Current Medical Imaging, 2023, *19*, 977-994

SYSTEMATIC REVIEW ARTICLE

Using Cone Beam Computed Tomography for Radiological Assessment Beyond Dento-maxillofacial Imaging: A Review of the Clinical Applications in other Anatomical Districts

Ivan Corazza[1,*], Emanuele Giannetti[2], Giancarlo Bonzi[2], Alessandro Lombi[3], Giulia Paolani[4], Miriam Santoro[4], Maria Francesca Morrone[4], Margherita Zecchi[1] and Pier Luca Rossi[3]

[1]*Department of Medical and Surgical Sciences (DIMEC), Alma Mater Studiorum University of Bologna, Medical Physics Activities Coordination Centre, Bologna, Italy;* [2]*Cefla Sc, Imola, Italy;* [3]*Department of Physics and Astronomy, Alma Mater Studiorum University of Bologna, Bologna, Italy;* [4]*Medical Physics Specialization School, Alma Mater Studiorum University of Bologna, Bologna, Italy*

Abstract: ***Background***: Cone Beam Computed Tomography (CBCT) represents the optimal imaging solution for the evaluation of the maxillofacial and dental area when quantitative geometric and volumetric accuracy is necessary (*e.g.*, in implantology and orthodontics). Moreover, in recent years, this technique has given excellent results for the imaging of lower and upper extremities. Therefore, significant interest has been increased in using CBCT to investigate larger and non-traditional anatomical districts.

Objective: The purpose of this work is to review the scientific literature in Pubmed and Scopus on CBCT application beyond head districts by paying attention to image quality and radiological doses.

Methods: The search for keywords was conducted in Pubmed and Scopus databases with no back-date restriction. Papers on applications of CBCT to head were excluded from the present work. From each considered paper, parameters related to image quality and radiological dose were extracted. An overall qualitative evaluation of the results extracted from each issue was done by comparing the conclusive remarks of each author regarding doses and image quality. PRISMA statements were followed during this process.

Results: The review retrieved 97 issues from 83 extracted papers; 46 issues presented a comparison between CBCT and Multi-Detector Computed Tomography (MDCT), and 51 reviewed only CBCT. The radiological doses given to the patient with CBCT were considered acceptable in 91% of cases, and the final image quality was found in 99%.

Conclusion: CBCT represents a promising technology not only for imaging of the head and upper and lower extremities but for all the orthopedic districts. Moreover, the application of CBCT derived from C-arms (without the possibility of a 360 ° rotation range) during invasive investigations demonstrates the feasibility of this technique for non-standard anatomical areas, from soft tissues to vascular beds, despite the limits due to the incomplete rotation of the tube.

ARTICLE HISTORY

Received: November 22, 2022
Revised: December 29, 2022
Accepted: January 11, 2023

DOI:
10.2174/1573405619666230202122947

Keywords: Cone beam computer tomography (CBCT), literature review, radiological dose to the patient, clinical outcome, non-standard anatomical districts, single- or multi-detector computer tomography.

1. INTRODUCTION

Currently, the traditional imaging technique for the 3D reconstruction of multiple anatomical districts (orthopedic, thoracic, cardiac, cerebral) is Computed Tomography (CT) [1]. Historically, the first technique to implement CT is based on fan beam emission with radiological signal acquisition through a single (SDCT single detector CT) or multiple linear detectors (MDCT multiple detector CT). Another interesting and powerful technique is Cone Beam Computer Tomography (CBCT). This last technology differs from the SDCT and MDCT for the conformation, shape of the X-ray beam (cone beam), and type of detector (digital plate) [2]. With a conic X-ray beam, modulating the beam shape and size of the digital plate, a single 360° scan around the patient allows us to acquire and build a full 3D image of the region of interest. In the past, since it was necessary to obtain a complete image of the object with a single scan, with receptor panels of limited dimensions and not optimized imaging chains, CBCT could be used to investigate only small anatomical districts. For this reason, the main application field for CBCT has become the 3D imaging of the head only (*e.g.*, both oral and extra-oral) [3-9].

*Address correspondence to this author at the Department of Medical and Surgical Sciences (DIMEC), Alma Mater Studiorum University of Bologna, Medical Physics Activities Coordination Centre, Bologna, Italy;
Tel: +390512143588; E-mail: ivan.corazza@unibo.it

Due to the good results in terms of image quality and low cost of the CB scanners [10], the interest in using CBCT to investigate non-traditional anatomical districts (*e.g*., arms, legs, *etc*.) has been increasing [8, 11].

The simplest and most immediate evolution was to use commercial dental CBCT equipment to study the anatomical extremities, and the direct consequence was the placement in the market of small CBCT equipment dedicated to the limbs (*e.g*., Carestream, Planmed). At the same time, a few manufacturers have developed gantry-CBCT, capable of scanning portions of the entire human body (*e.g*., NewTom 5G and NewTom 7G, Cefla, Imola, Italy). This equipment comprises "native" CBCT devices and allows full-range rotations of 360° (Full-Rotation CBCT, FR-CBCT).

Moreover, in addition to full rotation and native CBCT, many manufacturers have transformed their traditional C-arms radiological systems in CBCT scanners by adding engines and advanced 3D reconstruction algorithms. With these systems, operators can perform acquisitions in cone beam CT mode without a full 360 ° rotation range (Partial Rotation CBCT, PR-CBCT), allowing an adequate 3D reconstruction (using, for example, FDK algorithms or iterative reconstruction) [12].

Other fundamental current applications of full rotation CBCT are Image-Guided Radiotherapy (IGRT) or Adaptive radiotherapy (ART), stereoscopic mammography, or digital breast [11, 13].

Nowadays, CBCTs for non-standard anatomical areas are used by clinicians who can leverage protocols and machine settings already preset by the manufacturer based on previous experience in the maxillofacial field and conventional radiology. A direct comparison, in terms of image quality and radiological dose, between the standard (MDCT) and the new technology (CBCT) has been made in a few cases with the final goal of extending CBCT to the whole human body; however, making it a valid alternative to MDCT is still far away.

The purpose of this work is to verify, through a literature review, the possible applications of Cone Beam Computer Tomography (both full and partial Rotation CBCTs) in non-standard anatomical districts (no maxillofacial or dental ones or head districts) and to investigate differences in image quality and radiological dose with standard CT.

2. MATERIALS AND METHODS

We searched PubMed, Web of Sciences, and Scopus databases for original articles published up to December 31st, 2021, with no back-date restriction, using the keywords (all languages; "CBCT" or "cone beam computer tomography") without any limitation. In addition, references of selected retrieved articles were scanned manually to identify any other additional studies. The searches were conducted by 3 independent investigators (authors: M.F.M., G.P., M.S.). PRISMA statements were followed.

Exclusion criteria were: (1) studies on the head anatomical district (maxillo-facial, dental, cervical splines, ears, *etc*.), (2) publications other than original articles (*e.g*., abstracts from conferences, letters, correspondence, reviews, duplicate publications, full texts without raw data available for retrievals), (3) literature reviews, and (4) papers on CBCT technology for radiotherapy. After removing duplicate publications, three authors independently screened the titles and abstracts of all identified citations. The full texts of citations evaluated as potentially eligible were obtained and independently considered for eligibility by three reviewers. Any doubt about the eligibility of each study was resolved by discussion with all authors.

The following parameters were extracted: Type of CBCT device, target (patient, phantom, cadaver), number of samples, anatomical area of interest, dosimetric parameters (measured directly or supplied by the scanner output), evaluation of the image quality, and diagnostic information (objective and subjective parameters) (Table **1**).

This work focuses on CBCT applied to unconventional anatomical districts, with reference to the achievement of the clinical goal and, if present, to the assessment of the radiological risk for the patient. Therefore, the settled operating device conditions (mA, kV, irradiation times) have not been evaluated and discriminated. Although some numerical parameters were present in an adequate number of extracted

Table 1. Extracted parameters.

Instrumentation	**Full rotation CBCT (FR-CBCT), Partial Rotation CBCT (PR-CBCT)**		**Model and Manufacturer**
Target	**Patient, Cadaver, Anthropomorphic Phantom, Cylindric Phantom**		
Dosimetric parameters	Directly measured	Absorbed dose (D), mGy	Dosimeter type (TLD[1], MOSFET, OSLD[2]) or numerical method (Montecarlo Simulation)
		Effective Dose (E), mSv	
	From Scanner output	DAP[3] (mGy*cm^2)	
		DLP[4] (mGy*cm)	
		CTDI[5] (mGy)	
Image quality evaluation	Subjective	Scores and clinical outcome	
	Objective	Physical quantities	CNR[6], MTF[7], SNR[8], DQE[9]

Note: 1: Thermo Luminescent Dosimeter; 2: Optical Stimulated Luminescence Dosimeter; 3: Dose Area Product; 4: Dose Length Product; 5: Computed Tomography Dose Index; 6: Contrast-to-Noise Ratio; 7: Modulated Transfer Function; 8: Signal-to-Noise Ratio; 9: Detective Quantum Efficiency [3, 14].

works, no meta-analysis was performed because, as already reported by similar reviews [15], these parameters refer to different operating conditions, anatomical districts, and acquisition systems. Therefore, a direct comparison can be confusing and misleading.

However, an overall assessment of each work, based on the conclusions presented by the individual authors, was performed. Specifically, it was considered (1) whether the CBCT images allowed an "adequate" / "inadequate" evaluation of the clinical problem, (2) whether patient dose levels with CBCT were "adequate" / "not adequate" for the radiological procedure under consideration, (3) if the image quality obtained with CBCT were “worse” / ”equal” / ”better” to that obtained with MDCT, and (4) if patient dose levels with CBCT were “lower” / “equal” / “higher” than those obtained with MDCT. Points 3 and 4 were evaluated only if a comparison between CBCT and MDCT was made.

3. RESULTS

The first search retrieved 11222 results from Pubmed and 14765 from Scopus database for “CBCT” and 15170 from Pubmed and 9229 from Scopus for “cone beam computer tomography”. Then, by applying filters on “article type” and excluding articles on the dental or maxillo-facial districts, the reviewers selected 83 papers. However, since some of them presented two or more separate protocols (*e.g*., different operating conditions), a total of 97 “issues” were considered: 51 cases with only CBCT and 46 cases with both CBCT and MDTC.

The PRISMA flowchart is shown in Fig. (**1**). The selected articles are reported in Table **2**.

