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Systematic Review

Diagnosis Efficacy of Cone-Beam Computed Tomography in Endodontics—A Systematic Review of High-Level-Evidence Studies

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Abstract: Introduction: The integration of clinical inspection and diagnostic imaging forms the basis for endodontic diagnosis, decision making, treatment planning, and outcome assessments. In recent years, CBCT imaging has become a common diagnostic tool in endodontics. CBCT should only be used to ensure that the benefits to the patient exceed the risks. As such, our aim in this study was to evaluate the high level diagnostic efficacy studies and their risk of bias. Methods: A systematic search of the literature was conducted to identify studies evaluating the use of CBCT imaging in endodontics. The following databases were searched: Medline (PubMed), Scopus, and Cochrane Central. The identified studies were subjected to rigorous inclusion criteria. Studies considered as having a high efficacy level were then subjected to a risk of bias assessment using the Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy. Results: Initially, 1568 articles were identified for possible inclusion in the review. Following title and abstract assessment, duplicate removal, and a full-text evaluation, 22 studies were included. Of those studies, 2 had a low risk of bias and 20 had a high risk of bias. Six studies investigated non-surgical treatment, eight investigated surgical treatment, two investigated both non-surgical and surgical treatment, and six studies investigated diagnostic thinking or decision making. Conclusion: The evidence for the influence of CBCT on decision making and treatment outcomes in endodontics is predominantly based on studies with a high risk of bias.

Keywords: cone-beam computed tomography; endodontics; diagnosis efficacy; systematic review

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1. Introduction

Cone-beam computed tomography (CBCT) was developed due to the need for a diagnostic tool that produces high-resolution, three-dimensional scans of the dentomaxillofacial region with lower radiation doses than medical CT [1–3]. CBCT has become an accepted diagnostic tool in daily endodontic practice [2,3]. Numerous studies have addressed the use and efficacy of CBCT for various clinical indications in endodontics including: surgical versus non-surgical treatment [4]; pre-operative versus intra- [5] and post-operative [4] evaluations; and the evaluation of anterior versus posterior teeth [6]. However, these studies present substantial inconsistencies in terms of study design, results, and conclusions [4–6].

Evidence-based dentistry (EBD) is an approach to oral healthcare that incorporates the best available clinical evidence to help practitioners make decisions for an individual patient's treatment needs and preferences [3,7–10]. Thus, a comprehensive review of the diagnostic efficacy and risk of bias assessment of CBCT imaging in endodontics literature, using evidence-based dentistry principles, would be of great use [3,8,9].

A previous literature review of the diagnostic efficacy of CBCT imaging in endodontics [3] identified 485 possibly relevant articles. On closer examination, only five articles met the review's inclusion criteria for assessing the effects of CBCT on decision making, and only one article assessed CBCT's effect on treatment outcomes [3]. The authors concluded that the probable benefits of CBCT imaging for endodontic patients are not yet clear and that current knowledge is mainly limited to assessments based on low levels of efficacy [3]. Comparable results were also reported by Kruse et al. in 2015 [11], who assessed the diagnostic efficacy of CBCT for periapical lesions, and concluded that the efficacy of the technique has only been assessed in studies with low diagnostic efficacy [11].

Since 2015, additional articles have been published regarding the indications of CBCT in endodontics [12–15]. Thus, an updated systematic review of the available literature regarding the diagnostic efficacy of CBCT in endodontics and its effects on decision making and treatment outcomes is timely [7,8,11,16,17]. In addition, the previous reviews [3,11] concentrated on ranking the reviewed articles according to levels of diagnostic efficacy; however, the efficacy and methodological quality of CBCT in the context of specific clinical indications is as yet unclear [4]. To the best of our knowledge, a comprehensive analysis of the methodological quality and characteristics of the studies in the literature, and especially those that support a high level of CBCT diagnostic efficacy, has not yet been conducted.

The aim of this study was to assess the studies with a high level of diagnostic efficacy and their risk of bias by a systematic review of the literature.

2. Materials and Methods

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

A systematic search of the literature was performed to identify and examine studies evaluating the diagnostic efficacy of CBCT imaging in endodontics [3]. In an effort to select studies evaluating the effects of CBCT on clinical diagnosis, decision making, and treatment outcomes, articles were categorized into one of six levels of efficacy based on the diagnostic efficacy hierarchical model (efficacy model) presented by Fryback and Thornbury [3,18,19]. Only studies defined as having a high level of efficacy [3,18] were chosen for analysis.

