RESEARCH ARTICLE

IAEA survey of dental cone beam computed tomography practice and related patient exposure in nine Central and Eastern European countries

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Objectives: Cone beam CT (CBCT) in dentistry and maxillofacial surgery is a widely used imaging method for the assessment of various maxillofacial and dental pathological conditions. The objective of this study was to summarize the results of a multinational retrospective–prospective study that focused on patient exposure in this modality.

Methods: The study included 27 CBCT units and 325 adult and paediatric patients, in total. Data on patients, clinical indications, technical parameters of exposure, patient dose indicator, or, alternatively, dose to phantom were collected. The dose indicator used was air kerma–area product, P_{KA} .

Results: In most scanners operators are offered with a variety of options regarding technical parameters, especially the field of view size. The median and the third quartile value of P_{KA} for adult patients in 14 different facilities were 820 mGy cm² and 1000 mGy cm² (interquartile range = 1058 mGy cm²), and 653 mGy cm² and 740 mGy cm² (interquartile range = 1179 mGy cm²) for children, as reported by four different institutions. Phantom dose data were reported from 15 institutions, and median P_{KA} ranged from 125 mGy cm² to 1951 mGy cm². Median P_{KA} values varied by more than a 10-fold between institutions, mainly due to differences in imaging protocol used, in particular field of view and tube current–exposure time product.

Conclusions: The results emphasize the need for a cautious approach to using dental CBCT. Imaging only when the clinical indications are clear, accompanied with the appropriate radiographic techniques and the optimum imaging protocol, will help reduce radiation dose to patients. *Dentomaxillofacial Radiology* (2020) 49, 20190157. doi: [10.1259/dmfr.20190157](https://doi.org/10.1259/dmfr.20190157)

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Introduction

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Cone beam CT (CBCT) in dentistry and maxillofacial surgery is used for radiological imaging of the teeth, jaw bones and related structures. Apart from an X-ray tube, its key design feature is a two-dimensional (2D) digital

detector and computer which allow acquisition and reconstruction of a three-dimensional (3D) volumetric image in one complete or partial rotation.

The first dental CBCT scanner was reported by Mozzo *et al.*¹ Other scanners were introduced later, and within the next two decades they became commercially available.^{2,3} The number of installed CBCT scanners has been increasing ever since and, unlike the case with conventional CT, many manufacturers are competing in the market.^{4,5} This has led to different technical specifications that influence image quality, radiation dose, and the procedure itself.⁶

Clinically, CBCT is a widely used imaging method for the assessment of various maxillofacial and dental pathological conditions. However, CBCT offers more; CBCT data sets can be used for image-guided surgery, orthodontic assessment and analysis, implant planning, as well as computer-aided design (CAD) and computer-aided manufacturing (CAM) of implant prosthetics.⁷ The access to CBCT and its rapidly growing use triggered some alarm in radiation protection community due to the associated risk from the radiation exposure. Effective doses from dental CBCT are significantly higher compared to those from the conventional 2D dental radiographs, with reported variations ranging from 5 to 1073 μSv depending on the scanning volume, equipment and technique.^{6,8–10} This calls for attention to justified use of this modality and optimization of patient protection.

Several national and international organizations have published guidelines related to the appropriate use of CBCT, including the European Commission, the United Kingdom's Health Protection Agency, the American Academy of Oral and Maxillofacial Radiology, the European Academy of Dentomaxillofacial Radiology, and others.^{9–13} The International Commission for Radiological Protection published recommendations on CBCT that focus on justification and appropriate use of CBCT in dental practice, taking into consideration the use of alternative imaging modalities.¹⁴

The European Federation of Organisations for Medical Physics, jointly with the International Atomic Energy Agency and the European Society for Radiotherapy and Oncology, has published a protocol on quality control in CBCT that unified test parameters for assessing the image quality and radiation dose in all types of CBCT systems, including dental.¹⁵

All modern CBCT scanners display or record some type of patient dose indicator, commonly referred to as “patient dose”. The dose indicator available on most CBCT scanners in use today is the air kerma–area product (P_{KA}), also abbreviated as KAP, and defined as the integral of the air kerma over the area of the X-ray beam in a plane perpendicular to the beam axis.¹⁶ This dose descriptor correlates well to the total radiation energy delivered to a patient during a procedure. It can be easily measured during the examination

using a transparent ionization chamber fixed at X-ray tube housing window, or calculated from exposure parameters.