A further distinction was made between Full Rotation CBCT (FR-CBCT) and Partial Rotation CBCT (PR-CBCT); FR-CBCT was used in 57 cases (59%) [16, 17, 20, 22, 24, 26-30, 32-35, 40, 42, 43, 45, 49-57, 60, 62, 63, 65-68, 71-74, 76-78, 81, 82, 85, 88, 90, 92, 96] and PR-CBCT in 40 cases (41%) [18, 19, 21, 23, 31, 36-39, 41, 44, 46-48, 58, 59, 61, 64, 69, 70, 75, 79, 80, 83, 84, 86, 87, 91, 93, 94, 97, 98]. Detailed data are shown in Table **3**.

In detail, the FR-CBCT devices used in the extracted papers are:

- PedCat, InREach e Line UP (CurveBeam LLC, Warrington, Pennsylvania): 7 [20, 65-67, 78, 85, 88].
- NewTom 5G XL (NewTom/Cefla S.C., Imola, Italy): 12 [26-28, 33, 52, 53, 55, 68, 72, 73, 82].
- Planmeca ProMax 3D (Planmeca Oy, Helsinki, Finland): 1 [17].
- Planmed Verity (Planmed Oy, Helsinki, Finland): 20 [16, 34, 42, 43, 54, 56, 57, 60, 62, 63, 71, 74, 81, 89, 90, 92].
- O-arm (Medtronic, Minneapolis, MN, US): 9 [22, 24, 29, 32, 35, 45, 49, 51, 77].
- Artiste Siemens KView InLine (Siemens Healthineers, Erlangen, Germany): 1 [40].
- TrueBeam Radiation Therapy Machine (Varian Medical System, Palo Alto, CA, USA): 3 [50, 96].
- Experimental and not commercial devices: 4 [25, 30, 76].

The devices classified as PR-CBCT are:

- Ziehm Vision RFD (Ziehm Imaging GmbH, Nuremberg, Germany): 1 [18].
- Toshiba Infinix VC-i (Canon Medical System Corporation, Tochigi, Japan): 2 [59].
- Artis zee BA Twin (Siemens Healthineers, Erlangen, Germany): 1 [61].
- Artis Zeego (Siemens Healthineers, Erlangen, Germany): 14 [23, 36, 39, 48, 59, 64, 69, 80, 87].
- Innova 4100IQ (GE Healthcare, Chicago, IL, US): 3 [83, 91, 94].
- Arcadis Orbic (Siemens Healthineers, Erlangen, Germany): 3 [86].
- Multitom Rax (Siemens Healthineers, Erlangen, Germany): 2 [38].
- Bransist Safire VC17 (Shimadzu, Kyoto, Japan): 1 [46].
- Allura Xper FD20/20 (Philips Healthcare, Amsterdam, The Netherlands): 10 [19, 31, 37, 44, 47, 61, 70, 79, 84, 98].
- Experimental and not commercial devices: 3 [21, 75].

Table **4** shows the different targets considered in the reviewed papers.

Table **5** shows the different investigated anatomical districts.

Most of these districts have been investigated for the assessment of the integrity of bones, cartilages, or ligaments. Despite that, in 19% of cases (Table **6**), the anatomical district was not investigated for standard orthopedic purposes (*e.g*., fractures, bone integrity, *etc*.).

3.1. Only CBCT (FR-CBCT or PR-CBCT)

In this group (51 total cases), 20 papers (39%) performed a dosimetric evaluation on patients (16 issues) [24, 28, 31, 41, 46-48, 57, 58, 61, 64, 75, 80, 82, 84, 86, 98] and anthropomorphic phantom (1 case) [65]. Most values were directly reported by the radiological system (scanner output, in terms of DAP or CTDI, 15 cases [24, 28, 31, 41, 47, 48, 57, 58, 61, 64, 75, 84, 86, 98], 3 evaluations used TLD dosimeters [80, 82], 1 OSL dosimeters [65], and 1 Monte Carlo simulation) [46].

Regarding the patient’s dose, although there was no direct comparison with similar measurements carried out with MDCT in 15 studies (29%) [17, 47, 48, 57, 58, 61, 65, 80, 82, 84], the dose was compared to the one already stated in the literature and considered acceptable, with respect to both clinical evaluation and national and international regulations [99].

Table **7** shows different methods of image quality evaluation performed in this group of cases.

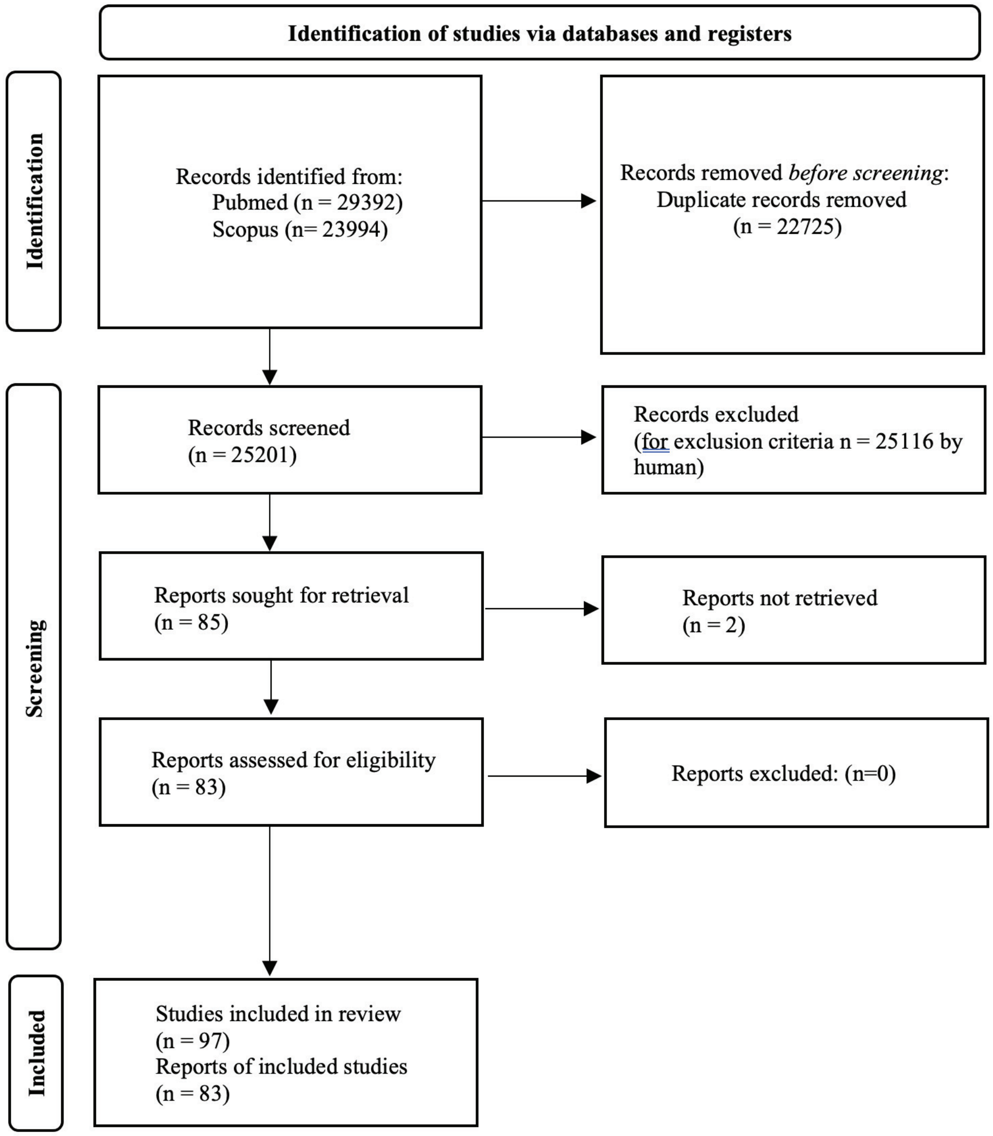

Fig. (1). PRISMA flowchart for data collection and analysis.

Table 2. Issues considered in this revision.

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Aurell Y. *et al.* [16]	Upper and lower extremities	CBCT	FR	Patient	No	-	Objective	Adequate	-	-	-
Borel C. *et al.* [17]	Wrist	CBCT	FR	Patient	No	-	Subjective	Adequate	-	Acceptable	-
Borggrefe J. *et al.* [18]	Wrist	CBCT and MDCT	PR	Cadaver	Yes	From scanner output	Subjective	Adequate	-	Acceptable	Lower