Table 1 sets out the six levels of diagnostic efficacy [18], and their further allocation to the low or high categories of efficacy [3], and the parameters required to be measured for each level [3,18,19].

Table 1. Diagnostic efficacy levels and categories of CBCT in endodontics [3,18].

Diagnostic Efficacy Category	Diagnostic Efficacy Levels	Efficacy Type	Efficacy Definition	Required Measured Parameters
Low	1	Technical efficacy	Technical quality of the images	Physical parameters (e.g., dose, spatial resolution, presence of artifacts)
	2	Diagnostic accuracy efficacy	Ciagnostic accuracy associated with interpretation of the images	Accuracy evaluation (e.g., Sensitivity, specificity, positive/negative predictive value)

Table 1. *Cont.*

Diagnostic Efficacy Category	Diagnostic Efficacy Levels	Efficacy Type	Efficacy Definition	Required Measured Parameters
High	3	Diagnostic thinking efficacy	Effect of obtained radiographic information on clinician's estimate of the probability that a patient suffers from a disease or health condition	Changes in diagnosis or prognostic assessment, before and after the CBCT evaluation
	4	Therapeutic efficacy	Effects of the radiographic information on patient management plan	Changes in treatment plan (e.g., institution of new therapy, avert the need for therapy)
	5	Patient outcome efficacy	Effect of obtained radiographic information on patient outcomes	Outcome parameters (e.g., success or survival rates, quality of life, complications)
	6	Societal efficacy	Impact of the imaging modality on society as a whole	Societal cost–benefit analyses

3. Criteria for Considering Studies

Our inclusion criteria for this review were as follows [3]:

1. The study evaluated the use of CBCT imaging for endodontic purposes.
2. The study included an assessment of at least one of the diagnostic efficacy criteria belonging to the high-level-efficacy category (levels 3–6) [3,18].
3. The study measured the parameters required for the evaluated level of efficacy (Table 1).

The exclusion criteria were as follows [3]:

1. Case reports, reviews, or studies that were not relevant to the topic of this study.
2. Studies that evaluated diagnostic efficacy levels that were categorized as low level (levels 1 or 2) [3].
3. Studies that did not provide meticulous information regarding the parameters required for the defined levels of diagnostic efficacy.

4. Search Methods for Identification of Studies

The following electronic databases were searched: MEDLINE using the PubMed search engine (http://www.ncbi.nlm.nih.gov/sites/pubmed (accessed on 1 January 2020)), Scopus (http://www.scopus.com (accessed on 1 January 2020)), and the Cochrane Library (https://www.cochranelibrary.com/central (accessed on 1 January 2020)).

The following keywords were used for the electronic search: endodontic, root canal, CBCT, and cone-beam computer tomography.

The Medical Subject Headings (MeSH) for each database was received as follows:

For PubMed:

((“endodontal”[All Fields] OR “endodontic”[All Fields] OR “endodontical”[All Fields] OR “endodontically”[All Fields] OR “endodontics”[MeSH Terms] OR “endodontics”[All Fields] OR (“dental pulp cavity”[MeSH Terms] OR (“dental”[All Fields] AND “pulp”[All Fields] AND “cavity”[All Fields]) OR “dental pulp cavity”[All Fields] OR (“root”[All Fields] AND “canal”[All Fields]) OR “root canal”[All Fields]) AND (“CBCT”[All Fields] OR “cone beam”[All Fields])) AND ((humans[Filter]) AND (English[Filter]))

For Scopus:

TITLE-ABS-KEY (“endodontic” OR “root canal” AND “CBCT” OR “cone beam computer tomography”) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SUBJAREA, “DENT”)) AND (LIMIT-TO (LANGUAGE, “English”))

For the Cochrane Library (Central):

(Endodontic OR root canal): ti,ab,kw AND (CBCT OR cone beam computer tomography):ti,ab,kw

After the removal of duplicates, the reference lists of related literature reviews that appeared in the PubMed search engine were screened manually for suitable articles that were not identified by the electronic search [3].