Patient dose assessment provides an objective basis for comparison between CBCT equipment and optimization of CBCT protocols. The International Basic Safety Standards and the European Basic Safety Standards Directive require all X-ray facilities, including dental, to compare their local dose values with the relevant national or regional diagnostic reference levels (DRLs).^{17,18} Although DRLs have been recognized as a useful tool for optimization of patients radiation protection, their existence for CBCT is still limited, and most published studies of patient doses come from single institutions.^{19–22}

With the objective to study the dental CBCT practice and related patient exposure in CBCT in Central and Eastern European countries, a survey was launched in the framework of the IAEA regional technical cooperation project titled “Strengthening Radiation Protection of Patients and Medical Exposure Control”. This paper presents the results of this multi national survey.

Methods and materials

Survey methodology

The study was designed as both a prospective and retrospective multinational study, to assess indication-based radiation dose values and related CBCT exposure factors and practice. National representatives, supported by the IAEA coordinator and experts, agreed on methods to collect data. Structured instructions and forms were provided to project participants to ensure consistency of data necessary for reliable comparison. Data collection was performed in nine countries: Armenia (AM), Bosnia and Herzegovina (BA), Bulgaria (BG), Croatia (HR), Estonia (EE), North Macedonia (MK), Montenegro (ME), Serbia (RS), and Slovakia (SK) from March 2015 until June 2017.

The preferred survey method included collection of dosimetry data for adult and/or paediatric patients (age of 16 y and less) in terms of P_{KA} as reported by the CBCT equipment. The project participants were asked to provide data using standardized data collection forms that included details of CBCT scanner, patient demographic and anthropometric data, the clinical indication for the procedure, the technical parameters of exposure, P_{KA} values, use of shielding and subjective image quality assessment of clinical images.

Data collection included also relevant information of CBCT scanners related to dose and image quality, such as type of image detector, tube filtration, and availability of automatic exposure control (AEC).

Technical parameters for each patient exposure were recorded, which included field of view (FOV) size (cm^2), tube potential (kV), tube current (mA) and exposure time (s). Basic demographic and anthropometric data (patient's age, gender, height and weight) were collected

Figure 1 Acquiring the air KAP: (a) displayed air KAP value by exposing of anthropomorphic phantom and, or (b) in-air, possible only when automatic exposure control is not in use. Image shows verification process by an external KAP meter. KAP, kerma–area product

because of their potential impact on the clinical indication for the procedure, which would be expected to influence the selected exposure parameters.

Image quality was subjectively evaluated by local dentists, using a simple 3-point scale scoring system. Images were marked either as “acceptable”, with quality being “higher than needed”, or “unacceptable” (a retake was needed). Quantification of image quality was not within the focus of this study and this simple subjective scoring was selected to support the comparison of related dose parameters.

In cases where patient data collection was not possible, one of the alternative methods was used: (1) provision of the technical and dose parameters displayed by the CBCT equipment following the exposure of a phantom, or (2) provision of the equipment displayed parameters after in-air exposure on CBCT systems with no AEC, selecting the corresponding standard protocol (Figure 1). Phantom measurements lack patient-specific parameters but provide information on the typical dose values.

In general, the survey relied on dosimetry results indicated by CBCT equipment. Some project participants verified the “integrated dose indicator calibration,” or KAP meter accuracy and found the relative difference between the measured and equipment reported values to be below the recommended suspension level of 35%.²³

Statistical analysis

Data were collected and analyzed using spreadsheets in Microsoft® Excel and Access. Statistical analysis

was done using Kolmogorov–Smirnov normality tests, Student's *t*-test for hypothesis testing of normally distributed data, Kruskal–Wallis one-way analysis of variance (one-way ANOVA on ranks), Spearman's ρ correlation test, Pearson χ^2 test for analysis of differences between the sets categorical data, and the Mann–Whitney *U* test. The significance level was set to $\alpha = 0.05$. Interquartile range (IQR) was used as a measure of statistical dispersion.

Facilities and equipment

The study included 27 CBCT scanners: 1 in Armenia, 1 in Bosnia and Herzegovina, 2 in Bulgaria, 3 in Croatia, 13 in Estonia, 1 in North Macedonia, 4 in Montenegro, 1 in Serbia, and 1 in Slovakia. Table 1 shows the type of scanners, year of installation, image detector type, filtration, and dose display.

All scanners were installed within the last 8 years and display doses in air KAP. CBCT scanners used in the study operate using either complementary metal–oxide–semiconductor (CMOS), charge-coupled device (CCD) or amorphous Silicon (a-Si) detectors. Dimensions of the FOV, defined as the cross-sectional area of the reconstructed FOV in the isocentre, are governed by the size and shape of the detector, as well as the beam projection geometry and possible selection of the beam collimation.³ Table 1 reports the nominal values of the tube filtrations, as reported by vendors, which was ≥ 2.5 mm Al for all scanners.

