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Cone beam computed tomography (CBCT) in pediatric dentistry

Authors:
Theys S DDS[1,*],
Olszewski R DDS, MD, PhD, DrSc, Prof[2, 3].

Affiliations:

[1] Department of Dentistry, Nîmes University Hospital Center - Carémeau, Nîmes, France
[2] Department of oral and maxillofacial surgery, Cliniques universitaires Saint-Luc, UCLouvain, Brussels, Belgium
[3] Oral and maxillofacial surgery research Lab, NMSK, IREC, SSS, UCLouvain, Brussels, Belgium
[*]Corresponding author: Theys S, Department of Dentistry, Nîmes University Hospital Center - Carémeau, Nîmes, France. Stephanie.THEYS@chu-nimes.fr.
ORCID iD: https://orcid.org/0000-0003-4657-8046
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Abstract

Objective: The aims of this systematic review of the literature were to investigate the uses of cone beam computed tomography (CBCT) in pediatric dentistry and, if possible, identify the indications.

Material and methods: A literature search was conducted using the PubMed and Scopus electronic databases and the keywords "CBCT and pediatric dentistry". This search provided us with 1518 references. The selected publications were all clinical articles written in French or English and referring to a pediatric population. After screening, 461 eligible full text articles remained.

Results: In total, there were 169 references that met the inclusion criteria. Different topics, mainly relating to orthodontics, anatomy, and cleft lips and palate, were discussed. There was large variability in the information concerning the technical parameters. The radiographic protocols that we analyzed showed a large heterogeneity.

Conclusions: The level of evidence provided by our work is limited because only two randomized double-blind controlled studies are included. Two indications can be distinguished: for orthodontics and for the rehabilitation of cleft lips and palate. There are a multitude of radiographic protocols. More research is needed to identify other potential clinical indications as well as to determine a standard CBCT protocol for children and adolescents.

Keywords: CBCT, pediatric dentistry, cleft palate, systematic review

Introduction

Cone beam computed tomography (CBCT) is a medical imaging technique that started being used in the 1990s [1]. Compared to traditional two-dimensional radiographs, CBCT is characterized by its three-dimensional visualization of larger anatomical regions and the use of higher energy and radiation intensities [2]. The dose of radiation generated by the CBCT is therefore greater than that of traditional dental X-rays. However, this dose is lower than that generated by multiple slices computed tomography (MSCT) [1]. The type of device used, and the selected acquisition parameters influence this dose [2].

Since the advent of this technique, equipment has continued to evolve. Currently, a multitude of devices are available, all with their own characteristics and properties [2]. The uses of CBCT imaging have also developed over time, and this technology has become increasingly important in dentomaxillofacial imaging. Despite this fact, we need to keep in mind the three basic principles of radiation protection: justification, limitation, and optimization. Practitioners need to be even more attentive when radiation is used in a pediatric population (patients up to the age of 18 years old) [3].

The risk posed by ionizing radiation depends on the population exposed, while the damage caused depends on the age and sex of the patient. There is a multiplication factor for risk according to the age of the patients, with the risk being higher for young people (x3 below 10 years, for a coefficient of 1 to 30 years) and lower for the elderly (negligible risk above 80 years for a coefficient of 1 to 30 years). Regarding sex, women are more sensitive to the development of damages than men, and this at all age. The main risks of radiation are the development of cancer and hereditable effects [4].

The constant evolution of this technology and of its uses necessitates the creation and the continuous updating of guidelines, recommendations of good practice and justifications for radiographic applications [5]. Several academies of professionals have issued recommendations or basic principles for the use of CBCT, such as the European Academy of Dental and Maxillofacial Radiology in 2009 [6], the American Academy of Oral and Maxillofacial Radiology in 2013 [7], and the American Association of Endodontists / American Academy of Oral and Maxillofacial Radiology in 2015 [8]. The European Commission has also proposed evidence-based guidelines for the use of CBCT in 2012 [4]. The issue of pediatric dentistry is poorly addressed in these recommendations. According to Aps, CBCT indications in pediatric dentistry are not yet well established and must be justified on an individual basis by assessing the benefit-risk ratio [3]. It is also important to bear in mind that even if these European recommendations exist, there is not a common legislation for all European countries. Each one has his own legislation, regulation and even guidelines for radioprotection and imaging technique in the medical and dental field.

In this context, the purposes of this systematic review of the literature are to investigate the uses of CBCT in pediatric dentistry, and if possible, identify the indications.

Materials and methods

Inclusion and exclusion criteria

The inclusion and exclusion criteria mainly concerned the language and the category of the papers.

Inclusion criteria

Only articles written in French and English were included in this research. All clinical articles were considered if their title, abstract, or full text scrupulously referenced the study population, mentioning either age or an associated term such as child, adolescent, or pediatric. Case reports of five cases or more were also included in this review.