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Braak S. *et al*. [19]	Thorax and abdomen	CBCT and MDCT	PR	Patient	Yes	Montecarlo Simulation + Scanner Output	Subjective	Adequate	-	Acceptable	Lower
Burssens A *et al*. [20]	Ankle	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Carrino J. *et al*. [21]	Cylindrical phantom	CBCT and MDCT	PR	Cylindrical phantom	Yes	From scanner output	Objective	Adequate	Equal	Acceptable	lower
Carrino J. *et al*. [21]	Upper and lower extremities	CBCT and MDCT	PR	Cadaver	No	-	Subjective	Adequate	Equal	-	-
Cheng E.Y. *et al*. [22]	Spine	CBCT and MDCT	FR	Patient	Yes	From scanner output	-	Adequate	Equal	Acceptable	Lower
Cordemans V. *et al*. [23]	Spine	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Costa F. *et al*. [24]	Spine	CBCT	FR	Patient	Yes	From scanner output	-	-	-	-	-
De Cesar Netto C. *et al*. [25]	Foot	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
De Charry C. *et al*. [26]	Radius	CBCT and MDCT	FR	Cadaver	Yes	From scanner output	Objective	Adequate	Lower	Acceptable	Lower
De Cock J. *et al*. [27]	Wrist	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
De Smet E. *et al*. [28]	Upper and lower extremities	CBCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	-	-	-
Dea N. *et al*. [29]	Spine	CBCT	FR	Patient	No	-	Objective	Adequate	-	-	-
Demehri S. *et al*. [30]	Hand	CBCT and MDCT	FR	Cadaver	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Demehri S. *et al*. [30]	Knee	CBCT and MDCT	FR	Cadaver	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Dong J. *et al*. [31]	Carotid artery	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	-	-
Drazin D. *et al*. [32]	Sacrum	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Dubreuil T. *et al*. [33]	Upper and lower extremities	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	lower
Edlund R *et al*. [34]	Wrist	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Farah K. *et al*. [35]	Spine	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Fukuda K. *et al*. [36]	Vertebral artery	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Garnon J. *et al*. [37]	Sacrum	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Grunz J. *et al*. [38]	Upper and lower extremities	CBCT and MDCT	PR (Standard dose protocol)	Cadaver	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Grunz J. *et al*. [38]	Upper and lower extremities	CBCT and MDCT	PR (low dose protocol)	Cadaver	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Guggenberger R. *et al*. [39]	Shoulder	CBCT and MDCT	PR (5s protocol)	Anthropomorphic phantom	Yes	TLD	Both	Not adequate	Lower	Acceptable	Lower
Guggenberger R. *et al*. [39]	Shoulder	CBCT and MDCT	PR (20s protocol)	Anthropomorphic phantom	Yes	TLD	Both	Adequate	Lower	Not Acceptable	Higher
Held M. *et al*. [40]	Thorax, pelvis, knee	CBCT	FR	Anthropomorphic phantom	No	-	Subjective	Adequate	Equal	-	-
Hermie L. *et al*. [41]	Abdomen	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	-	-
Hirschmann A. *et al*. [42]	Knee	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Huang A.J. *et al*. [43]	Upper and lower extremities	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Hui T.C. *et al*. [44]	Spine	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Hurley R.K. Jr. *et al*. [45]	Spine	CBCT	FR	Cadaver	No	-	Subjective	Adequate	-	-	-
Hwang Y. *et al*. [46]	Abdomen	CBCT	PR	Patient	Yes	Montecarlo Simulation	-	-	-	-	-
Ierardi A.M. *et al*. [47]	Spine	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Jiao D. *et al*. [48]	Media intestinal lesions	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Joseph J.R. *et al*. [49]	Lumbar spine	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Kim S. *et al*. [50]	Body center	CBCT and MDCT	FR	Cylindrical phantom	Yes	TLD	-	-	-	Acceptable	Lower
Kim S. *et al*. [50]	Body surface	CBCT and MDCT	FR	Cylindrical phantom	Yes	TLD	-	-	-	Acceptable	Lower
Kim T.T. *et al*. [51]	Spine	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Koivisto J. *et al*. [52]	Wrist	CBCT and MDCT	FR (Plamed Verity)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [52]	Wrist	CBCT and MDCT	FR (Newtom 5G)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [53]	Ankle	CBCT and MDCT	FR (Plamed Verity)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [53]	Ankle	CBCT and MDCT	FR (Newtom 5G)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [54]	Knee	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [55]	Elbow	CBCT and MDCT	FR (Plamed Verity)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Koivisto J. *et al*. [55]	Elbow	CBCT and MDCT	FR (Newtom 5G)	Anthropomorphic phantom	Yes	MOSFET	-	-	-	Acceptable	Lower
Kortekangas T. *et al*. [56]	Ankle	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Koskinen S.K. *et al*. [57]	Wrist	CBCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Kothary N. *et al*. [58]	Liver	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Kwok Y.M. *et al*. [59]	Thorax	CBCT and MDCT	PR (Artix Zeego, 8s prot.)	Anthropomorphic phantom	Yes	TLD	-	-	-	Not Acceptable	Higher

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Kwok Y.M. *et al*. [59]	Thorax	CBCT and MDCT	PR (Infinix VC-I, 10s prot.)	Anthropomorphic phantom	Yes	TLD	-	-	-	Not Acceptable	Higher
Kwok Y.M. *et al*. [59]	Thorax	CBCT and MDCT	PR (Artix Zeego, 16s prot.)	Anthropomorphic phantom	Yes	TLD	-	-	-	Not Acceptable	Higher
Kwok Y.M. *et al*. [59]	Thorax	CBCT and MDCT	PR (Infinix VC-I, 15s prot.)	Anthropomorphic phantom	Yes	TLD	-	-	-	Not Acceptable	Higher
Lang H. *et al*. [60]	Wrist	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Lower	Acceptable	Lower
Lee S.M. *et al*. [61]	Lung	CBCT	PR (axiom Artis)	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Lee S.M. *et al*. [61]	Lung	CBCT	PR (Allura FD20)	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Lepojärvi S. *et al*. [62]	Ankle	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Lepojärvi S. *et al*. [63]	Ankle	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Liu J.F. *et al*. [64]	Upper and lower extremities	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Ludlow J.B. *et al*. [65]	Upper and lower extremities	CBCT	FR	Anthropomorphic phantom	Yes	OSLD	Objective	Adequate	-	Acceptable	-
Ludlow J.B. *et al*. [66]	Upper and lower extremities	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	OSLD	Objective	Adequate	Equal	Acceptable	Lower
Ludlow J.B. *et al*. [67]	Feet and ankle	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	OSLD	-	-	-	Acceptable	Lower
Maffezzoni F. *et al*. [68]	Distal radius	CBCT and MDCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Maier J. *et al*. [69]	Knee	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Marshall E. *et al*. [70]	-	CBCT and MDCT	PR	Patient	Yes	From scanner output	-	-	-	Acceptable	Equal
Myller K.A. *et al*. [71]	Knee	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Mys K. *et al*. [72]	Wrist	CBCT and MDCT	FR	Patient	No	-	Objective	Adequate	Equal	-	-
Nardi C. *et al*. [73]	Knee	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Neubauer J. *et al*. [74]	Wrist	CBCT and MDCT	FR	Cadaver	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Equal
O'Connel A. *et al*. [75]		CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	Acceptable	-
Osgood G.M. *et al*. [76]	Upper and lower extremities	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Park P. *et al*. [77]	Spine	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Patel S. *et al*. [78]	Ankle	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Perry B.C. *et al*. [79]	Spine	CBCT and MDCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Pireau N. *et al*. [80]	Thoracic-lumbar spine	CBCT	PR (low dose prot.)	Patient	Yes	TLD	Subjective	Adequate	-	Acceptable	-
Pireau N. *et al*. [80]	Thoracic-lumbar spine	CBCT	PR (high dose prot.)	Patient	Yes	TLD	Subjective	Adequate	-	Acceptable	-
Pugmire B.S. *et al*. [81]	Foot-ankle	CBCT and MDCT	FR	Patient	Yes	MOSFET	Subjective	Adequate	Equal	Acceptable	Lower
Ricci M. *et al*. [82]	Upper and lower extremities	CBCT	FR	Patient	Yes	TLD	Subjective	Adequate	-	Acceptable	Lower
Roux C. *et al*. [83]	Pelvic bone	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Sailer A.M. *et al*.	Abdomen	CBCT	PR	Patient	Yes	From scanner output	-	-	-	Acceptable	-
Schnapauff D. *et al*. [84]	Prostatic artery	CBCT	PR	Patient	Yes	From scanner output	-	Adequate	-	Acceptable	-
Segal N.A. *et al*. [85]	Knee	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Seki S. *et al*. [86]	Spine	CBCT	PR	Patient	Yes	From scanner output	Subjective	Adequate	-	-	-
Shellikeri S. *et al*. [87]	Unspecified Bones	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-

(Table 2) contd….

First Author Refs.	Anatomical Site	Devices	Type (PR or FR CBCT)	Target (Patient, Anthropomorphic Phantom, Cylindrical Phantom)	Radiation Dosimetry Evaluation (Yes/No)	Dosimeter Evaluation Type	Image Quality Evaluation (Subjective /Objective)	Overall Image Quality Evaluation	Overall Quality Comparable to MDCT (YES/NO)	Overall Dose Evaluation	Dose CBCT *vs.* MDCT
Shih C.D. *et al*. [88]	Foot	CBCT	FR	Patient	No	-	Subjective	Adequate	-	-	-
Tscahauner S. *et al*. [89]	Upper and lower extremities	CBCT and MDCT	FR	Patient	Yes	From scanner output	Both	Adequate	Higher	Acceptable	Lower
Tscahauner S. *et al*. [90]	Wrist	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	TLD	Subjective	Adequate	Equal	Acceptable	Lower
Tscahauner S. *et al*. [90]	Ankle	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	TLD	Subjective	Adequate	Equal	Acceptable	Lower
Tselikas L. *et al*. [91]	Unspecified Bones	CBCT and MDCT	PR	Patient	Yes	TLD and Scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Turunen M.J. *et al*. [92]	Knee	CBCT and MDCT	FR	Patient	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Vetter S.Y. *et al*. [93]	Ankle	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Wang M.Q. *et al*. [94]	Iliac artery	CBCT	PR	Patient	No	-	Subjective	Adequate	-	-	-
Wihlm R. *et al*. [95]	Wrist	CBCT and MDCT	FR	Cadaveric	Yes	From scanner output	Subjective	Adequate	Equal	Acceptable	Lower
Yang C. *et al*. [96]	Abdomen	CBCT and MDCT	FR	Anthropomorphic phantom	Yes	From scanner output	Objective	Adequate	Lower	Acceptable	Lower
Zimmermann F. *et al*. [97]	Spine	CBCT and MDCT	PR	Patient	No	-	Subjective	Adequate	Equal	-	-

Table 3. Number of papers with FR-CBCT and PR-CBCT.

Instrumentation	Number of Cases - (%)		
	FR-CBCT	PR-CBCT	Total
CBCT e CT	30 (31%)	16 (16%)	46 (47%)
CBCT only	27 (28%)	24 (25%)	51 (53%)
Total	57 (59%)	40 (41%)	97 (100%)

Table 4. Number of different targets.

Target/Refs.	Number of Cases - (%)		
	CBCT and MDCT	CBCT Only	Total
Cadaver [18, 21, 26, 30, 38, 45, 74, 95]	9	1	10
Anthropomorphic phantom [39, 52-55, 59, 66, 67, 90, 96, 40]	18	2	20
Cylinder phantom [21, 50]	3	0	3
Patients [16, 17, 19, 20, 22-25, 27-29, 31-37, 41-44, 46-49, 51, 56-58, 60-64, 68-71, 75-89, 91-94, 97, 98]	16	48	64
Total	46	51	97 (100%)

Table 5. Anatomical districts investigated by the authors.