Patients

Patient data were collected in all but one country—Estonia, where the work was done using an

Table 1 Models of CBCT scanners used in the study, with the year of their installation, detector type, filtration, displayed dose unit of air kerma–area product

Scanner model	Number of units	Year of installation	FPD ¹ type	Nominal filtration	Dose display unit	AEC used
Carestream Health CS 8100 3D	4	2014–2016	CMOS ²	4.5 mm Al	mGy cm ²	Yes ⁶
Ins. Dent. Orthopantomogr. OP300 Maxio	1	2014	CMOS	3.2 mm Al	mGy cm ²	Yes ⁶
Kodak 9000 3D	1	2010	CMOS	2.5 mm Al	mGy cm ²	Yes ⁶
MyRay Hyperion X9	3	2014–2017	a-Si ³ – CsIa	3.2 mm Al	cGy cm ²	Yes ⁷
Planmeca ProMax 3D Classic	7	2013–2016	a-Si – CsI	2.5 mm Al + 0.5 mm Cu	mGy cm ²	Yes ⁷
QR S.r.l. NewTom VGi evo	1	2015	a-Si	12 mm Al	mGy cm ²	Yes ⁷
Samsung Rayscan α Expert 3D	1		CMOS	2.5 mm Al	mGy cm ²	Yes ⁶
Sirona Orthophos XG	1	2013	CMOS	2.5 mm Al	mGy cm ²	No
Sirona Orthophos XG 3D	1	2014	CsI	2.5 mm Al	mGy cm ²	No
Sirona Orthophos XG Plus	1	2014	CCD ⁵	2.5 mm Al	mGy cm ²	No
Soredex Cranex 3D	1	2014	CMOS	3.2 mm Al	mGy cm ²	Yes ⁷
Soredex Scanora 3D	3	2008–2011	CMOS	2.7 mm Al	mGy cm ²	No
Soredex Scanora 3Dx	1	2013	a-Si	4 mm Al	mGy cm ²	No
VSM Rotograph Evo 3D	1	2017	a-Si – CsI	2.5 mm Al	dGy cm ²	Yes ⁶

CMOS, Complementary metal–oxide–semiconductor; FPD, flat panel detector; a-Si, amorphous silicon.

¹FPD – flat panel detector, ²CMOS – Complementary metal–oxide–semiconductor, ³a-Si – Amorphous silicon, ⁴Caesium iodide, ⁵Charge-coupled device, ⁶pre-set adaptation to patient's morphology, ⁷tube current modulation according to the scout image

anthropomorphic phantom (Figure 1a). Table 2 shows the number of patients included in the study, separated in two age groups: adults and children younger than 16 years old. Most data come from a single CBCT unit in Serbia (86, or 26%), followed by results from 4 CBCT scanners in Montenegro (80, or 25 %), and 3 units in Croatia (77, or 24 %). In total there were 335 patients, 298 adults and 37 children (Figure 2).

Although the majority of patients were female (53.5%), the proportion does not differ significantly from 50% probability of occurrence (one sample binomial test, $p = 0.222$).

The histogram (Figure 3) shows that patient age was not normally distributed (Kolmogorov–Smirnov test, $p < 0.001$).

Table 2 Number of patients included in the study (n) classified in different age and gender groups in each participating country, namely: Armenia (AM), Bosnia and Herzegovina (BA), Bulgaria (BG), Croatia (HR), Estonia (EE), North Macedonia (MK), Montenegro (ME), Serbia (RS), and Slovakia (SK)

Country	Age group												Total	
	Adults						Children (<16 y)							
	Male		Female		Total		Male		Female		Total			
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)		
AM	3	(2)	3	(2)	6	(2)	2	(18)	4	(25)	6	(22)	12	(4)
BA	5	(4)	5	(3)	10	(3)	0	(0)	0	(0)	0	(0)	10	(3)
BG	19	(14)	20	(13)	39	(13)	0	(0)	1	(6)	1	(4)	40	(12)
HR	32	(23)	44	(28)	76	(26)	1	(9)	0	(0)	1	(4)	77	(24)
ME	40	(29)	40	(25)	80	(27)	0	(0)	0	(0)	0	(0)	80	(25)
MK	6	(4)	4	(3)	10	(3)	0	(0)	0	(0)	0	(0)	10	(3)
RS	30	(21)	37	(23)	67	(22)	8	(73)	11	(69)	19	(70)	86	(26)
SK	5	(4)	5	(3)	10	(3)	5	(0)	5	(0)	10	(0)	20	(3)
Total	140	(100)	158	(100)	298	(100)	16	(100)	21	(100)	37	(100)	335	(100)

Figure 2 Number of patient dose data contributing in the study.