Exclusion criteria

Articles in all other languages than French and English were excluded because they could not be read and understood by all observers. Experimental articles and articles concerning animals were excluded because the objective was to determine the clinical uses of CBCT in pediatric dentistry and then to identify recommendation concerning the indication of this kind of imaging in children.

Search equation

A literature search was conducted on the electronic databases PubMed (https://www.ncbi.nlm.nih.gov/pubmed) and Scopus (https://www.scopus.com/). These databases were searched using the keywords "CBCT and pediatric dentistry". Two different spellings of the word were used pediatric and paediatric. This search was carried out a first time on August 7, 2017 and for a second time on February 23, 2020. All references published until February 2020 were considered without any other date restrictions set (i.e., from 1948 to the present).
The search equation used on PubMed was CBCT [All Fields] AND ("paediatric dentistry" [OR] "pediatric dentistry" OR ("pediatric" [All Fields] AND "dentistry" [All Fields]) OR "pediatric dentistry" [All Fields]). This search led to 228 references.
The search equation used on Scopus was cbct AND pediatric AND dentistry AND (EXCLUDE (PUBYEAR, 2017)). The immediate result of this search consisted of 1492 references.
The analysis of all titles and abstracts was performed by two independent observers.

Data collection

For each article included in the literature review, various data were collected concerning the characteristics of the population studied (age, sex, group of interest), the technical information regarding CBCT, the reason CBCT was used and how CBCT was used, depending on the topic.

Results

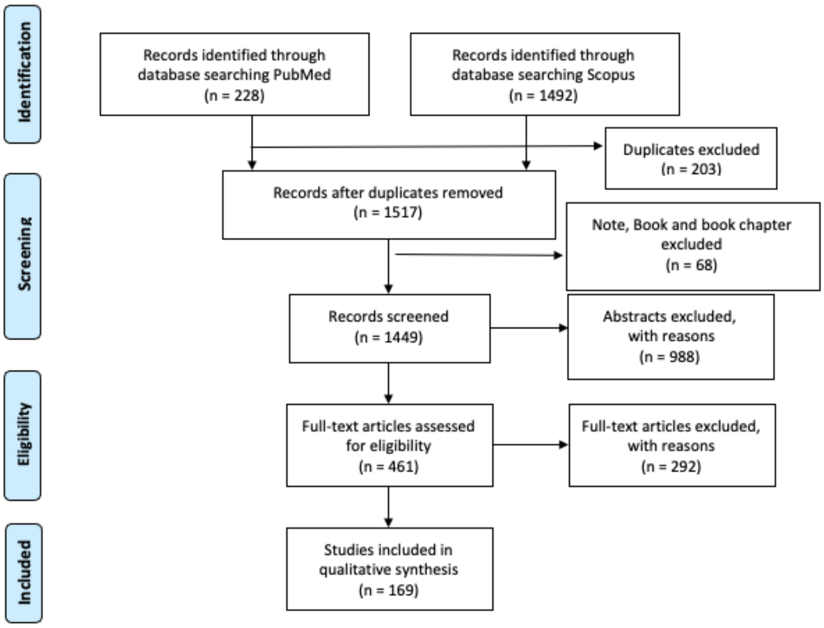
A total of 169 articles were included in this systematic review after the screening of 1720 records.

Of the 228 references found on PubMed, the following exclusions were done: 1 duplicate, 130 abstracts and 56 full texts with reasons (16 concerned adults, 6 did not mention neither the age of the sample population nor an associated term, 3 reported an insufficient number of cases, 23 did not distinguish between children and adults, 7 were not clinical articles and 1 did not distinguish between CT scans and CBCT). Finally, 41 articles from PubMed were included in our systematic review.

Of the 1492 references from Scopus, the following exclusions were done: 202 duplicates, 68 sources other than articles (notes, books, and book chapters), 858 abstracts and 236 full texts with reasons (63 concerned adults, 36 did not mention the age of the study population or an associated term, 8 reported an insufficient number of cases, 82 did not distinguish between children and adults, 18 did not refer to CBCT, 5 were out of the scope of this study, 23 were not clinical articles and one did not distinguish between CT scans and CBCT). Finally, 128 articles from Scopus were included in our systematic review.

Out of our original 1720 references, 461 articles were read in full, and 169 articles were selected for the inclusion in the review.

The PRISMA flow diagram of this systematic review of the literature process is presented below in Figure 1.



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Fig. 1. Prisma flow of the review of the literature on CBCT and pediatric dentistry.

These articles covered different topics, such as orthodontics, anatomy, and growth, allowing us to establish a classification by subject (Table 1). The classification is used below in the presentation of the results. All 169 papers concerned pediatric patients up to the age of 18 years old.

Table 1. Classification according to the subject of articles included.