Anatomical District	Number of Cases - (%)		
	CBCT and MDCT	CBCT Only	Total
Thoracic or lumbar spine	3 (2%)	17 (13%)	20 (16%)
Ankle	10 (8%)	9 (7%)	19 (15%)
Knee	4 (3%)	9 (7%)	13 (10%)
Wrist	13 (10%)	7 (6%)	19 (15%)
Hand	9 (7%)	5 (4%)	14 (11%)
Foot	10 (8%)	5 (4%)	15 (12%)
Sacrum	/	4 (3%)	4 (3%)
Abdomen	1 (1%)	2 (2%)	3 (2%)
Thorax	/	2 (2%)	2 (2%)
Media intestinal district	/	1 (1%)	1 (1%)
Vertebral artery	/	1 (1%)	1 (1%)
Breast	/	1 (1%)	1 (1%)
Elbow	2 (2%)	/	2 (2%)
Radius	3 (2%)	/	3 (2%)
Liver	1 (1%)	/	1 (1%)
Shoulder	2 (2%)	/	2 (2%)
Carotid Artery	/	1 (1%)	1 (1%)
Prostatic and iliac artery	1 (1%)	1 (%)	2 (1%)
Tibias	1 (1%)	/	1 (1%)
Lung	/	2 (2%)	2 (2%)
Total cases	59 (47%)	67 (53%)	126 (100%)

Table 6. Non-orthopedic clinical applications.

Non-Orthopedic Clinical Application/Refs.	Number of Cases - (%)		
	CBCT and CT	CBCT Only	Total
Needle insertion during biopsy [48, 64, 87]	2 (2%)	3 (2%)	5 (4%)
Spinal navigation [51]	/	1 (1%)	1 (1%)
Embolization and vascular applications [31, 36, 41, 46, 58, 70, 84, 94, 98]	/	9 (7%)	9 (7%)
Oncology [22, 32, 48, 58, 64, 79, 88]	2 (2%)	5 (4%)	7 (6%)
Breast evaluation [75]	/	1 (1%)	1 (1%)

Table 7. Image quality evaluation methods for papers with CBCT only.

Image Quality/Refs.	Number of Cases - (%)
Evaluated only through clinical outcome [23, 25, 28, 31, 32, 34, 36, 37, 40, 41, 42, 44, 45, 47-49, 51, 56, 58, 61-64, 69, 77, 78, 80, 82, 83, 85, 86, 88, 93]	35 (69%)
Subjective score [17, 20, 57, 71, 73, 75, 76, 87, 94]	9 (18%)
Objective (CNR, SNR...) [16, 29, 65]	3 (6%)
Not evaluated [24, 46, 84, 98]	4 (8%)

A specific evaluation was performed in 12 papers (24%), 9 by subjective scores and 3 by evaluation of objective parameters. Alongside this group, there was a large sub-group (35 papers, 69%), in which, although no specific assessment of the quality of the images was performed, they were subjectively assessed by the doctor concerning the clinical outcome. Therefore, the image quality with CBCT was judged "adequate" in 47 cases (92%) and "inadequate" in 1 sub-case (2%) (soft tissues in Koskinen *et al*. 2013) [57].

3.2. CBCT (FR-CBCT or PR-CBCT) + MDCT

Regarding the works comparing classical MDCT and CBCT (46 total cases), the dosimetric evaluation was performed in 41 cases (89%) (12 patients, 8 cadavers, 18 anthropomorphic phantoms, and 3 cylindrical plastic phantoms). Table **8** summarizes the type of evaluation carried out.

Patient dose measured with FR-CBCT or PR-CBCT was lower than that obtained with MDCT in 34 cases (74%) [18, 19, 21, 22, 26, 27, 33, 35, 38, 39, 43, 50, 52-55, 60, 66, 67, 79, 81, 89-91, 95, 96], equal in 2 (4%) [70, 74], and higher in 5 (11%) [39, 59]. In 5 cases (11%), no dosimetric evaluation was conducted.

Image quality was assessed subjectively through a score or the achievement of the clinical goal in 22 cases (48%) and objective parameters in 5 cases (11%). In 3 cases (7%), the evaluation was made with both methodologies. Table **9** summarizes these data.

The comparison of image quality between MDCT and CBCT is summarized in Table **10**.

Overall, the authors examined the doses measured during CBCT investigations as acceptable in 37 cases (80%) [18, 19, 21, 22, 26, 27, 30, 33, 35, 38, 39, 43, 50, 52-55, 60, 66, 67, 70, 74, 79, 81, 89-91, 95, 96] and non-acceptable in 5 cases [39, 59].

However, the final image quality was considered adequate in 30 cases (65%) [18, 19, 21, 22, 26, 27, 30, 33, 35, 38, 39, 43, 60, 66, 74, 79, 81, 89-91, 95, 96], inadequate in 1 case [39], and not evaluated in the remaining 15 cases (usually investigations carried out on anthropomorphic phantom).

Table 8. Dosimetric evaluation methods in CBCT+TC papers.

Measurement Methods/Refs.	Number of Cases - (%)				
	Patients	Cadaver	Anthrop. Phantom	Cylindric Phantom	Total Cases
Monte Carlo simulation [19]	1 (3%)	/	/	/	1 (2%)
Scanner output (DAP, CDTI, DLP) [18, 21, 22, 26, 27, 30, 33, 35, 38, 43, 60, 70, 74, 79, 89, 95, 96]	9 (20%)	8 (20%)	1 (3%)	1 (3%)	19 (46%)
TLD (measured) [39, 50, 59, 90, 91]	1 (3%)	/	8 (20%)	2 (5%)	11 (27%)
MOSFET (measured) [52-55, 81]	1 (3%)	/	7 (18%)	/	8 (20%)
OSLD [66, 67]	/	/	2 (5%)	/	2 (5%)
Total	12 (28%)	8 (20%)	18 (45%)	3 (8%)	41 (100%)

Table 9. Image quality evaluation methods for papers including both CBCT and MDCT.

Image Quality/Refs.	Number of Cases - (%)
Evaluated through clinical outcome [19, 35, 79, 81, 91, 95]	10 (15%)
Subjective score [18, 30, 33, 38, 43, 60, 74, 89, 90]	12 (20%)
Objective (CNR, SNR...) [21, 26, 66, 96]	5 (11%)
Both (subj+obj) [39, 89]	3 (8%)
Not evaluated [22, 50, 52-55, 59, 67, 70]	16 (40%)

Table 10. Image quality comparison between CBCT and MDCT.

Comparison with MDCT	Number of Cases - (%)			
	Lower/Refs.	Equal / Refs.	Higher / Refs.	Not Present / Refs.
Image quality: Comparison with MDCT	5 (11%) [26, 39, 60, 96]	21 (46%) [21, 22, 27, 30, 33, 35, 38, 43, 66, 74, 79, 81, 90, 91, 95]	1 (2%) [89]	19 (41%) [18, 19, 50, 52-55, 59, 67, 70]

In 4 cases [26, 60, 96] and protocol 20s [39], despite the image quality being lower than the one obtained with MDCT, it was considered adequate for clinical purposes.

4. DISCUSSION

Multidetector computer tomography (MDCT) represents the gold standard for 3D radiology in almost all clinical settings. It is an advanced technology, well known and optimized for wide spectrum clinical applications [1]. However, this method has some limitations, mainly related to the costs of the instruments, the dimensions of the equipment, and the doses delivered to the patient during the investigation [100-104]. Alongside the traditional MDCT, there is another technology in the market, the cone beam CT, which differs mainly in terms of beam shape, type of detectors, and Field of View (FOV). Its use has become common in orthodontic and maxillofacial fields, becoming the reference standard in implantology. Moreover, CBCT is increasingly evolving for orthopedic investigations of the upper and lower human extremities (hands and feet). Since CBCT has some advantages over traditional MDCT, such as lower cost and lower patient doses, interest is increasing in developing devices that exploit CBCT to scan large areas throughout the human body, even with contrast medium investigation.

Therefore, radiological equipment manufacturers have started to provide their instruments with motorized handling systems and specific image reconstruction algorithms to transform C-arm devices with planar imaging into partial rotation cone beam CT (PR-CBCT).

Although the quality of the images obtained with this technology is considered adequate [12], it is limited by the reduced rotational capacity of the arm and the restrictions imposed by single devices. In this regard, some authors have reported advantages both in terms of image quality and dose [105] by modifying only the angular range of rotation of the arc and optimizing the centering of the target organ.

The only device that overcomes these limitations is the Medtronic O-Arm, which is configured as a full rotation CBCT for use in the interventional setting, dedicated primarily to neurosurgical imaging, that can be positioned around the patient through manual handling. This equipment is used in 9 of the considered papers, mainly for vertebral and spinal imaging, with positive results both in terms of image quality and dose. Most of the commercial FR-CBCT reviewed (CurveBeam, Planmeca, and Planmed devices, for 28 considered issues) are commonly used in the orthopedic field to investigate the extremities with excellent results in terms of clinical outcome (adequate in all 22 cases in which image quality was assessed) and patient dose (acceptable in all 16 cases with dosimetric evaluation). In one case [57], the image quality of the soft tissues (cartilages and ligaments) was assessed as insufficient.

The only FR-CBCT considered in this review is the NewTom 5G because it is in the market with an adequate gantry for scanning districts of the whole human body. This FR-CBCT was reported in 12 studies, usually as a reference to the orthopedic imaging of peripheral areas (arms, elbows, wrists, feet, knees, and ankles). In all studies involving NewTom 5G, both the image quality and the final dose were considered acceptable.

Overall, in all the studies involving FR-CBCT, the image quality was considered adequate in all cases, excluding the analysis of soft tissues performed by Koskinen *et al*. in 2013 [57]. A total of 11 cases with no image quality evaluation [22, 50, 52-55, 67] were carried out with phantoms, and the primary evaluation was based on the radiation dose. The patient's radiation exposure was considered acceptable in all 30 cases with dosimetric evaluation (26 papers had no data). In 14 cases [26, 35, 43, 52-55, 66, 67, 81, 92], the effective dose was lower with FR-CBCT compared to MDCT, with differences ranging between -95% and -30%. In terms of CDTI, the values obtained with FR-CBCT were always found to be lower than those with TC (range: -86% ÷ -6%) [26, 30, 33, 50, 60, 74, 89, 90, 95, 96].

Despite the limitations imposed by the reduced movement dynamics, the PR-CBCTs provided an image quality suitable for clinical outcomes in 32 out of 40 cases (80%). In one case, the image was not considered adequate [39], while it was not evaluated in 7 cases [46, 59, 70, 98]. As for the patient dose, this was considered acceptable in 24 cases, inadequate in 5 cases [39, 59], and not evaluated in the others. As for the studies in which the dose of PR-CBCT was lower than that of MDCT [19, 39, 70, 79], the reduction in terms of effective dose varied between -69% and -54%. In 5 cases, in which the dose with CBCT was assessed as non-acceptable [39, 59], the effective dose calculated with PR-CBCT was reported to be greater than that obtained with MDCT (range + 38% ÷ + 174%).