Results

Demographic and anthropometric patient data

Some project participants reported demographic and anthropometric data (patients' age, height and weight). Adult patients' ages ranged from 16 to 77, with a median of 47 years. The youngest patient was a 5-year-old girl. Adult patients' median height and body mass were

172 cm and 70 kg, respectively. The body mass average of adults older than 18 was 72.5 kg (standard deviation = 13.7 kg), which was not significantly different from the European average (Student's *t*-test, $p = 0.105$). The average body mass index of all patients was of 24.2 kg/m². The distribution of body mass index was the same across different institutions (Kruskal–Wallis test, $p = 0.060$).

Figure 3 Patient age histogram. Values do not present normal distribution ($n = 274$, Kolmogorov–Smirnov test, $p < 0.001$).

Table 3 Clinical indications for CBCT examinations for adults and children in small dental practices and large public institutions covered in the study

Indication of examination	Type of institution									
	Large institutions					Small dental practices				
	Age group					Age group				
	Adults		Children		n	Adults		Children		n
	n	(%)	n	(%)		n	(%)	n	(%)	
Abscess	1	(1)	0	(0)	3	(1)	0	(0)	4	(1)
Cancer	4	(6)	0	(0)	1	(0)	0	(0)	5	(2)
Cystic lesion	0	(0)	0	(0)	10	(4)	0	(0)	10	(3)
Develop. disturbances	22	(33)	0	(0)	4	(2)	0	(0)	26	(8)
Fracture	11	(16)	0	(0)	1	(0)	1	(6)	12	(4)
Impacted tooth	1	(1)	0	(0)	6	(3)	1	(6)	7	(2)
Implant planning	19	(28)	0	(0)	116	(48)	0	(0)	135	(44)
Maxillary sinusitis	0	(0)	0	(0)	2	(1)	0	(0)	2	(1)
Orthodontic assessment	0	(0)	0	(0)	10	(4)	0	(0)	10	(3)
Other conditions	2	(3)	0	(0)	3	(1)	9	(50)	5	(2)
Unknown (not reported)	7	(10)	19	(100)	84	(35)	7	(39)	91	(30)

CBCT, cone beam CT.

Examinations

The list of possible clinical indications was included in the data collection form, with the possibility to choose from one of the following: implant planning, impacted tooth, cystic lesion, supernumerary tooth, temporomandibular joint pathology, osteomyelitis, abscess, tumour, malignant tumour, fracture, maxillary sinusitis, developmental disturbances, orthodontic assessment, fibro-osseous lesion and other conditions. Table 3 shows the number of reported clinical indications for CBCT examination for adults and children, separated in two groups: small dental practices and large (public) institutions. These results for frequency of the most common clinical indications are summarized in two pie charts shown in Figure 4. More patients with developmental disturbances and fractures reported to large (public) institutions, while small dental practices (private or public) worked with patients in the context of implant treatment. Information about the clinical indication was not reported in 91 (30%) of adult patients and 26 (70 %) of children.

Radiographic techniques, dosimetry, and image quality

Table 4 shows differences in radiographic techniques used for different examinations. The IQR of tube current and tube current-exposure time product indicates how these quantities vary between different patients/institutions. The median values of tube potential (U), FOV and PIt for some clinical indications for CBCT examination of adults in different institutions are presented in Table 5.

Depending on the scanner model, the operators were offered a variety of options regarding the FOV size. In order to evaluate the influence of selected FOV size on patient dose, the FOV area was calculated by multiplying the height and width of the selected FOV.

Figure 5a shows how air kerma-area product (PKA) and air KAP normalized per unit of tube current-exposure time product (nPKA) changed with FOV. Figure 5b shows the regression line with 95% confidence intervals between different FOV areas and nPKA. The correlation between FOV and both PKA and nPKA, was significant (Spearman's rho, p < 0.001). The regression curve (solid line) in Figure 5b, with 95% confidence intervals (dotted

Figure 4 Differences between large institutions and small dental practices in known clinical indications for CBCT examinations in the study. CBCT, cone beam CT; FOV, field of view; KAP, kerma-area product.