Topics	**Number of references**
Orthodontics	75
Anatomy	44
Cleft lips and palate	20
Growth	7
Characteristics of patients referred for CBCT	7
Various	18

Orthodontics

A little less than half of the articles (75/169) included in this review related to orthodontics with most concerning maxillary expansion. Thus, this topic is addressed separately.

Most studies (14/32) evaluated the skeletal and dental effects of various orthodontic appliances [9-29]. Other studies analyzed the effects of these treatments on the maxillary sinuses (1/32) [30], on the temporomandibular joint (4/32) [27, 31-33], and on the upper airways (9/32) [21-23, 26, 34-38]. In these situations, CBCT scans were performed before and after treatment to observe and measure changes following orthodontic treatment.

Two papers compared the use of two-dimensional (2D) and three-dimensional (3D) imaging for establishing orthodontic treatment plans [39, 40]. The advantages of the 3D information are that it seems to be more accurate, and that it more closely resembles reality, and thus, its use reduces the risk of practitioner-dependent errors [40].

The last six articles included in this review concern the detection of tonsillar hypertrophies by orthodontists [41], the detection of mandibular asymmetry in patients presenting a unilateral versus a bilateral posterior crossbite [42], the evaluation of the influence of the maturational stage of the zygomaticomaxillary suture on the response to maxillary protraction [20], the effect of traction discontinuation on maxillary central incisor sulcal depth and alveolar bone ridge level [18], the analyzis of the development and the stability of the roots and the alveolar bone in orthodontically treated labial inversely impacted maxillary incisors [29], and the comparison of the palatal total support tissue and bone support tissue between mouth breathers with a high narrow palate and a nose breathers with normal palate in the case of orthodontic mini-implant implantation [24].

Maxillary expansion

Maxillary expansion was treated in 43 of the 75 articles concerning orthodontics. All but five, discussed the effects of various maxillary expansion treatments at the skeletal [43-54], dentoalveolar [43, 49, 51, 52, 54-60], soft tissue [61], roots [62-64] and upper airway [59, 65-78] levels. One article evaluated the short- and long-term effect of the use of a particular treatment protocol for Class III patients [79]. Two articles compared two types of treatment used in particular situations [80, 81]. The last three articles of this category concerned various topics: the determination of the reliability and the predicting performance of a classification and a methodology [82], the detection of age-related morphological changes in the median and transverse palatal suture that could affect the outcome of the treatment [83], and the evaluation of the validity of the use of a software for segmenting and measuring the upper airway [84]. CBCT was systematically performed before and after the maxillary expansion treatment to measure the impact of the treatment on the anatomical structures of interest.

Three articles described limitations in the use of CBCT when measuring the volume of the upper airways [68, 72, 73]. The volume of the upper airways is influenced by many factors, including the position of the head, the position of the tongue, and the breathing, and swallowing movements at the time of image acquisition. The lack of a standardized position when taking CBCT scans calls into questions the reliability, and the reproducibility of CBCT for the measurement of the upper airways.

Anatomy

The anatomical structures studied by 44 articles included in this work are shown in Table 2. Approximatively one-third of the studies were carried out in Turkey [85-96], including five studies conducted by the same team [85, 86, 89-91]. The populations studied were not sufficiently representative to generalize the observations to the general population. However, all studies confirmed the reliability and accuracy of the use of CBCT images in detecting and describing the anatomical structures observed.

Table 2. Anatomical structures observed on pediatric CBCT.

Anatomical structure	Country	Field of view	Number of articles	Number of patients
Tonsils	Canada [145, 148]	12 inches	2	10, 39
Teeth				
– Temporary maxillary incisors and canines	South Korea [149]	40 mm	1	38
– Temporary mandibular second molar	China [150]	60 mm	1	283
– Permanent central maxillary incisor	Brazil [78]	?	1	26
– Permanent maxillary canines	Sweden [151]	?	1	20
– Second premolar	Brazil [147]	?	1	31
– First permanent mandibulary molar	India [172]	60 mm	1	30
– Third molar	Canada [163]	?	1	179
– Included supernumerary teeth	Turkey [87]	4 cm	1	22
– Mesiodens	South Korea [146]	?	1	293
– Root resorptions	Sweden [175]	4 cm x 4 cm 6 cm x 6 cm 8 cm x 8 cm	1	63
– Interproximal contact	India [171]	80 mm x 80 mm	1	28
Mandible				
– Condyle	Belgium [152]	?	1	20
	South Korea [153]	24 cm x 19 cm	1	282
	USA [166]	17 mm x 23 mm	1	60
	Italy [168]	16 cm x 8 cm 16 cm x 11 cm	1	71
– Condyle and coronoid process	Brazil [167]	Full	1	39
– Temporomandibular joint	South Korea [165]	?	1	356
	Canada–Denmark Germany–Norway [170]	18 cm x 16 cm 19 cm x 24 cm	1 1	66 28
– Accessory mental foramen	Turkey [92]	? - 9 inch	2	14 and 63
– Lingula	Turkey [85, 88]	?	1	269
	Turkey [91]	13 cm x 16 cm	1	280
– All the mandible via five land-marks	Australia–USA [159] Turkey [86]	?	1	100

