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Impact of cone beam computed tomography (CBCT) on diagnostic thinking in endodontics of posterior teeth: A before- after study

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ABSTRACT

Objectives: The aim of this study was to evaluate the impact of limited volume CBCT upon diagnosis as part of endodontic management of posterior teeth. The null hypothesis that CBCT does not make any difference in endodontic diagnosis was tested.
Methods: A single-centre "before-after" study was conducted in a secondary healthcare establishment. Eligible patients were all adults aged 18 years or over who were referred to a specialist endodontic unit. Further inclusion criteria were that the cases were either re-treatment or *de novo* root canal treatment where the anatomy was judged to be complex. Exclusion criteria included vulnerable groups and *de novo* endodontic treatment with uncomplicated root canal anatomy. As well as a full history and clinical examination, a high quality colour photographic intraoral image, two paralleling technique periapical radiographs and limited volume CBCT examination were carried out for each patient. All components, except the CBCT dataset, were combined into a Powerpoint presentation and assessed by 4 observers. A questionnaire was designed for the observers as part of the study.
Results: CBCT information only changed the radiological findings and the final diagnosis in a minority of cases. There was no clear evidence that CBCT increases the confidence of observers or that CBCT was helpful in making a diagnosis.
Conclusions: Routine use of CBCT cannot not be justified on the basis of a change in diagnosis and carefully selected use is appropriate.
Clinical significance: CBCT is being increasingly used in the field of endodontics. The benefits gained from the use of CBCT must be carefully balanced against the increased radiation dosage. Determination of selection criteria for the use of CBCT in endodontics is, therefore, essential.

1. Introduction

Cone beam computed tomography (CBCT) represents a major advance in the imaging of the dental and maxillofacial region. It is not surprising, therefore, that all dental specialties have explored its use for imaging dental problems, including in endodontics [1,2]. The limitations of conventional intraoral radiography in endodontic practice, relative to CBCT, have been highlighted [1]; two-dimensional images are limited in terms of diagnostic yield by anatomical superimpositions and distortions, as well as by exposure and processing errors. On the other hand, conventional intraoral radiographs are cheap, have a low radiation dose, have higher resolution than CBCT images and may often be sufficient for diagnosis. CBCT is expensive, invariably gives a higher radiation dose than conventional radiographs and suffers from artefacts [3–5]. Furthermore, CBCT is a collective term for a large number of imaging systems [6] which differ greatly in image quality, radiation dose and diagnostic potential and generalisations about its clinical value are not valid.

There is evidence that some CBCT systems may have greater diagnostic performance than conventional intraoral radiographs for various tasks relevant to endodontics, notably identification of root canal systems, resorptions, root fracture and periapical pathosis. Much of this research can be criticised for being performed in a laboratory setting on extracted teeth, using experimental models which do not adequately reproduce the patient and which lack the artefacts that affect clinical images. The design of research carried out on patients can also be challenged

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because of risk of bias: for example, they include “diagnostic accuracy” studies without a reference standard [7]. Fryback and Thornbury [8] developed a model of diagnostic efficacy, with the objective of encompassing the whole contribution of radiology to patient management. They explained that traditional assessments of radiological systems concentrated on image quality and upon sensitivity, specificity and other parameters of diagnostic accuracy. They highlighted, however, that diagnostic radiology is just part of a wider system “whose goal is to treat patients effectively and efficiently”. For example, it is possible to have an imaging system which offers better image quality and diagnostic accuracy than another but which fails to change outcomes for patients. They addressed this by defining a six-level hierarchical model of efficacy which extended from technical measures of image quality through to societal impact (Table 1). In order to understand the value of a radiological method in clinical practice, a comprehensive understanding of the diagnostic efficacy is desirable, encompassing information at each of these levels. Clinical research related to dental CBCT at the higher levels of diagnostic efficacy is, however, extremely limited.