5. Data Collection and Analysis

5.1. Selection of Studies

The identified articles were primarily assessed for relevance by two independent observers (E.R. and T.G.), on the basis of their titles and abstracts. Possibly relevant studies were submitted to a full-text assessment for suitability. Controversial incidents were further discussed until an agreement was reached [3].

5.2. Data Extraction

Data were extracted from the selected articles by two independent reviewers (E.R. and T.G.). In cases of a dispute, the data were subjected to combined evaluation by the reviewers until an agreement was reached.

The diagnostic efficacy of the identified articles was categorized as: diagnostic thinking efficacy, therapeutic efficacy, patient outcome efficacy, and societal efficacy [3].

The articles were further categorized by study design as retrospective or prospective, and by their specific clinical implications as follows: treatment modality (non-surgical treatment or surgical treatment); tooth type (anterior teeth or posterior teeth); CBCT timing (the CBCT was conducted pre-, intra-, or post-operative); and by the CBCT effect (CBCT had a positive, no, or a negative effect).

The risk of bias of each category was calculated.

5.3. Methodological Quality Assessment

The methodological quality of each study was evaluated independently and in parallel by two reviewers (E.R. and T.G.) according to the methodological quality parameters specified in Table 2 [20]. Each parameter was assessed as adequate, inadequate, or unclear. They were then grouped into subcategories in order to verify the validity of the studies [20]:

1. Low risk of bias (i.e., studies that met at least six of the quality criteria).
2. High risk of bias (i.e., studies that met no more than five of the quality criteria).

In cases of a discrepancy between the classification given by the two reviewers, a third reviewer was consulted (I.T.) to obtain a consensus. The authors of the articles were contacted when necessary to request clarification or to provide missing information.

6. Results

Systematic Literature Search

The search covered all articles published between 2003 and January 2020. The results of the electronic databases search and the manual search are shown in Figure 1, which presents a flowchart of the systematic review process [21].

Initially, 1568 possible relevant articles were identified. Following a screening of the titles and abstracts and a full-text evaluation, only 22 articles [4,12–15,22–37] met the inclusion criteria and were included for further analysis.

Methodological Quality Assessment: Two studies were considered to have a low risk of bias [26,29], with the other twenty studies having a high risk of bias [4,12–15,22–25,27,28,30–38].

Figure 2 presents a risk of bias graph.

Study design: Six articles described retrospective studies, of which none had a low risk of bias, and six had a high risk of bias. Of the 16 articles describing prospective studies, 2 had a low risk of bias and 14 had a high risk of bias.