Maxilla				
– Naso-palatal canal	Turkey [89]	8 cm x 8 cm 12 cm x 8 cm 15 cm x 12 cm 18 cm x 16 cm	1	368
– Mid-palatal suture	Brazil-Italy-USA [154]	Min 11 cm	1	140
	Iran [160]	6 cm x 8 cm	1	144
	Iran [169]	4 inch 9 inch	1	167
– Zygomaticomaxillary suture	Brazil-Italy-USA [161]	16 cm x 22 cm	1	74
	Iran [169]	4 inch 9 inch	1	167
– Anterior neurovascular variation	Turkey [90]	?	1	368
– Maxillary sinus	Turkey [93]	?	1	50
Cranial base				
– Skull base foramen	Turkey [94]	?	1	350
– Posterior cranial base	Canada–USA [162]	9 inch x 12 inch	1	60
Sella turcica	Turkey [95]	?	1	177
Hyoid bone	Japan [158]	?	1	60
	China [164]	?	1	60
Upper airway	Brazil [155]	13 cm x 16 cm	1	50
	USA [156]	?	1	387
	Saudi Arabia-USA	13 cm x 16 cm	1	81
	[157]	?	1	60
	China [164]	?	1	200
	Turkey [96]	?	1	62
	Japan [173]			

Clefts lips and palate

Cleft lips and palate are facial malformations that occur relatively frequently. They were discussed in 23 articles, 5 of which were included in our results concerning orthodontics [17, 28, 52, 75, 81].

The CBCT was obtained for various reasons such as orthodontic treatment, orthognathic surgery, pathology of the temporomandibular joint, supernumerary or impacted teeth, airway assessment, etc) other than for the completion of the submitted study in all but three articles [97-99] in which imaging was an element used in the preparation for and the follow-up after the alveolar graft surgery.

The images from the CBCT were used a second time to evaluate different aspects either related or not related to the presence of cleft lips and palate, such as the maxillary [100] or the sphenoid sinus [101], the mandibular condyle, and the glenoid fossa [102], the sella turcica [103], dehiscences and fenestrations of teeth [104, 105], the development of permanent maxillary central incisors [106], teeth in the premaxilla [107], the alveolar support of the teeth adjacent to the cleft [108], the cortical bone thickness of the infrazygomatic crest area [109], and the upper airways [110-112]. One article established a method for the classification of clefts based on CBCT images to facilitate a better understanding of this malformation [113]. Another article categorized and quantified the incidental findings from patients with cleft lips and palate [114].

Three-dimensional imaging allows a better evaluation of the bone volume than does 2D imaging does, but its limitation is its inability to evaluate the quality of the bone [97].

Growth

Six articles discussed various methods for evaluating the growth of skeletal structures [115-120]. Each of them compared a new method to a recognized method, such as the maturation of cervical vertebrae, to determine any possible correlation, and to evaluate the reliability of the innovative method. The last article included in this category focused on the relationship between the chronological age and the surface area of the developing mandibular third molar apices [121]. CBCT scans were not performed for this work but have previously been obtained for orthodontic reasons or as part of the institution's database.

Characteristics of patients referred for CBCT

Six articles were included in this category [1, 122-126]. These articles analyzed the reasons for prescribing a CBCT examination. Two of them [123, 125] also analyzed the technical setting, and one study observed its influence on the treatment planning [124].

These articles [1, 122-126] insisted on several recommendations for good practice, such as the need for the analysis of the patient's medical history and a prior clinical examination, the consideration of the "as low as reasonably achievable" (ALARA) principle and the choice of an adequate field of view (FOV) according to the indication. The selection of the FOV is more important in children because the FOV affects the optimal dose. In addition, an adequate FOV makes it easier to analyze the images obtained, and to limit incidental findings.

Various other topics

Eighteen articles covered a variety of topics. Each of the following subjects was dealt within a single article: direct pulp capping using three different materials [127], root fracture [128], the relation between the size of gonial angle and the inclination of the epiglottis in children with disordered sleep breathing [129], the minimum FOV needed to locate the maxillary impacted canine [130], the craniofacial and vertebral anomalies and asymmetries in patients with Goldenhar syndrome [131], the volume of the maxillary sinus and the dimension of the maxillae in patients with cleidocranial dysostosis [132], the impact of metallic artifacts and movements on the ability to answer the question asked [133], factors affecting patient movement and re-exposure [134], the comparison of three available 3D CBCT superimposition methods [135], and the need for X-ray examinations in people with disabilities (mentally handicapped dental patients) [136].