Guideline documents on CBCT in endodontics are in broad agreement that, on the basis of current evidence at the time they were written, CBCT should be reserved for cases where conventional intraoral radiographs fail to answer the diagnostic question for which imaging was undertaken [9–12]. The studies of Mota de Almeida et al. [13,14] found that CBCT examinations, selected on the basis of the European Commission guidelines [10], developed by the SEDENTEXCT project, had a significant impact on endodontic diagnosis and treatment planning although for a substantial number of teeth and patients there was no value. There is, however, a lack of knowledge of the impact of using CBCT in a less restricted patient sample. The European Commission document provided a guideline which suggested that localised CBCT may be indicated in selected cases in a variety of situations, but suggested that its use would be most probably applicable in multi-rooted teeth [10].

It seems reasonable to expect that the greatest chance of seeing a diagnostic benefit from using CBCT in an endodontic context would be in more complex cases, particularly in multi-rooted posterior teeth referred for specialist assessment. Consequently, the aim of this study was to measure the impact of limited volume CBCT upon diagnostic thinking as part of endodontic management of posterior teeth (molars and premolars) referred for an opinion to hospital-based endodontic specialists.

2. Material and methods

The reporting of this study conforms as far as possible to the CONSORT statement, with suitable adjustment for the particular study design informed by Meads & Davenport [15].

2.1. Study design

This was a single-centre “before-after” study conducted in a secondary healthcare establishment (Dental Hospital) in the United Kingdom. There were no changes to the study design after commencement.

2.2. Ethics

Ethical approval was obtained from the National Research Ethics Service (North West 1 Research Ethics Committee-Cheshire, UK).

2.3. Participants

Eligible patients were all adults aged 18 years or over who were referred from general dental practices to a specialist endodontic unit for opinion and management of premolar or molar teeth. Additional inclusion criteria were that the cases were either re-treatment or were *de novo* root canal treatment where the anatomy was judged to be complex e.g. sclerotic canals. Exclusion criteria were vulnerable groups, including prisoners, mentally deficient persons and severely injured patients, pregnant patients, anterior (incisor and canine) teeth and *de novo* endodontic treatment with uncomplicated root canal anatomy. Informed consent was obtained from each patient during their initial consultation with the chief investigator (registered specialist in Restorative Dentistry). They were provided with a patient information sheet at the time of their initial consultation. Patients handed in their consent form normally within 6 weeks of their consultation.

Table 1
The hierarchical model of efficacy of diagnostic imaging, described by Fryback & Thornbury [8], with some typical measures of analysis.

Efficacy level	Measures of analysis
Level 1: Technical efficacy	Spatial resolution. Contrast detail resolution. Linear/ angular measurement accuracy Accuracy of grey scale reproduction of true density differences. Artefact severity.
Level 2: Diagnostic accuracy efficacy	Sensitivity, specificity. Positive and negative predictive values. Area under ROC curves.
Level 3: Diagnostic thinking efficacy	Proportion of cases in a series in which image judged to be “helpful”. Difference in clinicians’ subjective estimated diagnosis probabilities pre- and post- imaging in a case series.
Level 4: Therapeutic efficacy	Proportion of cases in a series for which image judged to be “helpful” in planning treatment. Proportion of cases in which pre-imaging treatment plans were changed after imaging.
Level 5: Patient outcome efficacy	Proportion of patients improved with the imaging test compared to without the imaging test. Morbidity avoided by using imaging. Change in quality of life indices resulting from using imaging.
Level 6: Societal efficacy	Benefit- cost analysis from a societal standpoint. Cost-effectiveness analysis from a societal standpoint.

2.4. Study setting

The study took place at a dental school in a major UK city of around 500,000 inhabitants set centrally within a large urban area with a population of 2.25 million. The dental school is a National Health Service hospital providing a full range of dental and oral care, including a consultant-led specialist endodontic service. It receives referrals for opinions and treatments from general dental practitioners (GDPs) from throughout the urban area and beyond. Treatments are performed by NHS consultants and specialist trainees, postgraduate and undergraduate students.