Summarizing the results, image quality was considered adequate in 99% of cases with a final evaluation (71 out of 72 issues), and the radiological dose to the patient was considered acceptable in 50 cases out of 55 (91%). The analysis also highlighted the large number of applications that a CBCT could have, even in non-orthopedic areas. They are mostly specific applications carried out in different clinical settings and are still subject to evaluation in terms of image quality, patient's radiation dose, and achievement of the clinical goal. However, the final evaluations made by the individual authors and reported in this research showed that Cone Beam Computer Tomography represents an effective alternative to traditional MDCT in specific clinical contexts, despite the long way to go and the lack of standardized and dedicated protocols. In fact, the works considered in this review demonstrated how CBCT could be useful to improve diagnostic and therapeutic procedures (*e.g*., positioning of embolization catheters, probes for biopsies and prostheses) as an alternative to traditional 2D radiology. Further usefulness of CBCT for imaging all body districts (not only of the extremities) and "non-orthopedic" anatomical regions, such as blood vessels (with and without contrast media), liver, breast, lungs, and soft tissues in general, is also highlighted.

The main limitations of CBCT for non-maxillofacial anatomical areas are related to the long scanning time, during which the patient is required to remain motionless [27]. The movements related to breathing, if present, make it impossible to obtain images of adequate quality [2, 106, 107], despite different authors proposing algorithms to reduce motion artifacts and improve image quality [12, 108-113].

Another important limitation of this review is not to consider studies on CBCT for radiotherapy purposes since, in this field, the main goal of cone beam computed tomography is the localization of the target organ and not its clinical evaluation. Despite that, many works have been published about the optimization of image reconstruction with CBCT to better locate and define the target; it should not be overlooked that the achievement of this goal can only be obtained by improving the quality of the tomographic image. It is evident that this second aspect becomes leading if CBCT is considered a diagnostic tool for 3D imaging. For this reason, we included in the present review 2 papers [50, 96] that are representative of this effort. This great number of papers on CBCT optimization for radiotherapy highlights the feasibility of this technology for imaging the full body and not only for the orthopedic district. Sometimes, the 3D reconstructions during radiotherapy have led to important diagnostic evidence not directly related to the target localization (for example, the detection of COVID-19 in patients with lung cancers) [114, 115]. Of the considered papers, only the results were evaluated without detailing the machine protocols used for the acquisitions, which were therefore not reported. This choice was made mainly due to the great lack of homogeneity and the wide spread of parameters investigated by different authors (mainly for CBCT), which did not allow statistical data comparison. Moreover, the calculation of some dosimetric parameters (*e.g.*, effective dose E and CDTI) presents an intrinsic variability linked to the radiological models [14, 15], which makes an inter-job comparison not possible. Despite these findings representing a limitation of this review, they show the lack of scientific literature on the use of CBCT in anatomical areas other than dental and maxillofacial ones.

To make a better comparison, it would be useful to investigate the same orthopedic district both with CBCT and with MDCT to evaluate the same diagnostic question using anthropomorphic phantoms and evaluating both the dose to the organs (D) and the image quality parameters (*e.g.*, CNR, MTF, SNR, DQE). In this way, both a correct assessment of the radiological risk associated with the methodology and the optimization of the CBCT machine parameters aimed at optimizing the procedure would be possible.

CONCLUSION

CBCT is therefore proving to be an effective technique in terms of image quality (acceptable in 99% of the cases reported in this review) with a reduction in patient dose (compared to current techniques). Therefore, its use is increasing to investigate non-traditional anatomical districts (for example, vessels, liver, breast, lungs, *etc*.) also with the use of contrast media. For this reason, despite the way for CBCT to become a standard method in all areas of medicine seems quite long, the premises suggest an optimistic future.

AUTHORS' CONTRIBUTION

Ivan Corazza contributed to the investigation, data curation, formal analysis, supervision, and writing the original draft. Emanuele Giannetti contributed to the writing, reviewing, and editing. Giancarlo Bonzi contributed to the investigation, writing, reviewing, and editing. Alessandro Lombi, Giulia Paolani, Miriam Santoro, and Maria Francesca Morrone contributed to the investigation and formal analysis. Margherita Zecchi contributed to the investigation, formal analysis, writing, reviewing, and editing. Pier Luca Rossi contributed to the investigation, methodology, visualization, and writing the original draft.

LIST OF ABBREVIATIONS

CBCT	=	Cone Beam Computed Tomography
SDCT	=	Single Detector Computed Tomography
MDCT	=	Multi-Detector Computed Tomography
FR-CBCT	=	Full Rotation Cone Beam Computed Tomography
PR-CBCT	=	Partial Rotation Cone Beam Computed Tomography
D	=	Absorbed Dose (measured in mGy)
E	=	Effective Dose (measured in mSv)
TLD	=	Thermo Luminescent Dosimeter
OSLD	=	Optical Stimulated Luminescence Dosimeter
DAP	=	Dose Area Product (measured in $mGy*cm^2$)
DLP	=	Dose Length Product (measured in mGy*cm)
CTDI	=	Computed Tomography Dose Index (measured in mGy)
CNR	=	Contrast-to-Noise Ratio
MTF	=	Modulated Transfer Function
SNR	=	Signal-to-Noise Ratio
DQE	=	Detective Quantum Efficiency
FDK Algorithms	=	Feldkamp, Davis, and Kress algorithm
IGRT	=	Image-Guided Radiotherapy
ART	=	Adaptive Radiotherapy
FOV	=	Field of View

CONSENT FOR PUBLICATION

Not applicable.

STANDARDS OF REPORTING

PRISMA guidelines and methodology were followed.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

SUPPLEMENTARY MATERIAL

PRISMA checklist is available as supplementary material on the publisher's website along with the published article.

REFERENCES

[1] Seeram E. Computed tomography: Physical principles, clinical applications, and quality control. 4th ed.; St. Louis, Missouri: Elsevier 2016.

[2] Kumar M, Shanavas M, Sidappa A, Kiran M. Cone beam computed tomography - know its secrets. J Int Oral Health 2015; 7(2): 64-8.
PMID: 25859112

[3] Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS. Technical aspects of dental CBCT: State of the art. Dentomaxillofac Radiol 2015; 44(1): 20140224.
http://dx.doi.org/10.1259/dmfr.20140224 PMID: 25263643

[4] von Arx T, Lozanoff S, Bornstein MM. Extraoral anatomy in CBCT - a literature review. Part 1: Nasoethmoidal region. Swiss Dent J 2019; 129(10): 804-15.
PMID: 31392880

[5] von Arx T, Lozanoff S, Bornstein MM. Extraoral anatomy in CBCT - a literature review. Part 2: Zygomatico-orbital region. Swiss Dent J 2020; 130(2): 126-38.
PMID: 32024348

[6] von Arx T, Lozanoff S, Bornstein MM. Extraoral anatomy in CBCT - a literature review. Part 3: Retromaxillary region. Swiss Dent J 2020; 130(3): 216-28.
PMID: 32162855

[7] von Arx T, Lozanoff S, Bornstein MM. Extraoral anatomy in CBCT - a literature review. Part 4: Pharyngocervical region. Swiss Dent J 2020; 130(10): 768-84.
PMID: 33021766

[8] Casselman JW, Gieraerts K, Volders D, *et al.* Cone beam CT: Non-dental applications. JBR-BTR 2013; 96(6): 333-53.

[9] Ferrari M, Pianta L, Borghesi A, *et al.* The ethmoidal arteries: A cadaveric study based on cone beam computed tomography and endoscopic dissection. Surg Radiol Anat 2017; 39(9): 991-8.
http://dx.doi.org/10.1007/s00276-017-1839-6 PMID: 28299444

[10] Jain S, Choudhary K, Nagi R, Shukla S, Kaur N, Grover D. New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Sci Dent 2019; 49(3): 179-90.
http://dx.doi.org/10.5624/isd.2019.49.3.179 PMID: 31583200

[11] Posadzy M, Desimpel J, Vanhoenacker F. Cone beam CT of the musculoskeletal system: Clinical applications. Insights Imaging 2018; 9(1): 35-45.
http://dx.doi.org/10.1007/s13244-017-0582-1 PMID: 29302798

[12] Zhang Z, Han X, Pearson E, Pelizzari C, Sidky EY, Pan X. Artifact reduction in short-scan CBCT by use of optimization-based reconstruction. Phys Med Biol 2016; 61(9): 3387-406.
http://dx.doi.org/10.1088/0031-9155/61/9/3387 PMID: 27046218

[13] Bridge P, Tipper DJ. CT Anatomy for Radiotherapy. 2nd Revised Ed.; M&K Publishing, MK Update Ltd: UK, 2017.

[14] Kenny E, Caldwell D, Lewis M. Practical radiation dosimetry across a variety of CBCT devices in radiology. Phys Med 2020; 71: 3-6.
http://dx.doi.org/10.1016/j.ejmp.2020.01.021 PMID: 32056781

[15] Nardi C, Salerno S, Molteni R, *et al.* Radiation dose in non-dental cone beam CT applications: A systematic review. Radiol Med 2018; 123(10): 765-77.
http://dx.doi.org/10.1007/s11547-018-0910-7 PMID: 29869227

[16] Aurell Y, Andersson MLE, Forslind K. Cone-beam computed tomography, a new low-dose three-dimensional imaging technique for assessment of bone erosions in rheumatoid arthritis: Reliability assessment and comparison with conventional radiography - a BARFOT study. Scand J Rheumatol 2018; 47(3): 173-7.
http://dx.doi.org/10.1080/03009742.2017.1381988 PMID: 29318928

[17] Borel C, Larbi A, Delclaux S, *et al.* Diagnostic value of cone beam computed tomography (CBCT) in occult scaphoid and wrist fractures. Eur J Radiol 2017; 97: 59-64.
http://dx.doi.org/10.1016/j.ejrad.2017.10.010 PMID: 29153368

[18] Borggrefe J, Bolte H, Worms W, *et al.* Comparison of intraoperative flat panel imaging and postoperative plain radiography for the detection of intraarticular screw displacement in volar distal radius plate ostheosynthesis. Orthop Traumatol Surg Res 2015; 101(8): 913-7.
http://dx.doi.org/10.1016/j.otsr.2015.07.023 PMID: 26522382

[19] Braak SJ, van Strijen MJL, van Es HW, Nievelstein RAJ, van Heesewijk JPM. Effective dose during needle interventions: Cone-beam CT guidance compared with conventional CT guidance. J Vasc Interv Radiol 2011; 22(4): 455-61.
http://dx.doi.org/10.1016/j.jvir.2011.02.011 PMID: 21463755