Table 4 CBCT exposure settings used by the operators in the study: median ($\tilde{x}$) and IQR of FOV area, tube potential (U), tube current-exposure time product (P_{It}) and total tube energy (kWs)

Indication of examination	Age group															
	Adults								Children							
	Radiographic technique								Radiographic technique							
	FOV (cm ²)		U (kV)		P _{It} (mAs)		E (kWs)		FOV (cm ²)		U (kV)		P _{It} (mAs)		E (kWs)	
	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR
Abscess	36	98	88	5	63	26	5.5	2	.	.	.	.	.	.	.	.
Cancer	140	91	90	0	30	10	2.7	0.9	.	.	.	.	.	.	.	.
Cystic lesion	36	12	85	5	68	9	5.7	0.4	.	.	.	.	.	.	.	.
Dev. disturbances	231	66	90	0	24	8	2.2	0.7	.	.	.	.	.	.	.	.
Fracture	231	0	90	0	24	11	2.2	1	18	0	90	0	120	0	10.8	0
Impacted tooth	36	0	85	5	59	11	5.3	0.9	24	0	90	0	38.4	0	3.5	0
Implant planning	75	44	85	5	71	52	6	4	.	.	.	.	.	.	.	.
Maxill. sinusitis	48	0	90	0	79	0	7.1	0	.	.	.	.	.	.	.	.
Orth. assessment	64	52	90	5	59	72	5.3	6	.	.	.	.	.	.	.	.
Other conditions	109	287	85	5	56	32	4.8	2.6	64	46	90	0	18	10	.	.
Unknown (not reported)	64	87	90	0	121	39	10.9	4.2	100	0	90	0	45	44	2.5	1.9
Total	75	76	90	5	71	83	5.9	7.6	82	75	90	0	35	21	3.2	1.9

FOV, field of view; IQR, interquartile range.

line), indicates a linear relationship between the two variables ($R^2=0.857$).

Patient dose analysis

Table 6 shows the median values and IQRs of FOV area, tube current–exposure time product (P_{It}), and air kerma–area product (P_{KA}) for each institution included in the study, grouped in two patient age categories: adults and children. The last row includes the third quartile values (Q_{3i}) of median P_{KA} from all institutions for adults and children.

Further analysis of data show how patient doses were influenced by applying the acquisition protocols according to the clinical indications (Table 7).

Patient doses expressed in air KAP (mGy cm²) are shown on Figure 6 according to the type of medical institution.

The study included a simple image quality assessment, based on a question whether image quality was acceptable, higher than needed, or unacceptable (retake needed). In 144 cases the answer was omitted, but most institutions reported the appropriate quality of image.

Table 5 Median ($\tilde{x}$) values of tube potential (U), FOV and P_{It} for some clinical indications for CBCT examination of adults in different institutions included in the study

Institution	Indication of examination											
	Implant planning			Impacted tooth			Abscess			Develop. disturbances		
	U (kV)	P _{It} (mAs)	FOV (cm ²)	U (kV)	P _{It} (mAs)	FOV (cm ²)	U (kV)	P _{It} (mAs)	FOV (cm ²)	U (kV)	P _{It} (mAs)	FOV (cm ²)
	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$	$\tilde{x}$
B	90	20.1	88	.	.	.	.	.	.	.	.	.
C	85	67.5	36	85	67.5	36	85	67.5	36	85	67.5	36
D	90	58.5	36	90	58.5	36	90	58.5	36	.	.	.
E	90	79.4	48	.	.	.	.	.	.	.	.	.
F	85	85.2	64	.	.	.	.	.	.	.	.	.
G	90	24	132	90	45	25	90	24	231	90	24	231
J	85	85.2	64	.	.	.	.	.	.	.	.	.
K	83	106.4	76	.	.	.	.	.	.	.	.	.
M	90	140	81	.	.	.	.	.	.	.	.	.
B	90	20.1	88	.	.	.	.	.	.	.	.	.

CBCT, cone beam CT; FOV, field of view.

Figure 5 Change of (a) air PKA and (b) normalized air KAP (nPKA) with FOV area. Points represent the value of PKA and nPKA for calculated FOV area on all scanners, both adult and paediatric patients. FOV, field of view; KAP, kerma–area product.

Two images (1.0 %) were scored as unacceptable, while the quality of four images (2.0 %) was perceived to be higher than needed. All of the images taken on paediatric patients were acceptable.

Phantom and in-air dose analysis

Four countries participating in the project provided dosimetry data for exposures performed using a phantom, or in-air (possible only when AEC is not in use). Data collection was performed in 15 different institutions.