2.5. Interventions

A full history and clinical examination was performed for each patient (n = 34). Subsequently, for each patient, the following material was obtained:

A high quality colour photographic intraoral image. Two paralleling technique periapical radiographs of the tooth in question to permit parallax. Radiographs were taken using a Planmeca Intra-oral dental X-ray set, with rectangular collimation and a 20 cm focus-to-skin distance, operated at 66 kV_{cp}, 8 mA, with an exposure time selected by the radiographer and using Rinn XCP film holders (Dentsply-Rinn, Elgin IL, USA). The image receptor was the Vistascan Mini phosphor plate system (Dürr Dental AG, Bietigheim-Bissingen, Germany).

A limited volume CBCT examination. The CBCT scanner used was 3D-Accuitomo F170 (J. Morita, Tokyo, Japan), operated at 90 kV, with the tube current-exposure time product as deemed suitable by the radiographer, using a 4 cm by 4 cm field of view and a 360° rotation.

A summary of the clinical history and examination findings, the intra-oral photograph, the intraoral radiographs and the CBCT dataset formed a clinical scenario for each patient. Three such clinical scenarios are shown in Fig. 1. All components except the CBCT dataset were combined into a Powerpoint presentation containing words and images. The CBCT dataset was exported to CD with the manufacturer's "One Volume Viewer" software. The clinical scenarios were assessed by four observers. All observers were given one hour of training by one of the investigators (Registered Specialist in Dental and Maxillofacial Radiology) on the CBCT software. The observers were dentists otherwise uninvolved with the clinical care of the patients. For the study, observers were free to examine the full CBCT dataset using the viewing software as they wished. Observation of scans was performed in a clinical setting to reproduce reality as much as possible. This setting was a clinic within a dental hospital at the chairside using the PC and monitor normally used by clinicians for patient care.

A questionnaire was designed for the observers as part of the study. The case scenarios, for the 34 patients, were examined by each observer individually on two dates three months apart. On one date, all the information including CBCT images was given to each observer but, on the other date, the CBCT images were withheld. The purpose of the time separation between the two assessments was to minimise any risk of the observers giving an opinion on each case that was contaminated by the memory of the previous viewing. The patients were subsequently treated by postgraduate endodontic students, under the supervision of Endodontic/Restorative specialists.

The questionnaire consisted of five questions related to diagnosis;

1. What is your provisional diagnosis based on the clinical history and photographic images alone?
2. What are your radiological findings?
3. What is your final diagnosis based on clinical history, clinical photographs and radiological findings?
4. How confident are you of your final diagnosis?
5. How helpful were the radiographic images in determining the final diagnosis?

For questions 1–3, the observers were given a number of possible responses to select from (Table 2) and could select one or more responses.

The responses to questions 4 were recorded on a Likert scale, assigning them

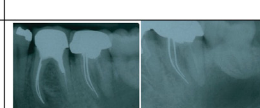
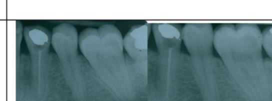
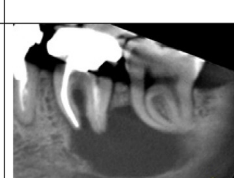
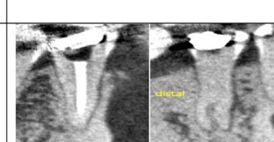
	Case 1	Case 2	Case 3
Patient details	Female 45 referred by GDP Long history of pain upper left quadrant	Female 38 referred by GPP Abscess 3 months ago in lower left quadrant Completed a course of antibiotics	Female 36 referred by GDP 34 root filled nine months ago Still occasional discomfort
Tooth/ symptoms	26 tender to percussion Buccal and palatal cortex tender and evidence of diffuse swelling buccally	37 tender to percussion Buccal sulcus tender	34 slightly tender to percussion
Clinical photograph			
Conventional radiographs			
CBCT cross-section			

Fig. 1. Three case scenarios.

Table 2
Questions 1, 2 and 3 – possible answers to select from.