One article studied the incidental findings in the maxillary sinus of 74 children [137], and one studied the prevalence of incidental discoveries of types of sinus pathology in 201 patients [138]. Two other articles discussed the use of CBCT pre-operatively and intraoperatively during autotransplantation [139, 140]. Regenerative endodontic was dealt with in two articles [141, 142]. Finally, two studies concerned the upper airway [143, 144].

CBCT characteristics and radiographic protocol

Table 3 shows the different types of CBCT and the technical parameters of the radiographic protocol (intensity, voltage, FOV, exposure time and voxels) used by the studies included in this review of the literature. Fifteen articles did not mention the type of equipment used [11, 17, 28, 57, 75, 98, 107, 115, 118, 124, 129, 140, 145-147].

Table 3. Types of CBCT and the technical parameters of the radiographic protocol.

CBCT equipment (Manufacturer)	Number of studies	Intensity (mA/s)	Voltage (kV)	FOV (D x h, cm)	Exposure time (s)	Voxel (mm^3)
3D Accuitomo (J Morita Mfg Corp, Kyoto, Japan) 3D Accuitomo FPD 3D Accuitomo 170 3D Accuitomo F80 FPD Veraviewepocs 3DR100 Veraviewepocs 3DR100/F40 Veraviewepocs X550 EX1	11	1-10 mA 59.1-59.9 mAs	60-90	4 x 4 4 x 6 6 x 4 6 x 5 6 x 6 6 x 8 8 x 4 8 x 5 8 x 8 10 x 5 10 x 10 14 x 5 14 x 10 14 x 14 17 x 5 17 x 12 17 x 17	10–17.5	0.1-0.25
Alphard (Asahi Roentgen Ind Co Ltd, Kyoto, Japan) 3030 VEGA	5	2 mA	80	20 x 17.9	17	0.39
CB Mercu Ray (Hitachi Medical Corporation, Tokyo, Japan)	4	2-15 mA	100 120	panoramic implant dental 12-inch	9.6	0.3-0.38
Galileos CBCT Scanner (Sirona, Bensheim, Germany)	3	7	85	16 x 22	14-20	0.49-0.5

I-Cat (Imaging Sciences International, Hatfield, PA, USA) Classic system FLX Next Generation New Generation Model 17-19	70	3-36, 9mA 6.19-23.87 mAs	65-120	8 x 8 16 x 4 16 x 6 16 x 8 16 x 10 16 x 11 16 x 13 16 x 13.3 16 x 22 16 x 23 13 x 17 21 x 17 23 x 17 9 x 12 inch 12- inch 40 mm 6 cm 11cm 13 cm	3.7-40	0.1-30
Illuma Cone Beam CT Scanner (3M IMTEC, Ardmore, OK, USA)	4	3.8 mA	120	19 x 24 21.1 x 14	20	0.29
KaVo 3D (KaVo Dental GmbH, Bismarckring, Germany)	7	5 mAs 3.8-8 mA	120		4.8–20	0.025-0.4
Kodak (Carestream Health, Rochester, NY, USA) 9000 9300 CS 9300	5	2-15 mA	70 80-90	5 x 3.75 5 x 5 17 x 11 17 x 13.5	6.15–10.8	0.2-50

New Tom (Quantitative Radiology, Verona, Italy) 3G 5G DVT 9000 VG	32	1–20 mA 6.19-140.69 mAs	110-120	8 x 8 12 x 8 15 x 12 15 x 15 18 x 13 18 x 16 13 cm 4-inch 6-inch 9-inch 12-inch	3.6-77	0.125-0.4
Vatech (Vatech, Kihung, Korea)	2	5-6 mA	120 kVp	24 x 19	24	0.3
Planmeca Promax® 3D Max (Planmeca Oy, Helsinki, Finland)	8	9-14 mA 109-244mAs	90–94	4 x 5 5 x 5.5 6 x 6 8 x 5 8 x 8 10 x 13 10 x 5.5 10 x 9 12 x 9 13 x 5.5 13 x 9 19 x 15 20 x 6 20 x 10 20 x 17	12–27	0.1–0.4
Scanora 3D (Soredex, Tuusula, Finland)	6	8 mA	85-90	6 x 6 7.5 x 10 7.5 x 14,5 14.5 x 13 23 x 17 6 cm	3.7–40	0.1-0.35
Cranex 3D (Soredex, Tuusula, Finland)	1	6 mA	89 kVp	6 x 8		0.2

The acquisition protocol used was not the same for all studies and was very heterogeneous. It was also observed that the FOV was not always presented in the same way: sometimes only one dimension was given, the units were not always the same across studies, and information was sometimes missing. Regarding the notion of time, not all studies differentiated exposure time and scanning time.
It should also be noted that the amount of information provided concerning the technical parameters of the protocol varied across articles (Table 4). Only 40 articles, or 24% of the total number of articles, included all the parameters of interest (intensity, voltage, FOV, exposure time and voxels).