[20] Burssens A, Peeters J, Buedts K, Victor J, Vandeputte G. Measuring hindfoot alignment in weight bearing CT: A novel clinical relevant measurement method. Foot Ankle Surg 2016; 22(4): 233-8.
http://dx.doi.org/10.1016/j.fas.2015.10.002 PMID: 27810020

[21] Carrino JA, Al Muhit A, Zbijewski W, *et al.* Dedicated cone-beam CT system for extremity imaging. Radiology 2014; 270(3): 816-24.
http://dx.doi.org/10.1148/radiol.13130225 PMID: 24475803

[22] Cheng EY, Naranje SM, Ritenour ER. Radiation dosimetry of intraoperative cone-beam compared with conventional CT for radiofrequency ablation of osteoid osteoma. J Bone Joint Surg Am 2014; 96(9): 735-42.
http://dx.doi.org/10.2106/JBJS.M.00874 PMID: 24806010

[23] Cordemans V, Kaminski L, Banse X, Francq BG, Detrembleur C, Cartiaux O. Pedicle screw insertion accuracy in terms of breach and reposition using a new intraoperative cone beam computed tomography imaging technique and evaluation of the factors associated with these parameters of accuracy: A series of 695 screws. Eur Spine J 2017; 26(11): 2917-26.
http://dx.doi.org/10.1007/s00586-017-5195-3 PMID: 28631190

[24] Costa F, Ortolina A, Cardia A, *et al.* Preoperative magnetic resonance and intraoperative computed tomography fusion for real-time neuronavigation in intramedullary lesion surgery. Oper Neurosurg 2017; 13(2): 188-95.
http://dx.doi.org/10.1093/ons/opw005 PMID: 28927206

[25] de Cesar Netto C, Schon LC, Thawait GK, *et al.* Flexible adult acquired flatfoot deformity. J Bone Joint Surg Am 2017; 99(18): e98.
http://dx.doi.org/10.2106/JBJS.16.01366 PMID: 28926392

[26] de Charry C, Boutroy S, Ellouz R, *et al.* Clinical cone beam computed tomography compared to high-resolution peripheral computed tomography in the assessment of distal radius bone. Osteoporos Int 2016; 27(10): 3073-82.
http://dx.doi.org/10.1007/s00198-016-3609-4 PMID: 27121345

[27] De Cock J, Mermuys K, Goubau J, Van Petegem S, Houthoofd B, Casselman JW. Cone-beam computed tomography: A new low dose, high resolution imaging technique of the wrist, presentation of three cases with technique. Skeletal Radiol 2012; 41(1): 93-6.
http://dx.doi.org/10.1007/s00256-011-1198-z PMID: 21603872

[28] De Smet E, De Praeter G, Verstraete KLA, Wouters K, De Beuckeleer L, Vanhoenacker FMHM. Direct comparison of conventional radiography and cone-beam CT in small bone and joint trauma. Skeletal Radiol 2015; 44(8): 1111-7.
http://dx.doi.org/10.1007/s00256-015-2127-3 PMID: 25761727

[29] Dea N, Fisher CG, Batke J, *et al.* Economic evaluation comparing intraoperative cone beam CT-based navigation and conventional fluoroscopy for the placement of spinal pedicle screws: A patient-level data cost-effectiveness analysis. Spine J 2016; 16(1): 23-31.
http://dx.doi.org/10.1016/j.spinee.2015.09.062 PMID: 26456854

[30] Demehri S, Muhit A, Zbijewski W, *et al.* Assessment of image quality in soft tissue and bone visualization tasks for a dedicated extremity cone-beam CT system. Eur Radiol 2015; 25(6): 1742-51.
http://dx.doi.org/10.1007/s00330-014-3546-6 PMID: 25599933

[31] Dong J, Bai X, Dmytriw AA, *et al.* Identification of carotid artery microstructure and plaque rupture using C-Arm cone-beam CT: A case report. Front Neurol 2021; 12: 801683.

http://dx.doi.org/10.3389/fneur.2021.801683 PMID: 35002941
[32] Drazin D, Bhamb N, Al-Khouja LT, *et al.* Image-guided resection of aggressive sacral tumors. Neurosurg Focus 2017; 42(1): E15. http://dx.doi.org/10.3171/2016.6.FOCUS16125 PMID: 28041320
[33] Dubreuil T, Mouly J, Ltaief-Boudrigua A, *et al.* Comparison of cone-beam computed tomography and multislice computed tomography in the assessment of extremity fractures. J Comput Assist Tomogr 2019; 43(3): 372-8. http://dx.doi.org/10.1097/RCT.0000000000000843 PMID: 30762657
[34] Edlund R, Skorpil M, Lapidus G, Bäcklund J. Cone-Beam CT in diagnosis of scaphoid fractures. Skeletal Radiol 2016; 45(2): 197-204. http://dx.doi.org/10.1007/s00256-015-2290-6 PMID: 26563560
[35] Farah K, Coudert P, Graillon T, *et al.* Prospective comparative study in spine surgery between O-Arm and airo systems: Efficacy and radiation exposure. World Neurosurg 2018; 118: e175-84. http://dx.doi.org/10.1016/j.wneu.2018.06.148 PMID: 30257292
[36] Fukuda K, Higashi T, Okawa M, Matsumoto J, Takano K, Inoue T. Utility of cone-beam computed tomography angiography for the assessment of vertebral artery dissection. J Clin Neurosci 2018; 48: 76-80. http://dx.doi.org/10.1016/j.jocn.2017.11.010 PMID: 29257748
[37] Garnon J, Koch G, Ramamurthy N, *et al.* Percutaneous imaging-guided screw fixation of osteoporotic transverse fractures of the lower sacrum with cement augmentation: Report of 2 cases. Cardiovasc Intervent Radiol 2017; 40(7): 1105-11. http://dx.doi.org/10.1007/s00270-017-1633-1 PMID: 28357574
[38] Grunz JP, Gietzen CH, Kunz AS, *et al.* Twin robotic X-ray system for 3D cone-beam CT of the wrist: An evaluation of image quality and radiation dose. AJR Am J Roentgenol 2020; 214(2): 422-7. http://dx.doi.org/10.2214/AJR.19.21911 PMID: 31799871
[39] Guggenberger R, Ulbrich EJ, Dietrich TJ, *et al.* C-arm flat-panel CT arthrography of the shoulder: Radiation dose considerations and preliminary data on diagnostic performance. Eur Radiol 2017; 27(2): 454-63. http://dx.doi.org/10.1007/s00330-016-4382-7 PMID: 27221562
[40] Held M, Sneed PK, Fogh SE, Pouliot J, Morin O. Feasibility of MV CBCT-based treatment planning for urgent radiation therapy: Dosimetric accuracy of MV CBCT-based dose calculations. J Appl Clin Med Phys 2015; 16(6): 458-71. http://dx.doi.org/10.1120/jacmp.v16i6.5625 PMID: 26699575
[41] Hermie L, Dhondt E, Vanlangenhove P, De Waele J, Degroote H, Defreyne L. Empiric cone-beam CT-guided embolization in acute lower gastrointestinal bleeding. Eur Radiol 2021; 31(4): 2161-72. http://dx.doi.org/10.1007/s00330-020-07232-7 PMID: 32964336
[42] Hirschmann A, Buck FM, Herschel R, Pfirrmann CWA, Fucentese SF. Upright weight-bearing CT of the knee during flexion: Changes of the patellofemoral and tibiofemoral articulations between 0° and 120°. Knee Surg Sports Traumatol Arthrosc 2017; 25(3): 853-62. http://dx.doi.org/10.1007/s00167-015-3853-8 PMID: 26537597
[43] Huang AJ, Chang CY, Thomas BJ, MacMahon PJ, Palmer WE. Using cone-beam CT as a low-dose 3D imaging technique for the extremities: Initial experience in 50 subjects. Skeletal Radiol 2015; 44(6): 797-809. http://dx.doi.org/10.1007/s00256-015-2105-9 PMID: 25652734
[44] Hui TCH, Tan GZL, Tan AKW, Pua U. The use of cone beam CT in achieving unipedicular spinal augmentation. Br J Radiol 2016; 89(1065): 20160030. http://dx.doi.org/10.1259/bjr.20160030 PMID: 27376703
[45] Hurley RK Jr, Anderson ER III, Lawson BK, Hobbs JK, Aden JK, Jorgensen AY. Comparing lumbar disc space preparation with fluoroscopy *versus* cone beam-computed tomography and navigation. Spine 2018; 43(14): 959-64. http://dx.doi.org/10.1097/BRS.0000000000002526 PMID: 29280932
[46] Hwang YS, Tsai HY, Lin YY, Lui KW. Investigations of organ and effective doses of abdominal cone-beam computed tomography during transarterial chemoembolization using monte carlo simulation. BMC Med Imaging 2018; 18(1): 2. http://dx.doi.org/10.1186/s12880-018-0247-7 PMID: 29402236
[47] Ierardi AM, Piacentino F, Giorlando F, *et al.* Cone beam computed tomography and its image guidance technology during percutaneous nucleoplasty procedures at L5/S1 lumbar level. Skeletal Radiol 2016; 45(12): 1669-76. http://dx.doi.org/10.1007/s00256-016-2486-4 PMID: 27699478
[48] Jiao D, Huang K, Wu G, Wang Y, Han X. Flat detector cone-beam CT-guided percutaneous needle biopsy of mediastinal lesions: Preliminary experience. Radiol Med (Torino) 2016; 121(10): 769-79. http://dx.doi.org/10.1007/s11547-016-0660-3 PMID: 27334008
[49] Joseph JR, Smith BW, Patel RD, Park P. Use of 3D CT-based navigation in minimally invasive lateral lumbar interbody fusion. J Neurosurg Spine 2016; 25(3): 339-44. http://dx.doi.org/10.3171/2016.2.SPINE151295 PMID: 27104283
[50] Kim S, Yoshizumi TT, Toncheva G, Yoo S, Yin FF. Comparison of radiation doses between cone beam CT and multi detector CT: TLD measurements. Radiat Prot Dosimetry 2008; 132(3): 339-45. http://dx.doi.org/10.1093/rpd/ncn305 PMID: 19074786
[51] Kim JS, Härtl R, Mayer HM, Drazin D. Minimally invasive spinal surgery. BioMed Res Int 2016; 2016: 5048659. http://dx.doi.org/10.1155/2016/5048659 PMID: 27213152
[52] Koivisto J, van Eijnatten M, Kiljunen T, Shi XQ, Wolff J. Effective radiation dose in the wrist resulting from a radiographic device, two CBCT devices and one MSCT device: A comparative study. Radiat Prot Dosimetry 2018; 179(1): 58-68. http://dx.doi.org/10.1093/rpd/ncx210 PMID: 29040707
[53] Koivisto J, Kiljunen T, Kadesjö N, Shi XQ, Wolff J. Effective radiation dose of a MSCT, two CBCT and one conventional radiography device in the ankle region. J Foot Ankle Res 2015; 8(1): 8. http://dx.doi.org/10.1186/s13047-015-0067-8 PMID: 25788986
[54] Koivisto J, Kiljunen T, Wolff J, Kortesniemi M. Assessment of effective radiation dose of an extremity CBCT, MSCT and conventional X ray for knee area using MOSFET dosemeters. Radiat Prot Dosimetry 2013; 157(4): 515-24. http://dx.doi.org/10.1093/rpd/nct162 PMID: 23825221
[55] Koivisto J, Eijnatten M, Ludlow J, Kiljunen T, Shi XQ, Wolff J. Comparative dosimetry of radiography device, MSCT device and two CBCT devices in the elbow region. J Appl Clin Med Phys 2021; 22(5): 128-38. http://dx.doi.org/10.1002/acm2.13245 PMID: 33811787
[56] Kortekangas T, Savola O, Flinkkilä T, *et al.* A prospective randomised study comparing TightRope and syndesmotic screw fixation for accuracy and maintenance of syndesmotic reduction assessed with bilateral computed tomography. Injury 2015; 46(6): 1119-26. http://dx.doi.org/10.1016/j.injury.2015.02.004 PMID: 25769201
[57] Koskinen SK, Haapamäki VV, Salo J, *et al.* CT arthrography of the wrist using a novel, mobile, dedicated extremity cone-beam CT (CBCT). Skeletal Radiol 2013; 42(5): 649-57. http://dx.doi.org/10.1007/s00256-012-1516-0 PMID: 22990597
[58] Kothary N, Abdelmaksoud MHK, Tognolini A, *et al.* Imaging guidance with C-arm CT: Prospective evaluation of its impact on patient radiation exposure during transhepatic arterial chemoembolization. J Vasc Interv Radiol 2011; 22(11): 1535-43. http://dx.doi.org/10.1016/j.jvir.2011.07.008 PMID: 21875814
[59] Kwok YM, Irani FG, Tay KH, Yang CC, Padre CG, Tan BS. Effective dose estimates for cone beam computed tomography in interventional radiology. Eur Radiol 2013; 23(11): 3197-204. http://dx.doi.org/10.1007/s00330-013-2934-7 PMID: 23793520
[60] Lang H, Neubauer J, Fritz B, *et al.* A retrospective, semi-quantitative image quality analysis of cone beam computed tomography (CBCT) and MSCT in the diagnosis of distal radius fractures. Eur Radiol 2016; 26(12): 4551-61. http://dx.doi.org/10.1007/s00330-016-4321-7 PMID: 27003138
[61] Lee SM, Park CM, Lee KH, Bahn YE, Kim JI, Goo JM. C-arm cone-beam CT-guided percutaneous transthoracic needle biopsy of lung nodules: Clinical experience in 1108 patients. Radiology 2014; 271(1): 291-300. http://dx.doi.org/10.1148/radiol.13131265 PMID: 24475839
[62] Lepojärvi S, Niinimäki J, Pakarinen H, Leskelä HV. Rotational dynamics of the normal distal tibiofibular joint with weight-bearing computed tomography. Foot Ankle Int 2016; 37(6): 627-35. http://dx.doi.org/10.1177/1071100716634757 PMID: 26922668
[63] Lepojärvi S, Niinimäki J, Pakarinen H, Koskela L, Leskelä HV. Rotational dynamics of the talus in a normal tibiotalar joint as