Question 1	Question 2	Question 3
Pulpitis	Periapical radiolucency	Pulpitis
Periapical periodontitis	Periapical radiopacity	Periapical periodontitis
Root fracture	Root fracture	Root fracture
Perforation	Root perforation	Perforation
Internal resorption	Internal resorption	Internal resorption
External resorption	External resorption	External resorption
Caries	Periodontal bone loss	Caries
Periodontal disease	Caries	Periodontal disease
Perio/Endo lesion	Separated instrument	Perio/Endo lesion
Other	Other	Other
Unable to give provisional diagnosis		Unable to give final diagnosis

values between 1 and 5 (1 being not confident and 5 very confident). For each clinical scenario, the confidence in diagnosis scores recorded before and after the availability of CBCT were compared. Similarly, a Likert scale was also completed for question 5.

2.6. Statistical analysis

The responses collated from the returns, on each of the two dates, were tabulated for analysis. The null hypothesis that CBCT does not make any difference in endodontic diagnosis was tested. For questions 1, 2 and 3 kappa statistical test as well as changes in diagnostic thinking with availability of CBCT were evaluated. For each observer, the proportion of cases where the availability of CBCT changed the final diagnosis and the complementary proportion for which there was no change in final diagnosis was calculated. Inter-observer agreement was measured using kappa statistics. Intra and inter observer agreement for provisional diagnosis (question 1), made without access to radiological images and therefore identical at both assessments, was also assessed using kappa statistics. For the last two questions (4 and 5), Wilcoxon sign rank test was used as the data did not follow a normal distribution. This was verified using Shapiro-Wilk statistical test. The data were analysed using SPSS package version 15.0.

3. Results

The patient sample (n = 34) was made up of 9 upper molars, 13 lower molars, 9 upper premolars and 3 lower premolars. The case mix was 18 endodontic re-treatments, 2 resorption (external cervical and external replacement resorption) and14 complex *de novo*.

With regard to provisional diagnosis, which did not involve radiological images (question 1), the responses of the four observers made at baseline and repeated again after three months were not entirely consistent. For this, a kappa analysis showed the intra-observer reliability to be 0.68, 0.88, 0.82, 0.68 for observers 1,2,3 and 4 respectively. Intra-observer reliability was tested for provisional diagnosis as all four observers examined exactly the same information on two occasions and three months apart. The inter-observer reliability (for all four observers) ranged from 0.56 (moderate agreement) to 0.76 (excellent agreement).

Table 3
Change in diagnostic thinking with the availability of CBCT (presented as a proportion of total number of cases).

	Observer 1	Observer 2	Observer 3	Observer 4
Radiological Findings	11/34	13/34	5/34	11/34
Final Diagnosis	15/34	9/34	7/34	8/34

Table 3 shows the numbers of cases for which there was a change in radiological findings and final diagnosis between the two assessments (with and without the availability of CBCT- Questions 2 and 3). Of these, changes in periapical periodontitis were most prominent. For all four observers, there was a change in radiological findings in a minority of cases. Inter-observer agreement ranged from 0.47 (moderate agreement) to 0.65 (good agreement). Similarly the availability of CBCT changed final diagnosis in a minority of cases, ranging from as low as 7 out of 34–15 out of 34. Inter-observer agreement (for all four observers) ranged from 0.47 (moderate agreement) to 0.76 (excellent agreement).

Changes in diagnosis of periapical periodontitis are shown in Table 4 and Fig. 2. All show an increase in diagnosis of periapical periodontitis, although only dramatically for Observer 1.

For confidence in diagnosis (question 4) and helpfulness in diagnosis (question 5), the results are summarized in Tables 5 and 6 respectively. Only one observer scored a statistically significant increase in confidence regarding their final diagnosis with the availability of CBCT. Similarly, only one observer, although not the same individual, reported a significant increase in his score for helpfulness of the diagnostic images when CBCT was available.