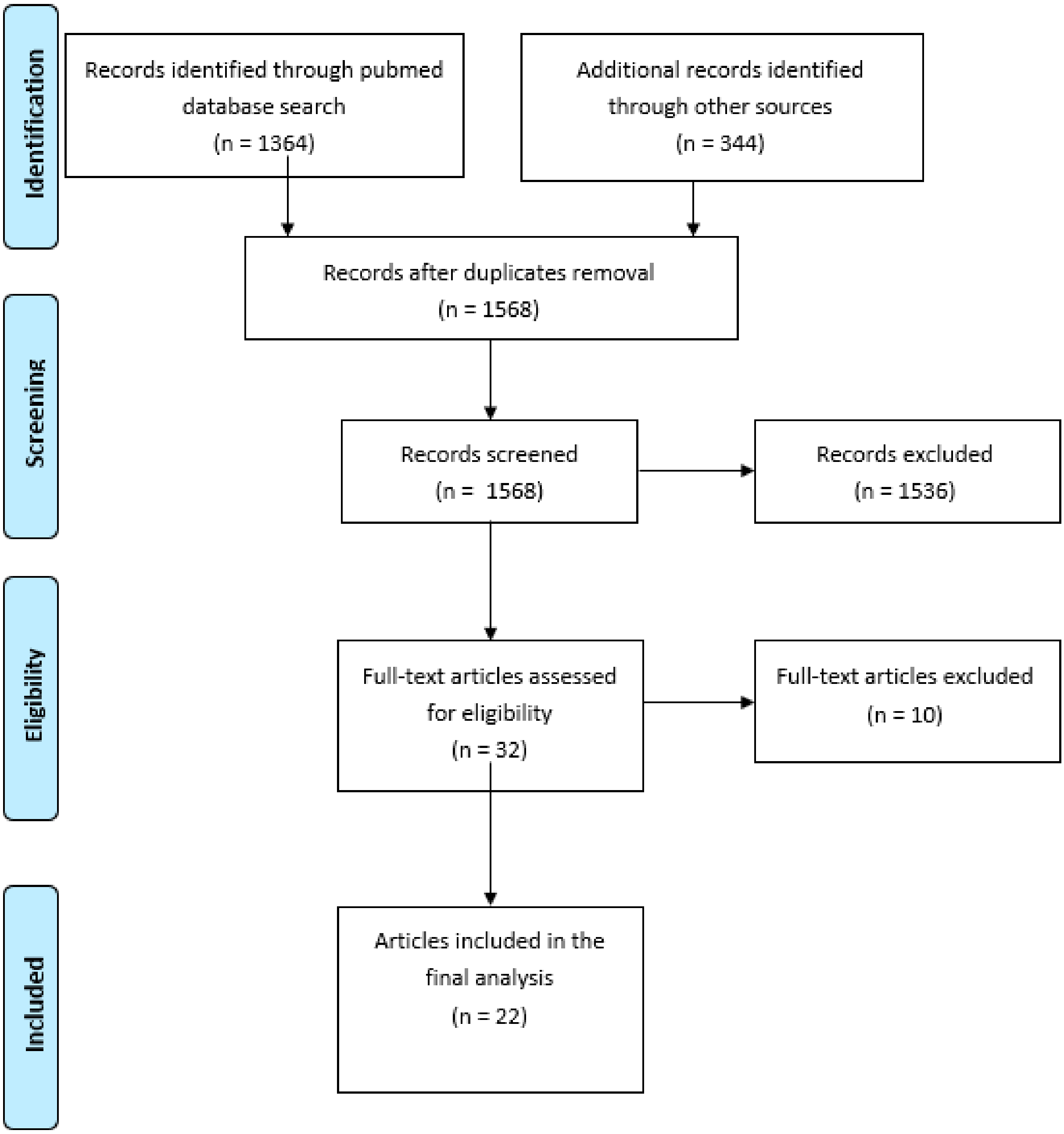

Figure 1. A flow chart of the systematic search process.

Treatment modality: Six studies investigated non-surgical treatment, with only one considered to have a low risk of bias. Eight studies investigated surgical treatment, with only one considered to have a low risk of bias. Two studies investigated both non-surgical and surgical treatment, and both were classified as having a high risk of bias. Six studies investigated diagnostic thinking or decision making, all of which were considered to have a high risk of bias.

Tooth type: Three studies investigated anterior teeth, all of which were considered to have a high risk of bias. Three studies investigated posterior teeth, and all were considered to have a high risk of bias. Twelve studies investigated both anterior and posterior teeth, with only two considered to have a low risk of bias.