The information provided by the study participants was diverse. Project counterparts performed measurements using standard imaging protocols in the surveyed institution. Unfortunately, protocol names were not standardized, neither were the exposure parameters. However, most of them could be classified in groups by the size of FOV and resolution (voxel size). Different FOV sizes were assigned to one of four categories: small (S,<40cm²), medium (M, 40–99cm²), large (L, 100–150cm²), and extra large (XL,>150cm²). Resolution, on the other hand, had two categories only—high definition with voxel size less than 0.2 mm and standard definition with voxel size ≥0.2 mm.

Figure 7 shows how median P_{KA} changed with the FOV size and resolution mode, based on data from 15

Table 6 Median ($\tilde{x}$) and IQR of FOV area, tube current–exposure time product (P_H), and air P_{KA} in all institutions included in patient dose study, grouped in patient age categories, sorted by adult P_{KA} median

Institution	Age group											
	Adults						Children					
	FOV (cm ²)		P _H (mAs)		P _{KA} (mGy cm ²)		FOV (cm ²)		P _H (mAs)		P _{KA} (mGy cm ²)	
	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR	$\tilde{x}$	IQR
L	45	(39)	32	(17)	236	(295)	55	46	20	10	146	165
G	88	(0)	17	(9)	304	(186)	.	.	.	.	.	.
N	36	(39)	59	(5)	390	(97)	.	.	.	.	.	.
K	64	(36)	85	(14)	402	(174)	.	.	.	.	.	.
E	.	.	110	(256)	435	(305)	.	.	108	(256)	218	(522)
M	36	(39)	68	(11)	468	(110)	.	.	.	.	.	.
F	48	(0)	79	(21)	578	(156)	24	(0)	38	(0)	279	(0)
A	64	(0)	85	(14)	693	(113)	.	.	.	.	.	.
C	.	.	76	(21)	718	(194)	.	.	.	.	.	.
D	.	.	122	(0)	820	(273)	.	.	109	(0)	738	(0)
J	40	(87)	123	(23)	1057	(1760)	.	.	.	.	.	.
B	231	(99)	24	(6)	1526	(619)	100	(0)	24	(21)	796	(863)
I	76	(39)	106	(11)	2327	(750)	.	.	.	.	.	.
H	81	(0)	140	(42)	2567	(937)	.	.	.	.	.	.
Total	75	(76)	71	(83)	820	(1058)	82	(75)	35	(21)	653	(578)
Q _{3i}	1000										740	

FOV, field of view; IQR, interquartile range; P_{KA} , kerma–area product. The last row includes the value of third quartile of medians from each institution (Q_{3i}). Names of institutions are anonymized.

Table 7 Median ($\tilde{x}$), IQR and third quartile (Q_3) of doses to patients expressed in air P_{KA} for different clinical indications for CBCT, sorted by examination frequency

Indication of examination	Age group									
	Adults					Children				
	FOV		P_{KA} (mGy cm ²)			FOV		P_{KA} (mGy cm ²)		
	$\tilde{x}$	n	$\tilde{x}$	Q_3	IQR	$\tilde{x}$	n	$\tilde{x}$	Q_3	IQR
Implant planning	75	135	596	1584	(1116)	.	0	.	.	.
Develop. disturbances	231	26	1526	1526	(0)	.	0	.	.	.
Fracture	231	12	1526	1526	(0)	18	1	987	987	(0)
Cystic lesion	36	10	468	578	(182)	.	0	.	.	.
Orthodontic assessment	64	10	390	693	(464)	.	0	.	.	.
Impacted tooth	36	7	468	468	(78)	24	1	279	279	(0)
Cancer	140	5	1241	1526	(285)	.	0	.	.	.
Other conditions	109	5	693	2035	(1567)	.	0	.	.	.
Abscess	36	4	468	997	(568)	.	0	.	.	.
Maxillary sinusitis	48	2	578	578	(0)	.	0	.	.	.
Unknown (not reported)	64	91	820	1093	(437)	100	35	653	796	(578)

CBCT, cone beam CT; FOV, field of view; IQR, interquartile range; P_{KA} , kerma–area product. Table shows used FOV area in cm² and number of observed patients (n).

different institutions. Patient dose for imaging performed using extra large FOV and high-resolution mode is 15 time higher than dose recorded for small FOV and low-resolution mode.

Radiation protection of patients and carers

The study included the analysis of radiation protection of patients and persons supporting the patient during

the examination. Apart from two institutions included in the study, in all others a lead apron was used to protect patients from scattered radiation. One institution provided thyroid collar shielding.