4. Discussion

The cases in this study were collected prospectively and, subject to patient consent, consecutively. Consequently the case mix was likely to be representative of the typical range of more challenging cases seen by a hospital-based specialist in endodontics. Other studies in the literature which have addressed diagnostic thinking efficacy of CBCT in an endodontic context [13,16–18] have used different case selection processes which, in some cases, are unclear or which may lead to selection bias. For example, Ee et al. [18] selected equal numbers of cases with a specific problem within six diagnostic categories. Pigg et al. [16] report a study of a highly specific patient group of suspected atypical odontalgia which is not relevant to the wider endodontic context, while the study of Abuabara et al. [17] is similarly focused on a single diagnostic task of identifying MB2 root canals. The study of Mota de Almeida et al. [19], however, used a case selection process which was similar, although not identical, to ours and comparisons with the results of our study are particularly appropriate. One methodological difference with their study is that whereas Mota de Almeida et al. [19] looked at the change in diagnosis when using CBCT

Table 4
Diagnosis of periapical periodontitis with and without the availability of CBCT.

	Observer 1	Observer 2	Observer 3	Observer 4
Before CBCT	12	18	26	26
After CBCT	24	20	29	28

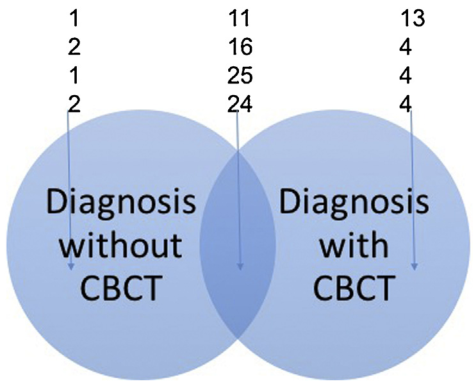


Fig. 2. Diagnosis of periapical periodontitis with and without CBCT. (Observers 1–4 from top to bottom of the Figure).

compared with clinical and conventional radiographic diagnosis, we also considered the change in diagnosis when using conventional imaging over clinical diagnosis alone.

It must be acknowledged that the method used in this "before-after" design, of providing observers with a case scenario based on clinical information, photographs and radiological information, is not the same as real history-taking and examination of a patient. Clinical examination performed by multiple observers is, however, challenging for the patient volunteers and methodologically open to criticism. It would have required a second patient attendance to satisfy the "before" and "after" assessments, with no guarantee that the patient would supply the same clinical information or that clinical examination would yield the same results. The scenario method is the only practicable way of conducting this kind of research.

The intra observer comparisons of provisional diagnoses made by the four observers, made without radiological information and based solely on clinical findings, were inconsistent, with two examiners performing relatively well and two less so. This demonstrates the variability in performance between dentists in clinical diagnosis, as does the even more variable inter observer reliability. These findings, although not central to the study, underline the importance of having multiple participants as observers in diagnostic studies. Research based upon the findings of single observers, such as those of Abuabara et al. [17] and Mota de Almeida et al. [13,19], run the risk of findings only being applicable to the individual involved and not to a wider community of dentists.

Table 5
Confidence of final diagnosis made by the four observers before and after the availability of CBCT images for the 34 case scenarios. For each case, the confidence in diagnosis scores recorded before and after the availability of CBCT were compared. A negative rank indicates a higher confidence score when only conventional radiographs were available, while a positive rank indicates a higher confidence score when CBCT was available.

Observer	Confidence before and after availability of CBCT	Summary (p-value)	Mean score Conventional	Mean score CBCT
One	5 negative ranks 12 positive ranks 17 ties 34 Total	No significant difference in the proportions of cases for which a higher confidence score was seen with and without the availability of CBCT (p = 0.531)	4.16	4.26
Two	6 negative ranks 4 positive ranks 24 ties 34 Total	No significant difference in the proportions of cases for which a higher confidence score was seen with and without the availability of CBCT (p = 0.527)	3.76	3.71
Three	11 negative ranks 13 positive ranks 10 ties 34 Total	No significant difference in the proportions of cases for which a higher confidence score was seen with and without the availability of CBCT (p = 0.172)	3.35	3.68
Four	4 negative ranks 14 positive ranks 16 ties 34 Total	Proportion of cases for which a higher confidence score was seen with availability of CBCT was significantly higher (p = 0.020)*	3.79	4.35

Table 6
Helpfulness of the radiological information as assessed by the four observers before and after the availability of CBCT images. For each case, the helpfulness scores recorded before and after the availability of CBCT were compared. A negative rank indicates a higher score for helpfulness when only conventional radiographs were available, while a positive rank indicates a higher score for helpfulness when CBCT was available.