Table 4. Amount of information provided concerning the technical parameters (intensity, voltage, FOV, exposure time and voxel) of the protocol.

Amount of technical information provided (Intensity, voltage, FOV, exposure time and voxel)	**Number of articles**
5	40 (24%)
4	34 (20%)
3	31 (18%)
2	22 (13%)
1	13 (8%)
0	29 (17%)

Discussion

The results of this review provided us with several considerations and/or questions that need to be addressed considering the background offered by the current literature. The issue of pediatric dentistry is poorly addressed. We all agree that CBCT indications must be justified on an individual basis by assessing the benefit-risk ratio. The optimization of our protocol must be a priority.
The only review found about CBCT in pediatric dentistry is the work by Aps et al. [3] but it is an overview of the literature and not a systematic review. Methodologies are not comparable. Aps brings a lot of information about doses, biological effects of ionization, radioprotection measure [3]. In this work, we did not focus on these specific topics. For clinical aspects, both works are in agreement.

Technical aspects

Special attention was given to the radiographic protocol with respect to the principles of justification, optimization (ALARA), and limitations. The last principle in particular must be followed since the population studied comprises children and adolescents aged 18 or younger. It has been found that young people under the age of ten are three times more sensitive to the effects of ionizing radiation [1]. In some studies, included in this review of the literature, there was a lack of information concerning the doses of radiation administered and the means used for establishing radioprotection.

Large heterogeneity was also observed in the radiographic protocols. Each research team followed their protocol of choice. There was no standard pediatric radiographic protocol. The comparison of studies with different protocols is thus complex.

Moreover, not all the protocols referred to the same information of interest (intensity, voltage, FOV, exposure time and voxels). Another challenge that existed was the heterogeneous presentation of technical information, such as the use of different units and the FOV given with one or two dimensions. This heterogeneity also made it difficult to perform comparisons between studies.

Regarding the notion of time, not all studies differentiated exposure time and scanning time. The times mentioned were therefore very heterogeneous and their distinction was complex.

FOV is a key factor in pediatrics. It is recommended to optimize the selection of the FOV according to the indication for CBCT [1]. An optimal FOV selection contributes to the selection of an optimal radiation dose, adherence to the ALARA principle [1, 122], and a faster analysis of the scan [122]. The use of CBCT images from existing databases appears to be an excellent way to avoid the repeating exposure to ionizing radiation. However, this process may lead to an inadequacy bias in the FOV because the FOV is not directly related to the research presented but is instead related to the initial indication for CBCT.

The CBCT equipment also influences the selection of the FOV because not all devices allow a selection of the size (small, medium or large) of the FOV to be selected. Ideally, CBCT equipment that will be used on pediatric patients, should have adjustable FOV, in order to be able to adhere to the ALARA principle [86].

The reliability and accuracy of the CBCT images are not questioned in the detection and in the description of anatomical structures. The FOVs used in this field are highly variable depending on the anatomical structure being studied. However, within the 44 studies included in this category [78, 85-96, 145-147, 148-173], 19 did not mention these data [78, 86, 90, 91, 93-96, 146, 147, 151, 152, 156, 158, 163-165, 173]. Studies using Alphard-3030 [47, 69, 158, 165, 173], Illuma [31, 33, 34, 92] and Vatech [18, 153] CBCT equipment chose to use large FOV that largely encompassed the children's heads. Large FOV should be avoided as much as possible in pediatric dentistry. However, their use may be justified in some indications, such as orthodontic analysis or the analysis of the upper airways. It should be noted that in children, a field of view of 8 x 8 cm is sufficient to obtain all the information useful for cephalometric analysis. It is also important to bear in mind that the prescribing practitioner must be able to interpret all the information shown in the images. The practitioner is responsible for the diagnosis of lesions, not only dental lesions. Moreover, special attention is focused mainly on clinical aspects such as the indications of CBCT in pediatric dentistry.

The radiation dose of a CBCT scan is significantly lower than that of a medical computed tomography scan (CT scan) [91]. SEDENTEXT offers selection criteria related to clinical indications for the realization of CBCT [4]. CBCT should only be used when the clinical issue cannot be resolved by conventional radiography, and the FOV should be defined according to the region of interest [4, 86, 91].

Overall, the widely recognized advantages of CBCT widely recognized include X-ray beam limitation, image accuracy, rapid scan time, display mode unique to maxillofacial imaging, reduced image artefacts and dose reduction. The effective dose of CBCT can be affected by up to an order of magnitude by the factors of patient size, FOV, region of interest and resolution [112].

According to Khan Asif et al, a small FOV, higher voxel resolution, rapid scan time, and beam limitation are features of CBCT technology that make it suitable for use in clinical and research studies [121].

