases may necessitate a larger FOV encompassing an entire quadrant of the jaw.

At the time of writing , France is in the process of implementing national DRLs. The IRSN [17] recommends establishing DRLs for three specific dental CBCT indications in adults: single implants without guidance or sinus lift, single impacted tooth extraction (exodontia), and endodontics. It proposes defining these DRLs in terms of DAP and setting a uniform value of 700 mGy·cm² for the three indications.

c) DRLs by FOV dimension

Historically, the first diagnostic reference level (DRL) value — although not designated as such at the time — was established by the UK’s Health Protection Agency, which proposed an achievable dose of 250 mGy·cm² for CBCT imaging aimed at the placement of an upper first molar implant in a standard adult patient, using a normalized 4×4 cm field of view (FOV). However, it is important to note that these values date back to 2010, and their applicability to current clinical practice may be limited given the significant advancements in equipment and imaging techniques over the past 15 years. Since then, other countries have adopted varying DRL values based on their own FOV dimensions, as illustrated in Table 3 below.

Table 3. Field of view-based diagnostic reference levels for CBCT

Country/date of implementation	FOV Size	DRL Value (DAP)	DRL Value (Kiso)
Germany [18]	Small FOV (≤ 25 cm ²)	500 mGy·cm ²	-

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2022	Large FOV (> 25 cm ²)	1000 mGy·cm ²	-
Japan [19]	FOV < 40 cm ²	841 mGy·cm ²	24 mGy
2020	FOV 40-100 cm ²	1670 mGy·cm ²	29 mGy
	FOV > 100 cm ²	1960 mGy·cm ²	16 mGy
Estonia [20]	FOV < 40 cm ²	440 mGy·cm ²	-
2025			

The differences in FOV dimensions and the corresponding DRLs are striking, likely reflecting variations in the CBCT equipment and imaging protocols predominantly used in each country — including differences in FOV size, image quality requirements, rotation angle, number of projections, tube voltage and voxel size. For instance, the DRL for a small FOV in Germany (500 mGy·cm²) is double the achievable dose initially proposed by the UK. Similarly, Japan’s DRL for a small FOV (841 mGy·cm²) is comparable to Germany’s value for a large FOV. These substantially higher Japanese DRLs underscore the need for cautious interpretation when adopting or comparing reference levels internationally. Additionally, the kerma at the isocenter (Kiso) values reported by Japan are atypical for DRL comparisons, as they do not account for FOV dimensions, potentially limiting their comparability. In Estonia, the proposed DRL for a procedure involving the placement of one to two dental implants using a FOV smaller than 40 cm² is 440 mGy·cm² — a value considerably lower than the DRLs reported by Japan for procedures with similar FOV sizes.

d) Adopting DRLs from other countries

Another method for stabilizing (and/or harmonizing) DRLs involves adopting values from other countries. For example, Ireland [21] and Italy [22] implemented DRLs originally established in the UK for dental radiography. This includes the DRL value for CBCT prior to maxillary molar implant placement, set at 265 mGy·cm².

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e) Other studies of interest

For comparison, additional CBCT dose studies are summarized in Table 4, including only those based on data from more than ten CBCT units. Although relatively few studies focus specifically on CBCT dose assessment — and despite considerable variability in reported dose levels — the Portuguese and Indian studies revealed similar values, likely due to the use of comparable FOV configurations. In contrast, the Korean study reported dose values notably higher than those established DRLs for implant planning (Table 1), while the U.S. study presented higher values compared to those defined for a 25 cm² FOV (Table 2). These discrepancies further highlight the urgent need for a standardized methodology for dose evaluation in the establishment of DRLs for CBCT.

Table 4. Summary Table of DAP in CBCT by Country / Study

Country / Study	DAP (3rd Quartile) [mGy·cm ²]	FOV	No. of CBCT units studied
Portugal[23]	580	≤10 cm height	36
India [24]	532	≤10 cm height	10
South Korea [25]	1856	Implant planning for the maxillary first molar	301
Missouri / Southern Illinois [26]	838	5 × 5 cm	21

4) Collection of accessory data

Even when data of exams is requested from clinics and hospitals within the process of establishing DRLs, differences can be observed. The Swiss study gathered general practice information, such as the number of CBCT conducted annually, whether services were provided for other referring physicians, and if patients under 18 were

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examined [7]. The French [17] inquired about clinical indications, FOV size and displayed DAP values, but also focused on collecting detailed technical data about devices, including brand, model, year of service, annual CBCT exam counts by indication, and specifics like patient size adjustments, resolution or voxel size (in μm), and use of dose reduction modes.

When requesting clinical dose data from institutions, it is essential to collect not only DRL values but also detailed contextual information, including the specific clinical indications, the use of high dose or dose reduction modes and FOV dimensions. These technical and procedural variables significantly influence patient dose and provide more meaningful insights into local optimization practices than DRL values alone. To ensure consistency and ease of data collection, this process should be organized using a structured, user-friendly format—such as a standardized spreadsheet with clear instructions. Additionally, guidance should be provided on how to document procedures where exposure settings vary depending on the clinical indication.

5) Challenges

The variability of DRLs observed in the previous sections underscores the critical importance of global collaboration and data sharing in establishing consistent and reliable reference levels. However, several challenges complicate this effort:

Low Response Rate to Inquiries: Surveys, as evidenced by Switzerland's experience where only 38% (227 out of 612 institutions) responded despite multiple contact attempts, demonstrate the challenge of low participation, which limits the representativeness and comprehensiveness of the data and hinders the establishment of accurate DRLs. Additionally, there is a difficulty in accessing and understanding the exposure parameters and technical specifications of CBCT units by users. Therefore, the creation of DRLs should be accompanied by a training program aimed at dentists, equipping them with the necessary skills to optimize imaging practices, ensure accurate data reporting, and improve compliance with DRL guidelines. While several countries have implemented a mandatory training program for users/referrers of CBCT, there is little information available regarding the physics content of such programs.