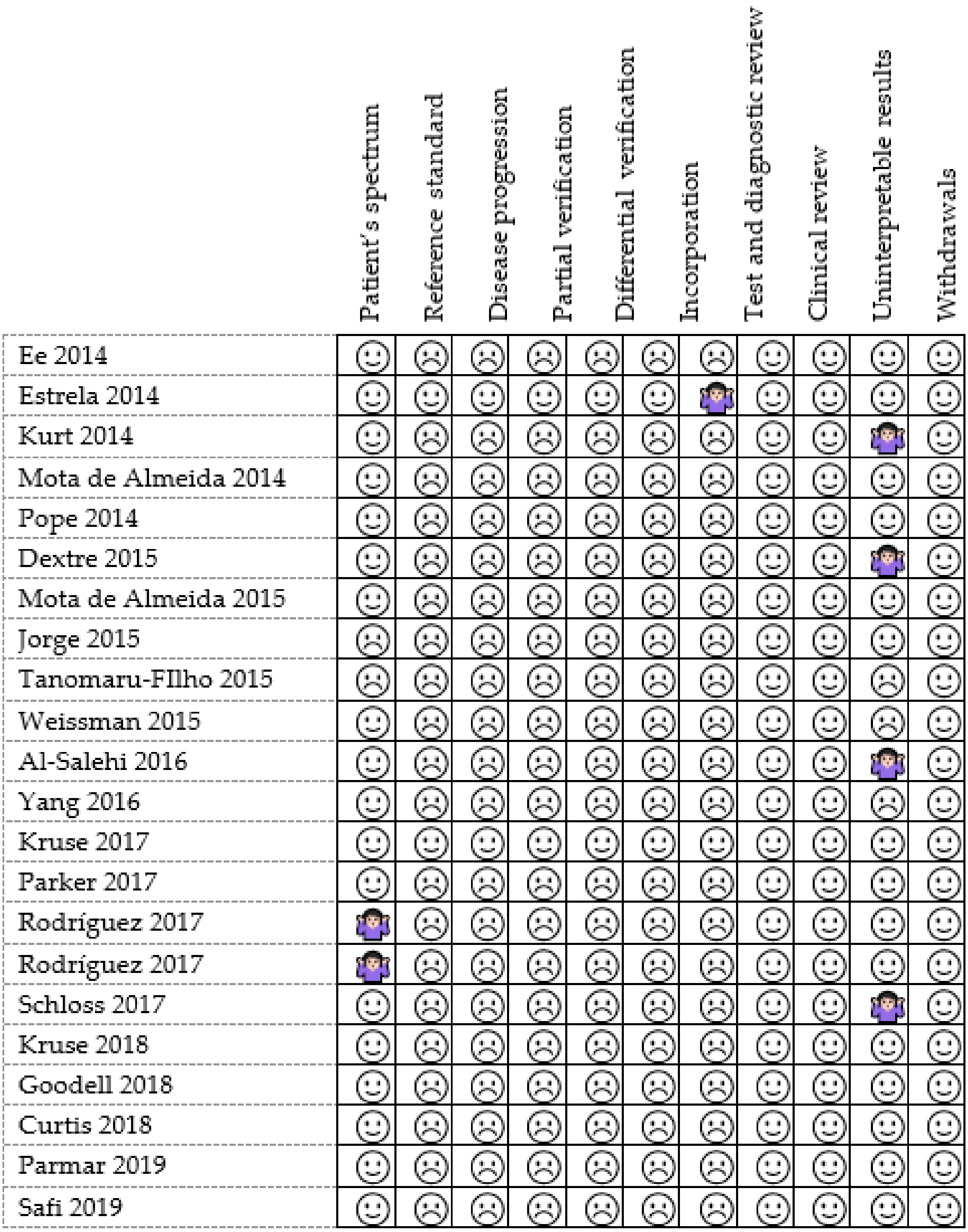

Figure 2. Risk of bias of the included studies: ☺—adequate, ☹—inadequate, 🤷—unclear.

CBCT timing: Pre-operative CBCT was conducted in 15 studies, with 2 studies considered to have a low risk of bias. One study, considered to have a high risk of bias, described post-operative CBCT. In six studies, the CBCT was conducted pre-and post-operatively, and all of them were considered to have a high risk of bias.

Proclaimed CBCT effect: Fifteen studies concluded that the CBCT scan had an effect on the subject investigated, and seven studies concluded that the CBCT scan had no effect.

Table 2 presents the characteristics of the articles reviewed.

Table 2. The characteristics of the included studies.