shown by weight-bearing computed tomography. J Bone Joint Surg Am 2016; 98(7): 568-75.
http://dx.doi.org/10.2106/JBJS.15.00470 PMID: 27053585

[64] Liu JF, Jiao DC, Ren JZ, Zhang WG, Han XW. Percutaneous bone biopsy using a flat-panel cone beam computed tomography virtual navigation system. Saudi Med J 2018; 39(5): 519-23.
http://dx.doi.org/10.15537/smj.2018.5.21872 PMID: 29738014

[65] Ludlow JB. Hand-wrist, knee, and foot-ankle dosimetry and image quality measurements of a novel extremity imaging unit providing CBCT and 2D imaging options. Med Phys 2018; 45(11): 4955-63.
http://dx.doi.org/10.1002/mp.13198 PMID: 30229941

[66] Ludlow JB, Johnson BK, Ivanovic M. Estimation of effective doses from MDCT and CBCT imaging of extremities. J Radiol Prot 2018; 38(4): 1371-83.
http://dx.doi.org/10.1088/1361-6498/aae44b PMID: 30255853

[67] Ludlow JB, Ivanovic M. Weightbearing CBCT, MDCT, and 2D imaging dosimetry of the foot and ankle. Int J Diagnos Imag 2014; 1(2): 1.
http://dx.doi.org/10.5430/ijdi.v1n2p1

[68] Maffezzoni F, Maddalo M, Frara S, *et al.* High-resolution-cone beam tomography analysis of bone microarchitecture in patients with acromegaly and radiological vertebral fractures. Endocrine 2016; 54(2): 532-42.
http://dx.doi.org/10.1007/s12020-016-1078-3 PMID: 27601020

[69] Maier J, Black M, Bonaretti S, et al. Comparison of different approaches for measuring tibial cartilage thickness. J Integr Bioinform 2017; 14(2): 20170015.
https://doi.org/10.1515/jib-2017-0015.

[70] Marshall EL, Guajardo S, Sellers E, *et al.* Radiation dose during transarterial radioembolization: A dosimetric comparison of cone-beam CT and angio-CT technologies. J Vasc Interv Radiol 2021; 32(3): 429-38.
http://dx.doi.org/10.1016/j.jvir.2020.10.021 PMID: 33358328

[71] Myller KAH, Turunen MJ, Honkanen JTJ, *et al. In vivo* contrast-enhanced cone beam CT provides quantitative information on articular cartilage and subchondral bone. Ann Biomed Eng 2017; 45(3): 811-8.
http://dx.doi.org/10.1007/s10439-016-1730-3 PMID: 27646147

[72] Mys K, Stockmans F, Vereecke E, van Lenthe GH. Quantification of bone microstructure in the wrist using cone-beam computed tomography. Bone 2018; 114: 206-14.
http://dx.doi.org/10.1016/j.bone.2018.06.006 PMID: 29909060

[73] Nardi C, Buzzi R, Molteni R, *et al.* The role of cone beam CT in the study of symptomatic total knee arthroplasty (TKA): A 20 cases report. Br J Radiol 2017; 90(1074): 20160925.
http://dx.doi.org/10.1259/bjr.20160925 PMID: 28467105

[74] Neubauer J, Benndorf M, Reidelbach C, *et al.* Comparison of diagnostic accuracy of radiation dose-equivalent radiography, multidetector computed tomography and cone beam computed tomography for fractures of adult cadaveric wrists. PLoS One 2016; 11(10): e0164859.
http://dx.doi.org/10.1371/journal.pone.0164859 PMID: 27788215

[75] O'Connell A, Conover DL, Zhang Y, *et al.* Cone-beam CT for breast imaging: Radiation dose, breast coverage, and image quality. AJR Am J Roentgenol 2010; 195(2): 496-509.
http://dx.doi.org/10.2214/AJR.08.1017 PMID: 20651210

[76] Osgood GM, Thawait GK, Hafezi-Nejad N, *et al.* Image quality of cone beam computed tomography for evaluation of extremity fractures in the presence of metal hardware: Visual grading characteristics analysis. Br J Radiol 2017; 90(1073): 20160539.
http://dx.doi.org/10.1259/bjr.20160539 PMID: 28281784

[77] Park P. Three-dimensional computed tomography-based spinal navigation in minimally invasive lateral lumbar interbody fusion: Feasibility, technique, and initial results. Neurosurgery 2015; 11(Suppl. 2): 259-67.
PMID: 25812070

[78] Patel S, Malhotra K, Cullen NP, Singh D, Goldberg AJ, Welck MJ. Defining reference values for the normal tibiofibular syndesmosis in adults using weight-bearing CT. Bone Joint J 2019; 101-B(3): 348-52.
http://dx.doi.org/10.1302/0301-620X.101B3.BJJ-2018-0829.R1 PMID: 30813789

[79] Perry BC, Monroe EJ, McKay T, Kanal KM, Shivaram G. Pediatric percutaneous osteoid osteoma ablation: Cone-beam CT with fluoroscopic overlay *versus* conventional CT guidance. Cardiovasc Intervent Radiol 2017; 40(10): 1593-9.
http://dx.doi.org/10.1007/s00270-017-1685-2 PMID: 28497188

[80] Pireau N, Cordemans V, Banse X, Irda N, Lichtherte S, Kaminski L. Radiation dose reduction in thoracic and lumbar spine instrumentation using navigation based on an intraoperative cone beam CT imaging system: A prospective randomized clinical trial. Eur Spine J 2017; 26(11): 2818-27.
http://dx.doi.org/10.1007/s00586-017-5229-x PMID: 28735464

[81] Pugmire BS, Shailam R, Sagar P, *et al.* Initial clinical experience with extremity cone-beam CT of the foot and ankle in pediatric patients. AJR Am J Roentgenol 2016; 206(2): 431-5.
http://dx.doi.org/10.2214/AJR.15.15099 PMID: 26797374

[82] Ricci PM, Boldini M, Bonfante E, *et al.* Cone-beam computed tomography compared to X-ray in diagnosis of extremities bone fractures: A study of 198 cases. Eur J Radiol Open 2019; 6: 119-21.
http://dx.doi.org/10.1016/j.ejro.2019.01.009 PMID: 30911591

[83] Roux C, Tselikas L, Yevich S, *et al.* Fluoroscopy and cone-beam CT-guided fixation by internal cemented screw for pathologic pelvic fractures. Radiology 2019; 290(2): 418-25.
http://dx.doi.org/10.1148/radiol.2018181105 PMID: 30422090