Orthodontics

The information necessary to establish a treatment plan will be more accurate when it is obtained from 3D images than when it is obtained from conventional 2D techniques [40]. However, no statistically significant difference was observed between treatment plans using conventional 2D and 3D information [39]. The use of 3D scans to obtain a 2D result raises questions regarding the ALARA principle. Conventional radiographs are subject to projection error as well as landmark identification and measurement problems. In contrast, 3D volumetric imaging technique such as CBCT provide a better geometric precision, and spatial resolution, and produce measurements that are not significantly affected by variation in skull orientation or head position. Furthermore, the SEDENTEXT guidelines stated that in the generalized application of CBCT for the developing dentition, studies on measurement accuracy are highly relevant in orthodontics diagnosis and treatment planning, and advocate that CBCT can produce a precise depiction of tooth interrelationship and associated bony anatomy [174].

CBCT is more suitable than classical helical CT scan for the evaluation of craniofacial structures because it allows a reduction in the dose of radiation, it is the least expensive method, it allows the use of a variety of FOV, it has a submillimetric spatial resolution, and it has increased accessibility [33].

Overall, the use of CBCT in orthodontics is considered acceptable when there is a clinical benefit and when rational doses are used [52].

Maxillary expansion

CBCT have proven to be an accurate and a distortion-free method of the visualization of the palatal area [83]. Moreover, this technology enables a 3D visualization of the whole craniofacial complex with the precise and reliable measurement of the change caused by maxillary expansion [53], even those that occur at a distance from the activation zone [48], including the effect on nasopharyngeal dimensions [84]. After activation, there may be an expansion that includes not only the maxilla but also the lateral bones of the nose and the zygomat-ic muscles. Asymmetric expansion can also occur [48]. It is important to bear in mind that the position of the head and tongue during the acquisition of CBCT scans, breathing movements, swallowing movements and repositioning of the tongue and of the mandible after maxillary expansion treatment are factors that influence the measurement of respiratory routes [68]. The positions of the tongue and soft tissues are important anatomical factors that influence the shape and size of the oropharynx airway volumes [73]. Differences in appliance design, airway measurement techniques and use of decongestants render comparisons between studies difficult [59].

CBCT is an effective technique for the evaluation of the degree of ossification and for the developmental stage of the midpalatal suture. It happens irrespectively of age due to the multiple viewpoints CBCT provides and its low radiation dose. Using CBCT facilitates decisions regarding the use of rapid maxillary expansion or more aggressive surgically assisted rapid maxillary expansion in young patients [160]. These parameters can be reliable in clinical decision-making between conventional rapid maxillary expansion and surgical-assisted rapid maxillary expansion in adolescents and in young adults [154]. The use of CBCT to determine the degree of ossification and morphology of the midpalatal suture is necessary in all patients [160].

CBCT images allowed to overcome the limitations of conventional postero-anterior cephalometric radiographic in transverse width measurement including the inability to reproduce reference landmarks and intercanine-, interpremolar- and intermolar width due to the superimposition of posterior segment [58].

Fast and slow maxillary expansion in patients with bilateral cleft lips and palate were compared in another study [52]. The rehabilitation of cleft lips and palate is one of the recognized indications for the use of CBCT by the evidence-based guidelines of the European Commission [4] and the clinical recommendations of the American Academy of Oral and Maxillofacial Radiology [7]. Either slow maxillary expansion or rapid maxillary expansion may be indicated to correct the constriction of the maxillary arch in patients with bilateral cleft lips and palate because the changes generated are similar between the two methods [81].

Radiological anatomy

Regardless of the imaging technique used, the identification of anatomical landmarks in children depends on multiple factors, such as image density, image sharpness, anatomical complexity, the superposition of hard tissue and soft tissue, definitions of landmarks, and the level of training of the observer [86]. CBCT offers an imaging solution that avoids projection and overlay errors that are present in the images created by traditional panoramic X-rays. CBCT is an excellent tool for assisting in accurate diagnoses, predictable treatment plans, condition management and effective patient education [86]. Its advantages include its lower radiation dose, lower cost, and similar image quality at a reduced dose of absorbed radiation, which is particularly important for children [93]. However, CBCT images also have the inherent drawbacks of soft tissue attenuation, patient movement artefacts, etc. This variation may affect the accuracy of measurements [162].

CBCT scanners can and will play an important role in the diagnosis of hard tissue structures in the dentomaxillofacial region [175], which includes the morphologic assessment of the bony structure of the temporomandibular joint [152, 166], but CBCT cannot image the soft tissue structures [166].