A questionnaire included the question regarding the presence of support during the paediatric examination. The practice differs from one institution to another. The results indicate that one of the surveyed institutions

Figure 6 Patient doses expressed in air kerma-area product (mGy cm²) for all CBCT examinations included in the study, separated by the type of medical institution that owns the scanner. CBCT, cone beam CT.

Figure 7 Median values of air kerma–area product (mGy cm²) for different FOV sizes and two resolution modes—HD (voxel size <0.2 mm) and SD (voxel size ≥0.2 mm) in 15 different institutions from four countries. FOV, field of view; HD, high definition; SD, standard definition.

allows parents to stay in room with lead apron and thyroid shield during the exposure. Others, however, either omitted the answer to the question or reported that no support was needed.

Discussion

Most patient data collected in this study were of adults (298) and only 37 were paediatric patients. This demonstrates a positive trend of less frequent use of CBCT in children, in line with the need of clear justification because of the associated higher risk from the radiation exposure during the childhood.

The histogram on Figure 3 shows a peak in frequency of CBCT exams at the age of 10–15, and a second peak at 50–55 years. This could be associated with the typical age of orthodontic treatment being considered for young patients and implant treatment being undertaken for adults. While the second was confirmed by the reported clinical indications for adults, the indications for CBCT in children were not identified. An 11-year-old boy underwent the examination due to an impacted tooth, while the reason for imaging in other cases was either not reported or indicated as “other conditions”.

The clinical indications for CBCT depended on patient age and varied from one institution to another (Table 3). The deterring factor for implant placement in children is the impending growth of maxilla and mandible, which is why no child in this study was reported to have a CBCT examination indicated due to implant planning.²⁴ Analysis of data in Table 3

show some specificities. Each dental practice could be assigned in one of the two groups: small independent dental practices, which are mostly private, and large institutions, associated with universities or university hospitals. While small practices report imaging more patients with needs for implant planning and orthodontic assessment, big hospitals work with patients with developmental disturbances, fractures, and in some cases tumours (malignant or benign). The differences were found to be significant (Pearson χ^2 test, $p < 0.001$). This is clearly seen on pie charts on Figure 4. While “implant planning” was the reason for CBCT in 74% of cases in small dental practices, “developmental disturbances” were the imaging cause for four patients only (3%). On the other hand, large institutions reported “developmental disturbances” as the leading indication for CBCT (37%). In the same sense, patients with fractures will most likely go to large (public) hospitals.

In five (2%) of patients CBCT was used for cancer imaging. The clinical reasons for these cases would require further investigation, since the evidence-based SEDENTEXCT Guidelines stay that CBCT is not appropriate for malignant lesions, and instead, contrast-enhanced CT or MRI is recommended.⁹ The guidelines suggest that limited volume, high resolution, CBCT may be indicated for evaluation of bony invasion of the jaws by oral carcinoma only when MRI or CT does not provide satisfactory information.⁹

Exposure parameters used, namely tube voltage (U), tube current (I), rotation time (t), and FOV size, were highly dependent of technical capabilities of the CBCT

scanner. Out of 10 type of scanners included in the study, 5 (50 %) were not equipped with AEC. In those CBCT units, the operator would select one of the standard protocol settings, which differ by the values of the U , I , t and/or desired image quality.

Significant correlations were found between FOV and both P_{KA} and ${}_nP_{KA}$ (Spearman's ρ , $p < 0.001$), even though data include results from all institutions participating in the study and both adults and paediatric patients were imaged using different tube potentials and currents.

The relationship between FOV area and ${}_nP_{KA}$ (Figure 5b) is close to linear ($R^2=0.857$). This indicates that patient dose is mostly dependant on selected FOV size and tube current–exposure time product. The correlation between ${}_nP_{KA}$ per unit of FOV area and tube potential, although positive and significant (Spearman's ρ , $p = 0.006$), is very weak ($R^2=0.030$).

The preceding analysis showed that the collected data, both technical and dosimetric, appear to be reliable. It coincides with known physical characteristics of the X-ray beam, such as linear dependence between P_{It} and air kerma, or field size and P_{KA} . This increased the confidence in proper data collection by all study participants, suggesting that no major typing or read-out mistakes happened.