Observer	Helpfulness before and after availability of CBCT	Summary (p-value)	Mean score Conventional	Mean score CBCT
One	7 negative ranks 13 positive ranks 14 ties 34 Total	Scores for helpfulness not significantly different with or without CBCT availability (p = 0.530)	3.35	3.53
Two	12 negative ranks 2 positive ranks 20 ties 34 Total	Scores for helpfulness significantly lower with availability of CBCT (p = 0.008)*	3.82	3.53
Three	6 negative ranks 16 positive ranks 12 ties 34 Total	Scores for helpfulness significantly higher with availability of CBCT (p = 0.009)*	3.44	3.88
Four	7 negative ranks 10 positive ranks 17 ties 34 Total	Scores for helpfulness not significantly different with or without CBCT availability (p = 0.368)	4.26	4.41

* $p < 0.05$.

While there is no apparent consensus on the right number of observers required in radiological studies, five seem to be frequently used and was originally planned for our study. It is unfortunate that one of our prospective observers withdrew from the study before completing all tasks and, in retrospect, recruitment of more observers would have been sensible to anticipate the risk of withdrawals.

Our observers were all general dental practitioners. It is important to bear in mind that the impact of the information available from CBCT may have been different if the observers had been specialist endodontists. Nonetheless, endodontic procedures are commonly performed by non-specialists and CBCT equipment is increasingly accessible by general dentists, so the results have "real world" applicability. Although involvement of a specialist dental radiologist is a requirement of owning and using a CBCT machine in some countries, for example in Sweden, in others it is not. In the UK it is possible for a dentist to start using CBCT with no additional training in interpretation, although non-enforceable guidelines [20] suggest attending a short course. One of the 34 cases was external cervical resorption (ECR). CBCT has demonstrated good diagnostic ability in the identification of ECR and the extent of the lesion which influences treatment [21]. All the observers identified the case as a resorptive lesion, but did so with using either conventional radiography or CBCT. They did not comment further as to the specific type of resorption which was apparent on the CBCT images. Obviously with only a single case of external cervical resorption in our sample, it is impossible to draw any conclusions about the value of CBCT in this specific context.

Examination of Table 3 shows that CBCT information only changed the radiological findings and the final diagnosis in a minority of cases, although there was considerable variation in the proportions between observers, ranging from 15% to 38% for radiological findings and 21% to 44% for final diagnosis. Where CBCT clearly made a difference was in the diagnosis of periapical inflammatory pathosis (Table 4). Thus, in the majority of patients for whom there was no change in diagnosis, there was no benefit from the financial cost and X-ray exposure of a CBCT examination. It is probably impossible to define selection criteria for CBCT which accurately differentiate between those for whom CBCT will be useful and those for whom it will not, but there is evidently scope for further research efforts in this area so that the proportion of patients benefiting from CBCT would be higher. Mota de Alameida et al. [19] used the European Commission guidelines to select patients for inclusion in their study. They found that using CBCT led to a change in diagnosis in 35% of cases, which fits with our results. Of course, their study design did not perform CBCT examination on patients who were excluded on the basis of the European guidelines, so it is possible that some of those patients also may have benefited from CBCT. It should also be noted that each case in their study was examined and a diagnosis made by a single observer. Ee et al. [18] found a change in diagnosis with the availability of CBCT in a substantial minority of cases (40%–46.6% of cases). As explained above, however, the different case selection method makes comparisons between their study and ours meaningless and the applicability of their results to a wider context dubious.