Study	Study Design	Treatment Modality	Tooth Type	CBCT Timing	CBCT Effect	Efficacy Level	Risk of Bias
Ee 2014 [34]	Retrospective	Diagnostic Thinking	Anterior/Posterior	Preoperative	Yes	4	High
Estrela 2014 [26]	Prospective	Non-surgical	Anterior/Posterior	Preoperative	No	3	Low
Kurt 2014 [33]	Prospective	Surgical	Posterior	Preoperative	Yes	5	High
Mota de almeida 2014 [27]	Prospective	Diagnostic Thinking	Anterior/Posterior	Preoperative	Yes	4	High
Pope 2014 {34}	Retrospective	Surgical	Anterior/Posterior	Preoperative	No	3	High
Dextre 2015 [35]	Retrospective	Non-Surgical	Anterior/Posterior	Postoperative	Yes	3	High
Mota de almeida 2015 [37]	Prospective	Diagnostic Thinking	Anterior/Posterior	Preoperative	Yes	3	High
Jorge 2015 [36]	Prospective	Surgical	Anterior	Preoperative/ Postoperative	No	3	High
Tanomaru-Filho 2015 [28]	Prospective	Surgical	Anterior	Preoperative/ Postoperative	No	3	High
Weissman 2015 [22]	Retrospective	Non-Surgical	Anterior/ Posterior	Preoperative	Yes	3	High
Al-Salehi 201[23]	Prospective	Diagnostic Thinking	Unknown	Preoperative	No	3	High
Yang 2016 [24]	Prospective	Non-Surgical	Posterior	Preoperative	Yes	5	High
Kruse 2017[29]	Prospective	Surgical	Unknown	Preoperative	No	3	Low
Parker 2017 [30]	Prospective	Non-Surgical	Posterior	Preoperative	Yes	4	High
Rodriguez 2017 [31]	Prospective	Diagnostic Thinking	Anterior/ Posterior	Preoperative	Yes	4	High
Rodriguez 2017 [32]	Prospective	Diagnostic Thinking	Anterior/ Posterior	Preoperative	Yes	4	High
Schloss 2017 [4]	Prospective	Surgical	Anterior/ Posterior	Preoperative/ Postoperative	Yes	3	High
Kruse 2018 [25]	Prospective	Surgical	Anterior/ Posterior	Preoperative	Yes	3	High
Goodell 2018 [13]	Retrospective	Surgical/ Non-Surgical	Unknown	Preoperative	Yes	4	High
Curtis 2018 [12]	Retrospective	Surgical/ Non-Surgical	Unknown	Preoperative/ Postoperative	Yes	3	High
Parmar 2019 [14]	Prospective	Surgical	Anterior	Preoperative/ Postoperative	No	3	High
Safi 2019 [15]	Prospective	Surgical	Anterior/ Posterior	Preoperative/ Postoperative	No	3	High

7. Discussion

The integration of clinical examination and diagnostic imaging forms the basis for endodontic diagnosis, decision making, treatment planning, and outcome assessments [3,38]. In recent years, CBCT imaging has become a common diagnostic tool in endodontics. If radiographic imaging is required, it should be carried out with a radiation dose as low as reasonably achievable (ALARA). The effective dose of CBCT scans is higher compared to that used for periapical radiography. The effective dose varies between CBCT scanners, and depending on the region of the jaw being scanned, exposure settings of the scanner, the size of the field of view (FOV), exposure time (s), tube current (mA), and the energy potential (kV) [39,40].Thus, due to its inherent risks of radiation, this use should be justified on an individual basis to ensure that the benefits to the patient exceed the risks [3,41–43].

An estimation of the predicted benefits to the patient should be based mainly on the efficacy of CBCT as a diagnostic imaging tool for the precisely needed endodontic indication [2,3,18,41,44].

The diagnostic efficacy of a technique is determined by the likelihood of a beneficial outcome when the procedure is conducted under optimal conditions [19]. Efficacy studies offer a means of understanding and comparing the usefulness of diagnostic imaging examinations and procedures [18]. In order to evaluate the influence of diagnostic imaging, it is important to determine the eventual profit of the procedure to the patient in a hierarchical manner. However, this benefit may be subjective and influenced by different perspectives. For example, the ability of diagnostic imaging to provide the finest and most accurate images does not necessarily mean that it will also improve our diagnosis ability or the treatment outcomes [2,18].

The decision to recommend the use of CBCT in endodontics should be supported by studies evaluating its efficacy in the specific clinical situation. Fryback and Thornbury [18] presented a broad, organized method for appraisal of the literature that employs a diagnostic efficacy hierarchical model with a number of levels of evidence assigned to a diagnostic test [18]. This model was used in previous studies to evaluate the diagnostic efficacy of CBCT in endodontic treatment [3,11]. The levels of imaging efficacy relate not only to an evaluation of the technical characteristics of the imaging modality (defined as low levels of efficacy), but also to the efficacy of the technique to help a practitioner make decisions and plan treatment, and the eventual treatment outcome (defined as high levels of efficacy) [3,18].

Traditionally, CBCT has been used mainly for pre-operative evaluations [1,26,27,29–32,45,46], although the technique can also be used intra-operatively to support the course of treatment [5,47,48] and post-operatively to assess the treatment outcomes [29,35,36]. In six of the studies reviewed, CBCT was performed both pre- and post-operatively [4,12,14,15,28,36].