Several key observations regarding the data in Table 6 must be noticed. Patient doses in terms of P_{KA} varied by more than 10-fold between institutions: median P_{KA} in institution L was 236 mGy cm², while the reported value in institution H was 2567 mGy cm². As expected, the reason behind this variation could be found in radiographic parameters used during the examination, mainly FOV size and P_{It} . Yet, this does not necessarily mean that CBCT scanner in the institution L is not optimized. Use of appropriate exposure parameters should be driven by the clinical indication. However, some peculiarities were found. For example, institution G with median P_{KA} of 1526 mGy cm², uses the largest FOVs not only for certain clinical indications that might justify that, but also for implant planning, which is associated with smaller FOVs. In the Institution M, on the other hand, very high values of P_{It} in comparison to others is used for the same clinical indication (Table 5). Both cases suggest that optimization of imaging procedure might be necessary.

Similar variations between scanners were found in other studies.^{21,22} In the study from Endo *et al*, which included results of P_{KA} from 21 CBCT units, the measured dose ranged from 126.7 mGy cm² to 1476.9 mGy cm².²¹ Although European guidelines recommended the adoption an achievable dose of 250 mGy cm² for CBCT imaging appropriate for the placement of an upper first molar implant in a standard adult patient, they also state that large FOV units can exceed this value, as found in the UK's Health Protection Agency preliminary study.⁹ In fact, in this study data had been normalized to an area corresponding to a 4 × 4 cm FOV at the isocentre of the equipment.²⁵

Median dose above 1000 mGy cm² was found in cases of clinical indications for cancer, developmental disturbances and fractures, while the lowest patient doses (median 390 mGy cm²) were reported when the reason for imaging was orthodontic assessment (Table 6).

The dose values correlated with the FOV area used during examinations. We could argue that more complicated imaging studies, that require larger volumes to be imaged, are bound to have patient doses higher than usual. Kralik *et al* have recognized the FOV size as one of the most important scanning parameters affecting the dose.²⁶ As seen on Figure 4, patients with medical conditions that require such imaging are usually referred to large hospitals. Due to the fact that patient doses are higher for these types of indications, we expected significant differences between patient doses in large hospitals and small private practices. This was proven to be true, both in cases of adults and children (Mann–Whitney U test, $p < 0.001$). Figure 6 clearly shows the difference. However, several outliers exist, and that they all come from only three institutions. Further analysis showed that the patients in question were imaged for implant planning, using high values of P_{It} (mAs).

The phantom and in-air data collection showed 15-fold variation of median P_{KA} depending on the FOV and resolution mode, from 125 mGy cm² for small FOV and low-resolution image up to 1952 mGy cm² for extra large FOV and high resolution. Choosing the most appropriate exposure protocol is certainly the most important aspect of procedure optimization available to the operator.

Although establishing DRLs was beyond the scope of this paper, for future reference we included the value of third quartile value of median doses (Q_{3i}), which is typically used to set DRL. For adult patients Q_{3i} was found to be 1000 mGy cm², and 740 mGy cm² for children. The experience gained by participants in the study can be used to proceed with establishment of local or national DRLs, considering the ICRP recommendations concerning the number of surveyed facilities.¹⁹ In smaller countries, such as those included in the study, the initial survey could include 30–50% of all installations. In that sense, this study should provide a good starting point, with data collection and analysis methodology, as well as the insight of expected results.

Having in mind results from both patient and phantom/in-air dose analysis, when setting up DRLs in dental CBCT one should consider clinical indications, which is a practice recommended in the ICRP report.¹⁹ Even when the same FOV is used, the examination may require different image quality which is directly correlated to patient dose.

Conclusions

This study presented demographic, anthropometric, clinical, radiographic, and dosimetric data for patients undergoing dental CBCT procedures on 27 CBCT

scanners in 9 Central and Eastern European countries. The focus was put on patient doses expressed in terms of air KAP as displayed by the CBCT equipment.

Although dosimetry results were consistent in physical behaviour for all CBCT scanners included in the study, the real patient doses varied depending on clinical indications and radiographic parameters used for imaging. Median P_{KA} for CBCT examinations for all indications and all patients included in the study was 820 and 745 mGy cm² for adults and children, respectively. However, it is important to note that respective IQR was 1058 and 1179 mGy cm², which indicates relatively high statistical dispersion of collected data. This illustrates how clinical indications and radiographic parameters influence the patient doses. Nevertheless, this study established baseline information on dose levels in countries participating in the project.

The results emphasize the need for a cautious approach to dental CBCT imaging. It should be carried out only when the clinical indications are clear and performed with the appropriate radiographic techniques which will contribute in reduction of ionising radiation dose to patients.

DRLs in dental CBCT should be established taking into account clinical indications for imaging procedure.

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