The results for observer confidence in diagnosis before and after the availability of CBCT (Table 5) were surprising in demonstrating an increased confidence for only one of the four observers. Other studies, in different dental contexts, have shown that availability of CBCT increases confidence of clinicians [14]. It is difficult to say why this was not the case here. Perhaps the cases were particularly challenging and beyond the experience of the dentists, although this seems unlikely when all had many years' experience in dental practice. Alternatively, the findings could be attributed to the observer being confused when interpreting the CBCT images [13,22]. Whatever the reason, it is apparent that there is no automatic increase in diagnostic confidence amongst dentists when using CBCT in an endodontic context. It is an interesting question whether confidence of clinicians is important in itself, as this does not automatically lead to improvement in patient outcomes. If an X-ray imaging improves clinician confidence without any benefit to the patient, it cannot be justified.

Table 6 provides information on "helpfulness" of the radiological images with and without availability of CBCT. The results were highly variable and, as in the case of clinician confidence, do not provide a resounding endorsement of CBCT. Even for the observer for whom a significant improvement was recorded (observer 3) the numerical difference on the Likert scale was less than a single unit, raising the question of whether the statistically significant difference was clinically significant. The helpfulness score in the current study is essentially the same as the usefulness assessment made by the observers in the study of Mota de Alameida (19). Our study, however, assessed this for conventional radiographs and for these with the addition of CBCT. Mota de Alameida [19] found that the observers rated the CBCT examination as providing "information that significantly improved my understanding of the patient's problem" ("D4") in 77% of cases. While the mean scores of our examiners were all greater than 3, the mid-point of our Likert scale and comparable to the D4 score used by Mota de Alameida [19], we found similar scores for the helpfulness of radiological images regardless of the availability of CBCT. In retrospect, to make sense of these findings, it would have been valuable to extend the questionnaire or perform a post-study interview with observers.

The CBCT equipment used in this study is capable of providing high image quality, as demonstrated by research on technical efficacy [23], and is often used in research studies. There is, however, a wide variation in image quality amongst the CBCT equipment on the market and the results seen in this study might be different for alternative machines. Bearing in mind that our CBCT equipment provides high image quality, it would seem, however, unlikely that equipment with equivalent or inferior image quality would lead to demonstrably greater impact on diagnostic thinking or perceived helpfulness or confidence of observers.

5. Conclusion

Overall, the study suggests that CBCT examination of patients in this sample of patients contributed to a change in diagnosis in a minority of patients, but that there was inter-observer variability in the proportion of patients. Both confidence in diagnosis and perceived helpfulness of CBCT was recorded as positive for all observers, based on mean scores, but the scores were not significantly greater for CBCT than for conventional radiographs.

The use of CBCT by dentists for endodontic purposes appears to be growing. This is in spite of the lack of evidence showing a clear benefit to the patient. This study suggests that routine use of CBCT would not be justified on the basis of a change in diagnosis and that carefully selected use is appropriate. Further research is required to increase our understanding of the impact of CBCT in endodontics at the higher levels of diagnostic efficacy.

Conflict of interest

None.

