RESEARCH ARTICLE

CBCT influences endodontic therapeutic decision-making in immature traumatized teeth with suspected pulp necrosis: a before-after study

1Fernando José Mota de Almeida, 2Dalya Hassan, 2Ghada Nasir Abdulrahman, 2Malin Brundin and 3Nelly Romani Vestman

1Tandvårdens Kompetenscentrum, Norrbotten Public Dental Service, Luleå, Sweden; 2Department of Odontology, Umeå University, Umeå, Sweden; 3Department of Endodontics, Region of Västerbotten, Sweden; Wallenberg Centre for Molecular Medicine, Umeå University, Umeå, Sweden

Objective: To evaluate the impact of cone-beam computed tomography (CBCT) in endodontic therapeutic decision-making of immature traumatized teeth with suspected pulp necrosis.

Methods: Over two years, consecutive patients with a dental trauma in their front teeth (apex >0.5 mm) and with suspected pulp necrosis based on clinical and radiographic findings were referred to a specialist clinic in Sweden. Fifteen patients aged 6–13 (18 teeth) were included and clinically examined by an endodontist. Intraoral radiographs and CBCT examinations were obtained. Five practitioners, three endodontists and two residents in endodontics, used these examinations to determine the most appropriate treatment for the 18 cases (all central incisors) on two occasions scheduled 19 weeks apart. On the first occasion, the practitioners had access to clinical information and the intraoral radiographs (‘before’ CBCT); on the second occasion, the practitioners had also access to a radiologist report and the CBCT images (‘after’ CBCT). Their treatment plans – no treatment, watchful waiting, endodontic orthograde treatment, or extraction – were made anonymously and independently. Results were analysed using descriptive statistics and Wilcoxon signed-rank test.

Results: ‘After’ CBCT, practitioners changed treatment plans in 30% of the 90 assessments, 74% of which were more aggressive (p = 0.028). In 49% of the assessments, practitioners who chose the watchful and waiting treatment plan ‘before’ CBCT changed to a more aggressive therapy such as endodontic orthograde treatment and extraction ‘after’ CBCT (p = 0.005).

Conclusion: This study provides evidence that CBCT influences endodontic therapeutic decision-making regarding immature traumatised teeth with suspected pulp necrosis, chiefly when expectant management (i.e., watchful and waiting) was selected before access to CBCT.

Dentomaxillofacial Radiology (2021) 50, 20200594. doi: 10.1259/dmfr.20200594

Cite this article as: Mota de Almeida FJ, Hassan D, Nasir Abdulrahman G, Brundin M, Romani Vestman N. CBCT influences endodontic therapeutic decision-making in immature traumatized teeth with suspected pulp necrosis: a before-after study. Dentomaxillofac Radiol 2021; 50: 20200594.

Keywords: Cone-beam computed tomography; Tooth Injuries; Clinical Decision-Making; Dental Pulp Necrosis; Tooth Apex
Introduction

Oro-facial trauma can result in instant injury of teeth and supporting dental structures, resulting in later complications such as pulp inflammation or necrosis, apical periodontitis, ankylosis, and root resorptions. These complications can lead to complex treatments and even tooth loss. Generally, accurate diagnoses require good clinical histories, thorough clinical examinations, and other diagnostic tests (e.g., sensibility tests and radiographs). Examinations may need to be repeated to detect and diagnose post-trauma complications. Injuries to young permanent immature teeth significantly increase the time spent in the dentist’s chair as they can pose more complex diagnostic and therapeutic problems.

Dental management of necrotic teeth with incomplete root formation represents a challenging clinical situation. If immature teeth lose their pulp vitality, the root formation stops. These teeth have consequently questionable long-term survival. The classical approach for treating these teeth is apexification and may involve multiple appointments with a prolonged treatment time. A new method using a regenerative approach aims to replace necrotic pulp tissues with regenerated pulp-like tissues to vitalize teeth. It is in practice but needs further assessment for general application. Tooth replacement with dental implants is contraindicated in young individuals since the craniofacial skeleton has not completed growing.