CBCT is a good technique for canal detection for both the accessory canal foramina [88], and other bone canals located in the anterior maxillary region that can enclose

neurovascular content [90], such as the nasopalatine canal, which has been shown to present multiple morphological and dimensional variations [89].
The visualization of the intraosseous pathway of neurovascular structures is limited in conventional X-rays. The detection of accessory mental foramen by means of a 3D reconstruction from a CBCT reduces the risk of paresthesia and postoperative pain in this area [85]. Understanding peri-mandibular neurovascularization is important for avoiding complications during anesthesia and during surgical procedures. Localization knowledge of the lingula (landmark of the mandibular nerve block) is also important to achieve effective anesthesia during dental care [91]. However, despite these advantages, CBCT should not be used for this purpose in children and in adolescents [88].
CBCT also allows the visualization of the upper airways as well as measurements of their volume and surfaces [151] with a good reliability and accuracy [164]. It is an accepted diagnostic tool for this purpose [155]. Three-dimensional airway analysis using CBCT requires a large FOV. This exposes the patient to more radiation compared to the more conventional 2D airway analysis using cephalometric images [157]. The use of low radiation exposure, multiple display mode in combination with accurate images, thin slice thickness, real size analysis, and minimal superimposition makes CBCT ideal for the evaluation of the nasal cavity [96].
Although CBCT is a good tool for studying the root and canal morphology of temporary teeth, it cannot be used routinely for nonsurgical endodontic treatment because there is a risk of overexposure to ionizing radiation. Until additional evidence is available, CBCT should be considered only when the information provided by conventional X-rays is limited and other data are necessary for diagnosis and/or treatment planning, while ensuring that the patient's exposure to radiation is as low as possible [150, 172]. As radiation exposure in children and young people is associated with greater risk of stochastic effect, appropriate use in pediatric dentistry is essential [171].
The presence of an ectopic canine seems to be a good indication for CBCT, as there are a large number of reported cases of root resorptions found on adjacent teeth. This technique allows the examination of small volumes and produces high-quality images [175].
CBCT is an effective diagnostic tool for the assessment of mesiodens. It can provide important data with regard to the position and direction of impaction, morphology, and the condition of adjacent teeth. Therefore, CBCT is also a useful tool for planning the further course of action after the diagnosis of mesiodens [146]. These 3D assessments may be able to reproduce teeth measurement with a high accuracy due to their 1:1 ratio image relationship [176].

Clefts lips and palates

CBCT, with its advancements, is becoming increasingly important in the diagnosis and treatment of craniofacial abnormalities. Through its use, a large amount of information has been made available. For patients with craniofacial anomalies, 3D images provide a better understanding of the real dimensions of defects and thus their extent and complexity [113]. In patients with cleft lips and palate, incidental findings from CBCT exams were present in the majority of cases; therefore

clinicians caring for patient with cleft lips and palate should be aware of incidental findings, which may warrant further investigation and/or treatment [114].
In individuals with a cleft lips and palate, the identification of the bone defect prior to orthodontic management is extremely helpful. CBCT allows a better assessment of the bone structure than can be gained through 2D imaging does. CBCT also makes it possible to visualize the presence of recession and/or fenestration [104] and to evaluate the position of the canine in relation to the root of the incisor and the crest of the alveolar bone [113].
CBCT has become the gold standard for analyzing the anterior part of the skull base [101]. The use of CBCT and analysis is an effective strategy for the 3D assessment of the pharyngeal airway. An adequate diagnosis using CBCT could contribute to cleft patients receiving more effective treatment in cooperation at an early stage [111]. CBCT must be indicated with caution and should always be performed with low dose protocols to obtain images of an adequate quality. Combining CBCT information with a 3D impressions and digital photographs allows practitioners to obtain the most complete 3D patient data [113].

Other indications

Other applications (evaluation of pulp capping, root fracture, incidental findings in the maxillary sinus or of sinus pathology, before and after autotransplantation, X-ray for patients with special needs, etc.) of CBCT have been mentioned in some publications [127-132, 135-144]. These studies are heterogeneous, and more research is needed to identify additional indications.

Limitations

The first limitation of this study is the small number of databases consulted. The use of more databases, including Cochrane and Embase, may provide a more complete picture and perhaps a better level of evidence. The latter is limited in our work because only two randomized double-blind controlled studies were included. Another limitation is the heterogeneity of the protocols established in the studies, making comparisons difficult to perform and preventing conclusions from being drawn. More research is needed to determine a standard CBCT protocol for use in children and adolescents.

Conclusion

Despite its low level of evidence, this systematic review of the literature allows us to distinguish two indications of CBCT in pediatric dentistry: for orthodontics and for the rehabilitation of cleft lips and palate. There are likely to be other indications whose identification requires more research. This work also shows that there exists heterogeneity in the acquisition protocol used. More research is needed to determine a standard CBCT protocol for children and adolescents.

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Authors contribution:

Author	Contributor role
Stephanie Theys	Data collection, Investigation, Validation, Writing original draft preparation, Writing review and editing.
Raphael Olszewski	Conceptualization, Methodology, Validation, Supervision, Writing review and editing.

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