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DAP Meter Accuracy: Older CBCT equipment may lack the capability to display dose-related parameters, and discrepancies between measured and displayed dose-area product (DAP) values are well documented—with average deviations reaching up to 25% [23]. Such variability must be considered during the development of DRLs, particularly as DAP accuracy information can often be retrieved from quality control reports or manufacturer documentation.

Normalization in FOV: Normalizing DRLs based on FOV remains a debated topic, as FOV size is a major factor influencing patient dose [27]. While such normalization facilitates cross-center comparisons and supports standardization efforts, it also carries the risk of masking critical issues — particularly the use of unnecessarily large FOVs for specific clinical indications. For example, Switzerland’s proposed third-quartile dose values were higher than those reported in other countries, with DRLs of 662 mGy·cm² for wisdom teeth and 683 mGy·cm² for single implants. However, after normalizing all values to a standard FOV of 25 cm², DRLs for all clinical indications — except endodontics — converged to 450 mGy·cm². The normalization is calculated using the following formula:

$$\text{Normalized DRL} = \text{Reported DRL} \times \left(\frac{\text{Standard FOV}}{\text{Original FOV}} \right)$$

. It is extremely important to clearly state when values presented are normalized, as this distinction is essential to avoid misinterpretation and to ensure accurate comparisons across studies and countries

Energy-dependence of patient dose: One of the primary reasons for adopting Dose-Area Product (DAP) as a dose index for CBCT is its practicality compared to the Computed Tomography Dose Index (CTDI) or its derivatives. [28][29]. However, as it is a measurement of tube output rather than a phantom-based measurement such as the CTDI, its relation to patient dose is more complex. Studies have shown that a straightforward linear conversion between DAP and effective dose is not feasible for dental CBCT [30][31]. One of the factors affecting this conversion is the beam energy, as CBCT scanners exhibit a wide range in terms of tube voltage (typically 70-120 kV) and filtration (min. 2.5 mm Al, but often with added Al or Cu filtration). When using

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DAP for DRLs, a cut-off between high- and low-energy scan protocols may have to be made based on the half-value layer (HVL) of the CBCT's X-ray spectrum. We tentatively suggest a HVL cut-off value of 6 mmAl between high- and low-energy CBCT scans, although exhaustive data regarding the voltage and filtration distributions for clinical CBCT scanners is lacking.

Pediatric DRLs: Among the countries surveyed, only the United Kingdom has established specific DRL values for paediatric CBCT examinations. In contrast, the French report highlights that current limitations in both the quantity and quality of available data render it impractical to define dedicated DRLs for paediatric imaging at this stage. Given the heightened radiosensitivity of children and their increased likelihood of undergoing repeated radiological procedures, there could be a strong rationale for prioritising the development of DRLs tailored to paediatric dental imaging. Nevertheless, the use of CBCT in paediatric patients requires further investigation, as existing data do not provide a comprehensive understanding of its global utilisation or clinical application.

6) Conclusion and Future Perspectives

There is substantial international variability in the reported dose values. For instance, the United Kingdom reports the lowest diagnostic reference levels (265 mGy·cm²), while South Korea presents the highest values (1856 mGy·cm²) for maxillary implants in adults. This disparity may reflect differences in clinical imaging protocols, equipment settings, or diagnostic requirements across countries.

As CBCT is becoming more common in clinical practice, the establishment of Diagnostic Reference Levels (DRLs) is particularly important. DRLs are essential tools for optimizing patient safety and promoting consistency in clinical practice. However, effective implementation requires the standardization of exposure parameters—particularly field of view (FOV) dimensions—and consensus on the appropriate image quality requirements for each clinical indication. Using the IAEA's proposed classification scheme in terms of clinical indications and FOV dimensions can be useful when creating new DRLs.

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Moreover, the development of robust methodologies is needed to address persistent challenges, such as discrepancies in dose-area product (DAP) meter accuracy and inconsistencies in data reporting. Streamlining data collection processes is also critical to facilitating broader participation from dental clinics, particularly in settings where access to medical physicists is limited.

These challenges, although not unique to CBCT, are amplified in dental imaging due to the wide variability in equipment types and clinical workflows. Overcoming them will require a combination of targeted professional training (as the Ireland example of training for CBCT based in RP 172 recommendations [32]), simplified data acquisition protocols, and improved dosimetric tools.

To support these efforts, the SIG Dental Imaging of EFOMP plans to conduct coordinated studies using data from the various countries where it has members. Given that CBCT dose levels are generally less influenced by patient biotype or individual anatomical variability, there is a strong rationale for proposing harmonized dose levels for dental CBCT imaging. The SIG is establishing a focus group dedicated to advancing DRLs, defining image quality metrics and requirements, and optimizing radiation exposures for pediatric and adult patient populations.

Limitations: As the survey was restricted to members of the Dental SIG of EFOMP, may not fully represent the global status. While the survey does not encompass all global stakeholders, the Dental SIG members represent a broad and diverse cross-section of dental professionals from (primarily) Europe, Asia, and North America. Additionally, the survey captures a snapshot in time and may not reflect ongoing developments or recent changes in national DRL policies. This limitation is inherent to most survey-based research. However, the study still provides a timely and relevant overview of the current landscape, highlighting gaps and inconsistencies that persist despite ongoing advancements. These findings can inform future longitudinal studies and policy updates, and they underscore the need for continuous monitoring and international collaboration.

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