Diagnostic challenges are also present. Sensibility pulp testing techniques have been considered less reliable for trauma, particularly in immature traumatized permanent teeth. Presently, it is not possible to adequately evaluate the condition of the pulp in teeth affected by trauma using electric or thermal pulp testing or other methods that measure pulpal blood circulation. The failure of these evaluation techniques may be the result of temporary damage to myelin sheaths, inflammation, pressure, tension, or the late development of the Raschkow plexus. Moreover, present criteria for pulpal necrosis (i.e., sensibility test, tooth discoloration, tenderness to percussion or palpation, and radiographic changes) cannot discriminate between pulp necrosis and traumatized pulp that will heal. Pulp necrosis, for example, is the most common complication following luxation injuries to the teeth. However, the general assessment of clinical and radiographic parameters after luxation injuries can be difficult to interpret or even misleading, especially in immature teeth, where there is a greater potential for pulp healing.

Radiographic examination is an important diagnostic tool, and intraoral radiography is the most commonly used technique. Radiography reveals not only the stage of root formation but also injuries (e.g., root and bone fractures) and complications (e.g., apical or root resorption processes). Some features might hinder a correct radiographic diagnosis such as the presence of an apical papilla in children or anatomical foramina that can overlap root apices. Unresponsive teeth to sensibility pulp testing without apical radiolucencies might be explained by aseptic necrosis and not only by damaged pulp with a healing potential, further complicating the clinical picture.

Over the last several decades, dentistry has used cone-beam computed tomography (CBCT), a technique that overcomes some of the drawbacks of two-dimensional radiography (e.g., overlapping of structures and distortion) although at the expense of more radiation and higher cost. Therefore, special attention should be given to studies that evaluate the accuracy of CBCT detecting apical periodontitis in primary infections, root fractures, and internal and external root resorptions. For example, in vitro studies have concluded that CBCT is more accurate at diagnosing apical periodontitis and recent human cadaver studies have concluded that CBCT is more accurate than conventional radiographs at detecting primary endodontic infections. CBCT is more sensitive than intraoral radiographs for the detection of fractures and root resorptions in non-root-filled teeth. CBCT has also been advocated for as an imaging tool for dental trauma and is currently being used for such purposes.

However, few studies in endodontics have investigated higher levels of efficacy of CBCT, as proposed by Frybaek and Thornbury, such as the effect of using CBCT information in decision-making or on patient outcomes. However, better test accuracy does not necessarily mean better clinical and patient outcomes. No studies have focused on the impact of CBCT in the choice of treatment of traumatized teeth. To fill this gap in knowledge, the present study investigates the effect of using CBCT as a complementary diagnostic tool in endodontic therapeutic decision-making of immature traumatized teeth with suspected pulp necrosis.

Methods and patients

Patients

The clinical and radiological material used in the current study was consecutively harvested from patients recruited from an ongoing study investigating regenerative treatments in immature traumatized necrotic teeth assessed by CBCT (NCT03544528). These patients were referred by general dental practitioners (GDPs) practicing in the Public Dental Service in Västerbotten County, Sweden to the endodontic department (a specialist clinic) at Umeå University Hospital (Umeå, Sweden). Referrals were received between March 2017 and March 2019. The time between trauma and the referral to the endodontic department varied between 28 days and 23 months.
Patients were consecutively included if they presented untreated and traumatized immature front teeth with suspicion of pulp necrosis and with no restoration or an adequate coronal restoration without signs of caries. Immature teeth were defined as having at least a 0.5 mm open apex based on intraoral radiographic examinations. The criteria for suspicion of pulp necrosis were based on clinical assessment (i.e., uncertain or loss of pulpal response on sensitivity tests) and/or on the presence of intraoral radiographic abnormalities. One patient could contribute with one or more teeth. None of the patients had clinical swellings or severe pain. The GDPs diagnosed the traumatized immature teeth (including hard tissue and luxation injuries) (Table 1). The initial study population consisted of 16 patients (10 male and 6 female) aged 6–13 (mean 9.3). One of the 16 patients (a nine-year-old female with two traumatized front teeth) was excluded because the CBCT was performed in another region using different CBCT equipment. In the final analysis, 15 patients contributed with a total of 18 teeth (all central incisors).

All patients were examined at the specialist clinic by the same experienced endodontist (NRV) one to 56 days (mean 29 days) after the referral. The initial examination gathered information using the following techniques: anamnesis (including subjective pain); clinical examinations (palpation, percussion, tooth and periodontal probing, mobility, and sinus tract); periapical radiographs of the young traumatized teeth; electric pulp test (Pulp Tester; Analytic Technology, Redmond, WA); and other pulp sensibility tests using a cold liquid (Endo Ice Roeo, Langenau, Germany) applied in the buccal surface of the tooth with a soaked cotton pellet for up to ten seconds if a negative response. Table 1 shows the information about the patients’ clinical status as determined by the specialist.