Intra-operative use of CBCT was found to be beneficial in the treatment of calcified canals in posterior teeth [24] and in its capacity to locate the MB2 canal in maxillary molars [30].

In two studies, CBCT was reported to be more effective than periapical radiography in detecting and following-up periapical lesions [22,35]. However, other results suggest a more questionable contribution of CBCT to the results. Resorption related to root canal infection and apical periodontitis was identified in 61.4% of the cases studied by SEM, whereas only 23.9% were detected by CBCT images [26]. Similarly, there was a significant variation in the PDL space of a healthy tooth as examined by CBCT, and about 19% of cases were wrongly diagnosed as having apical lesions when they were healthy, resulting in an overestimation of disease and overdiagnosis [34].

CBCT is specifically indicated for surgical endodontic treatments, for pre-surgical diagnosis, and treatment planning, and is suggested as a diagnostic method to assess the treatment outcome. We identified eight studies that investigated surgical treatment. In the study by Kruse [25], the use of CBCT for long-term follow-up after surgical endodontics resulted in an increased diagnosis of persisting or recurrent apical periodontitis, which frequently led to the proposal of more invasive treatment procedures.

Schloss et al. [4] and Tanomaru et al. [28] showed that CBCT analysis enabled a more accurate appraisal of periapical lesions and healing of endodontic microsurgery than periapical X-ray. However, in another three studies, both CBCT and periapical radiographs produced similar assessments of healing after periapical surgery [14,15,36].

In addition, a surgical study combined with the histological gold standard stated that not all lesions detected by CBCT represented periapical inflammatory lesions [29].

Regarding treatment outcome, preoperative CBCT examination was reported to positively contribute to treatment outcomes.

Five out of six studies investigating diagnostic thinking or decision making reported that CBCT had a considerable influence on diagnostic thinking and decision making [27,31,32,37,38]. However, the remaining study concluded that the information obtained from CBCT influenced the radiological findings and the final diagnosis in only a minority of cases, and there was no strong evidence that CBCT increased the observers' certainty or was helpful in making a diagnosis [23].

Regarding the tooth group, 3 studies investigated anterior teeth, 3 studies investigated posterior teeth, and 10 studies investigated both anterior and posterior teeth. CBCT was reported to have a minor effect on the diagnosis of anterior teeth [14,28,36] but was reported to assist during the treatment of posterior teeth, where it changed the treatment outcome [24,30,33]. In 9 of the 10 studies in which both anterior and posterior teeth were evaluated, the authors reported that the CBCT evaluation modified the diagnosis or treatment plan [4,22,25,27,31,32,35,37,38], but in the last study, there was no influence on the treatment plan [15]. In addition, in two of the studies, CBCT had a questionable effect on the diagnosis [26,34].

Even when a literature search identifies studies claiming to justify the use of CBCT for a specific endodontic indication, it is important to assess whether these studies are of acceptable methodological quality [20]. Methodological quality assessments should be based on a structured process of analyzing the risk of bias in the study This can be achieved by considering a set of quality items, such as checking whether the variety of patients is representative of the patients who will receive the test in practice and whether a valid reference standard was used to determine the presence or absence of the target condition (disease status) [20]. The results of these specific quality assessments can be used to determine the level of risk of bias of a study [20].

In the current study, the majority of the identified articles (n = 20, 90%) had a high risk of bias, and only two articles were identified as having a low risk of bias.

The results of our analysis indicate that the available endodontic literature assessing the effects of CBCT on diagnostic thinking, decision making, and treatment outcomes is limited, and the reliability of these studies is jeopardized by potential systematic errors or deviations from the truth, either in the results or in the inferences [20].

Well-designed studies are essential to inform endodontists and clinicians regarding diagnostic thinking, decision making, and treatment outcome assessment with CBCT imaging. Further in vivo research is essential and should be conducted in comparison to gold-standard techniques. The main problem is the difficulty in conducting comparative in vivo clinical research both in terms of diagnosis and outcome assessment due to ethical, practical, and clinical concerns.

8. Conclusions

The effects of CBCT on diagnostic thinking, decision making, and treatment outcomes in endodontics is unclear and is mostly based on studies with a high risk of bias. Additional well-designed studies are required to evaluate the validity of CBCT for endodontic purposes.

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Abbreviations

CBCT Cone-beam computed tomography

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