[84] Schnapauff D, Maxeiner A, Wieners G, *et al.* Semi-automatic prostatic artery detection using cone-beam CT during prostatic arterial embolization. Acta Radiol 2020; 61(8): 1116-24.
http://dx.doi.org/10.1177/0284185119891689 PMID: 31830430

[85] Segal NA, Nevitt MC, Lynch JA, Niu J, Torner JC, Guermazi A. Diagnostic performance of 3D standing CT imaging for detection of knee osteoarthritis features. Phys Sportsmed 2015; 43(3): 213-20.
http://dx.doi.org/10.1080/00913847.2015.1074854 PMID: 26313455

[86] Seki S, Kawaguchi Y, Nakano M, Makino H, Mine H, Kimura T. Rod rotation and differential rod contouring followed by direct vertebral rotation for treatment of adolescent idiopathic scoliosis: Effect on thoracic and thoracolumbar or lumbar curves assessed with intraoperative computed tomography. Spine J 2016; 16(3): 365-71.
http://dx.doi.org/10.1016/j.spinee.2015.11.032 PMID: 26656172

[87] Shellikeri S, Girard E, Setser R, Bao J, Cahill AM. Metal artefact reduction algorithm for correction of bone biopsy needle artefact in paediatric C-arm CT images: A qualitative and quantitative assessment. Clin Radiol 2016; 71(9): 925-31.
http://dx.doi.org/10.1016/j.crad.2016.04.021 PMID: 27262747

[88] Shih CD, Bazarov I, Harrington T, Vartivarian M, Reyzelman AM. Initial report on the use of in-office cone beam computed tomography for early diagnosis of osteomyelitis in diabetic patients. J Am Podiatr Med Assoc 2016; 106(2): 128-32.
http://dx.doi.org/10.7547/14-017 PMID: 27031549

[89] Tschauner S, Marterer R, Nagy E, Singer G, Riccabona M, Sorantin E. Experiences with image quality and radiation dose of cone beam computed tomography (CBCT) and multidetector computed tomography (MDCT) in pediatric extremity trauma. Skeletal Radiol 2020; 49(12): 1939-49.
http://dx.doi.org/10.1007/s00256-020-03506-9 PMID: 32535775

[90] Tschauner S, Marterer R, Nagy E, *et al.* Surface radiation dose comparison of a dedicated extremity cone beam computed tomography (CBCT) device and a multidetector computed tomography (MDCT) machine in pediatric ankle and wrist phantoms. PLoS One 2017; 12(6): e0178747.
http://dx.doi.org/10.1371/journal.pone.0178747 PMID: 28570626

[91] Tselikas L, Joskin J, Roquet F, *et al.* Percutaneous bone biopsies: Comparison between flat-panel cone-beam CT and CT-scan guidance. Cardiovasc Intervent Radiol 2015; 38(1): 167-76.
http://dx.doi.org/10.1007/s00270-014-0870-9 PMID: 24627161

[92] Turunen MJ, Töyräs J, Kokkonen HT, Jurvelin JS. Quantitative evaluation of knee subchondral bone mineral density using cone beam computed tomography. IEEE Trans Med Imaging 2015; 34(10): 2186-90.
http://dx.doi.org/10.1109/TMI.2015.2426684 PMID: 25935027

[93] Vetter SY, Euler F, von Recum J, Wendl K, Grützner PA, Franke J. Impact of intraoperative cone beam computed tomography on reduction quality and implant position in treatment of tibial plafond fractures. Foot Ankle Int 2016; 37(9): 977-82.

http://dx.doi.org/10.1177/1071100716650532 PMID: 27188693

[94] Wang MQ, Duan F, Yuan K, Zhang GD, Yan J, Wang Y. Benign prostatic hyperplasia: Cone-beam CT in conjunction with dsa for identifying prostatic arterial anatomy. Radiology 2017; 282(1): 271-80.
http://dx.doi.org/10.1148/radiol.2016152415 PMID: 27467466

[95] Ramdhian-Wihlm R, Le Minor JM, Schmittbuhl M, *et al.* Cone-beam computed tomography arthrography: An innovative modality for the evaluation of wrist ligament and cartilage injuries. Skeletal Radiol 2012; 41(8): 963-9.
http://dx.doi.org/10.1007/s00256-011-1305-1 PMID: 22064983

[96] Yang CC, Chen FL, Lo YC. Improving image quality of on-board cone-beam CT in radiation therapy using image information provided by planning multi-detector CT: A phantom study. PLoS One 2016; 11(6): e0157072.
http://dx.doi.org/10.1371/journal.pone.0157072 PMID: 27280593

[97] Zimmermann F, Kohl K, Privalov M, Franke J, Vetter SY. Intraoperative 3D imaging with cone-beam computed tomography leads to revision of pedicle screws in dorsal instrumentation: A retrospective analysis. J Orthop Surg Res 2021; 16(1): 706.
http://dx.doi.org/10.1186/s13018-021-02849-w PMID: 34863238

[98] Sailer AM, Schurink GWH, Wildberger JE, *et al.* Radiation exposure of abdominal cone beam computed tomography. Cardiovasc Intervent Radiol 2015; 38(1): 112-20.
http://dx.doi.org/10.1007/s00270-014-0900-7 PMID: 24798137

[99] de las Heras Gala H, Torresin A, Dasu A, *et al.* Quality control in cone-beam computed tomography (CBCT) EFOMP-ESTRO-IAEA protocol (summary report). Phys Med 2017; 39: 67-72.
http://dx.doi.org/10.1016/j.ejmp.2017.05.069 PMID: 28602688

[100] Anzai Y, Heilbrun ME, Haas D, *et al.* Dissecting costs of CT study: Application of TDABC (Time-driven Activity-based Costing) in a tertiary academic center. Acad Radiol 2017; 24(2): 200-8.
http://dx.doi.org/10.1016/j.acra.2016.11.001 PMID: 27988200

[101] Centonze M, Lorenzin G, Francesconi A, *et al.* Cardiac-CT and Cardiac-MR examinations cost analysis, based on data of four Italian Centers. Radiol Med 2016; 121(1): 12-8.
http://dx.doi.org/10.1007/s11547-015-0566-5 PMID: 26210815

[102] Jaine R, Kvizhinadze G, Nair N, Blakely T. Cost-effectiveness of a low-dose computed tomography screening programme for lung cancer in New Zealand. Lung Cancer 2018; 124: 233-40.
http://dx.doi.org/10.1016/j.lungcan.2018.08.004 PMID: 30268467

[103] Kothari S, Kalinowski M, Kobeszko M, Almouradi T. Computed tomography scan imaging in diagnosing acute uncomplicated pancreatitis: Usefulness *vs.* cost. World J Gastroenterol 2019; 25(9): 1080-7.
http://dx.doi.org/10.3748/wjg.v25.i9.1080 PMID: 30862996

[104] Lehtimäki T, Juvonen P, Valtonen H, Miettinen P, Paajanen H, Vanninen R. Impact of routine contrast-enhanced CT on costs and use of hospital resources in patients with acute abdomen. Results of a randomised clinical trial. Eur Radiol 2013; 23(9): 2538-45.
http://dx.doi.org/10.1007/s00330-013-2848-4 PMID: 23715771

[105] Schernthaner RE, Chapiro J, Sahu S, *et al.* Feasibility of a modified cone-beam CT rotation trajectory to improve liver periphery visualization during transarterial chemoembolization. Radiology 2015; 277(3): 833-41.
http://dx.doi.org/10.1148/radiol.2015142821 PMID: 26000642

[106] Fotouhi J, Fuerst B, Wein W, Navab N. Can real-time RGBD enhance intraoperative Cone-Beam CT. Int J CARS 2017; 12(7): 1211-9.
http://dx.doi.org/10.1007/s11548-017-1572-y PMID: 28343303

[107] Spin-Neto R, Wenzel A. Patient movement and motion artefacts in cone beam computed tomography of the dentomaxillofacial region: A systematic literature review. Oral Surg Oral Med Oral Pathol Oral Radiol 2016; 121(4): 425-33.
http://dx.doi.org/10.1016/j.oooo.2015.11.019 PMID: 26972541

[108] Capostagno S, Sisniega A, Stayman JW, Ehtiati T, Weiss CR, Siewerdsen JH. Deformable motion compensation for interventional cone-beam CT. Phys Med Biol 2021; 66(5): 055010.
http://dx.doi.org/10.1088/1361-6560/abb16e PMID: 33594993

[109] Gayou O, Colonias A. Imaging a moving lung tumor with megavoltage cone beam computed tomography. Med Phys 2015; 42(5): 2347-53.
http://dx.doi.org/10.1118/1.4917524 PMID: 25979029

[110] Nardi C, Borri C, Regini F, *et al.* Metal and motion artifacts by cone beam computed tomography (CBCT) in dental and maxillofacial study. Radiol Med 2015; 120(7): 618-26.
http://dx.doi.org/10.1007/s11547-015-0496-2 PMID: 25634792

[111] Ouadah S, Jacobson M, Stayman JW, Ehtiati T, Weiss C, Siewerdsen JH. Correction of patient motion in cone-beam CT using 3D-2D registration. Phys Med Biol 2017; 62(23): 8813-31.
http://dx.doi.org/10.1088/1361-6560/aa9254 PMID: 28994668

[112] Sisniega A, Thawait GK, Shakoor D, Siewerdsen JH, Demehri S, Zbijewski W. Motion compensation in extremity cone-beam computed tomography. Skeletal Radiol 2019; 48(12): 1999-2007.
http://dx.doi.org/10.1007/s00256-019-03241-w PMID: 31172206

[113] Yeung AWK, Azevedo B, Scarfe WC, Bornstein MM. Patient motion image artifacts can be minimized and re-exposure avoided by selective removal of a sequence of basis images from cone beam computed tomography data sets: A case series. Oral Surg Oral Med Oral Pathol Oral Radiol 2020; 129(2): e212-23.
http://dx.doi.org/10.1016/j.oooo.2019.07.003 PMID: 31416715

[114] Clough A, Sanders J, Banfill K, *et al.* A novel use for routine CBCT imaging during radiotherapy to detect COVID-19. Radiography 2022; 28(1): 17-23.
http://dx.doi.org/10.1016/j.radi.2021.07.011 PMID: 34332857

[115] Youssef I, Donahue B, Flyer M, Thompson S, Huang A, Gallant F. Covert COVID-19: Cone beam computed tomography lung changes in an asymptomatic patient receiving radiation therapy. Adv Radiat Oncol 2020; 5(4): 715-21.
http://dx.doi.org/10.1016/j.adro.2020.04.029 PMID: 32775781