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References

[1] S. Patel, New dimensions in endodontic imaging: part 2. Cone beam computed tomography, Int. Endod. J. 42 (2009) 463–475.
[2] D.A. Tyndall, H. Kohltfarber, Application of cone beam volumetric tomography in endodontics, Aust. Dent. J. 57 (*2012*) 72–81.
[3] H. Christell, S. Birch, M. Hedesiu, et al., SEDENTEXCT consortium, Variation in costs of cone beam CT examinations among healthcare systems, Dentomaxillofacial Radiol. 41 (2012) 571–577.
[4] A. Al-Okshi, C. Lindh, H. Salé, M. Gunnarsson, M. Rohlin, Effective dose of cone beam CT (CBCT) of the facial skeleton: a systematic review, Br. J. Radiol. 88 (2015) 20140658.
[5] R. Schulze, U. Heil, D. Gross, et al., Artefacts in CBCT: a review, Dentomaxillofacial Radiol. 40 (2011) 265–273.
[6] A. Nemtoi, C. Czink, D. Haba, et al., Cone beam CT: a current overview of devices, Dentomaxillofacial Radiol. 42 (2013) 20120443.
[7] C. Estrela, M. Reis Bueno, C. Rodrigues Leles, B. Azavedo, J. Ribamar Azevedo, Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis, J.Endod. 34 (2008) 273–227.
[8] D.G. Fryback, J.R. Thornbury, The efficacy of diagnostic imaging, Med. Decis. Making 11 (1991) 88–94.
[9] American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology, Use of cone-beam computed tomography in endodontics Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endodontol. 111 (2011) 234–237.
[10] European Commission Radiation Protection 172. Evidence based guidelines on Cone Beam CT for dental and maxillofacial radiology. Office for Official Publications of the European Communities: Luxembourg.URL https://ec.europa.eu/energy/sites/ener/files/documents/172.pdf (2012) (accessed 17.03.16.).
[11] S. Patel, C. Durack, F. Abella, et al., European Society of Endodontology position statement: the use of CBCT in endodontics, Int. Endod. J. 47 (2014) 502–504.
[12] Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften (AWMF). s2k-Leitlinie Dentale digitale Volumentomographie Version Nr. 9 vom 5 August 2013. AWMF-Register-Nummer:083–05. Düsseldorf: AWMF; 2013 Available from: http://www.awmf.org/uploads/tx_szleitlinien/083-005l_S2k_Dentale_Volumentomographie_2013-10.pdf (accessed 17.03.16.).
[13] F.J. Mota de Almeida, K. Knutsson, L. Flygare, The effect of cone beam CT (CBCT) on therapeutic decision-making in endodontics, Dentomaxillofacial Radiology 43 (2014) 20130137.
[14] F.J. Mota de Almeida, K. Knutsson, L. Flygare, Diagnostic thinking and therapeutic decision confidence after cone beam computed tomography in endodontics measured by a visual analogue scale (VAS), Proceedings of the 16th ESE (European Society of Endodontology) Biennial Congress, Lisbon, Portugal. 12–14 September, 2013.
[15] C.A. Meads, C.F. Davenport, Quality assessment of diagnostic before-after studies: development of methodology in the context of a systematic review, BMC Med. Res. Methodol. 9 (2009), doi:http://dx.doi.org/10.1186/1471-2288-9-3.
[16] M. Pigg, T. List, K. Petersson, et al., Diagnostic yield of conventional radiographic and cone-beam computed tomographic images in patients with atypical odontalgia, Int. Endod. J. 44 (2011) 1092–1101.
[17] A. Abuabara, F. Baratto-Filho, J. Aguiar Anele, et al., Efficacy of clinical and radiological methods to identify second mesiobuccal canals in maxillary first molars, Acta Odontol. Scand. 71 (2013) 205–209.
[18] J. Ee, M.I. Fayad, B.R. Johnson, Comparison of endodontic diagnosis and treatment planning decisions using cone-beam volumetric tomography versus periapical radiography, J. Endod. 40 (2014) 910–916.
[19] F.J. Mota de Almeida, K. Knutsson, L. Flygare, The impact of cone beam computed tomography on the choice of endodontic diagnosis, Int. Endod. J. 48 (2015) 564–572.
[20] Health Protection Agency Guidance on the safe use of dental cone beam CT (computed tomography) equipment, HPA-CRCE-010, Health Protection Agency, Chilton, UK, 2010.
[21] V. Gunst, A. Mavridou, B. Huybrechts, et al., External cervical resorption: an analysis using cone beam and microfocus computed tomography and scanning electron microscopy, Int. Endod. J. 46 (2013) 877–887.
[22] S.E. Yalcinkaya, Y.G. Berker, S. Peker, et al., Knowledge and attitudes of Turkish endodontists towards digital radiology and cone beam computed tomography, Niger. J. Clin. Pract. 17 (2014) 471–478.
[23] R. Pauwels, J. Beinsberger, H. Stamatakis, K. Tsiklakis, A. Walker, H. Bosmans, R. Bogaerts, R. Jacobs, K. Horner, SEDENTEXCT Project Consortium, comparison of spatial and contrast resolution for cone-beam computed tomography scanners, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. 114 (2012) 127–135.