**Radiographic examinations**

New intraoral digital radiographs were taken at the specialist clinic during the examination and were acquired using the standardized paralleling technique, as much as technically possible, with two identical dental radiography machines (Focus, Instrumentarium Dental, Tuusula, Finland; 70kV, 7mA for 0.125 sec). Digital periapical radiographs were examined and apices were measured using a Schick CDR sensor (Schick Technologies/Sirona Dental Inc.). CBCT examinations were performed at the department of Oral and Maxillofacial Radiology at Umeå University (Umeå, Sweden) using the same machine, a Morita 3D Accuitomo (J. Morita MFG. Corp., Kyoto, Japan) with the following parameters: 85kV, 7mA, 360°, volume of 4 × 4 cm. The samples were reconstructed for analysis with a slice thickness of 0.960 mm, with an interval of 0.48 mm. Intraoral digital radiographs and CBCT were performed from 0 to 42 days apart (mean 22 days). A report was written by one of three all highly experienced board-certified oral maxillofacial radiologists.

**Data collection – study stages**

Data collection for the study was performed in two stages: ‘before’ and ‘after’ access to CBCT. For convenience's
sake, the decision-makers were three experienced clinical endodontists (between 10 and 20 years of experience) and two first-year endodontic residents working at the endodontic specialist clinic at Umeå University Hospital. None of the decision-makers were researchers involved in the project. Decisions-makers did not take part in setting up the cases.

Before the decision-makers had access to CBCT (‘before’), they were presented unidentified anamnesis, referral, relevant clinical findings, and conventional periapical radiographs of the 18 injured central incisors. This presentation of information was done in the same room in December 2019 using an interactive web-based application (www.mentimeter.com). The presentations were simultaneously shown on a wall-mounted digital display screen and the decision-makers’ smartphones in a dimmed room. The web-based application was chosen to ensure anonymity and independence among decision-makers. The decision-makers were asked for treatment options for each case separately. Therapy plan options were in increasing level of aggressiveness: A) no treatment; B) watchful waiting; C) endodontic orthograde treatment; and D) extraction.

After the same decision-makers had access to CBCT (‘after’), 19 weeks later, they assessed the same cases in the same setting. They had access to the same information, but this time each case was accompanied by selected CBCT images and the CBCT report written by the radiologist. Radiologists have aligned the volume to the tooth axis when they believed it was appropriate for diagnosis using Sectra IDS7 PACS viewer (Sectra AB, Linköping, Sweden). The whole volume was thoroughly assessed in all planes by radiologists and the information was used as a base for decision-making. The images were analysed in Sectra PACS viewer IDS five version (Sectra, Linköping, Sweden) on an Eizo Flex Scan GS320 (20 inch, colour, 1536 × 2048, 32 bit) monitor. The selected images were chosen by the researchers (DH, GNA, NR V) and were considered to be representative of the respective cases with axial, sagittal, and frontal tomograms. The whole volume was available if requested. Two cases are represented in Figure 1.

**Data analysis**

As patient material was originally collected for a parent study, a sample size calculation was not performed for this part. The analysis was primarily descriptive as the study was explorative. Changes between the ‘before’ and ‘after’ CBCT were analysed using Wilcoxon signed-rank test in IBM SPSS Statistics version 26 (SPSS Inc., Chicago, IL, USA), which assumed decision-makers found the minimal number of changes for each case.
Agreement among the decision-makers was calculated using Fleiss’ κ (http://justusrandolph.net/kappa/).

Results

The agreement among decision-makers ‘before’ and ‘after’ CBCT was 71.7 and 84.4%, respectively. ‘Before’ CBCT, the free-marginal Fleiss’ κ was 0.62 (95% confidence interval 0.45–0.79) and after CBCT, it was 0.79 (95% confidence interval 0.65, 0.94).

The treatment choices for each case are presented in Table 2. The most common therapy plan ‘before’ CBCT for all the assessments (n = 90) was watchful waiting (48%), and the most common therapy plan ‘after’ CBCT was endodontic treatment (62%).

Changes in treatment plans occurred in 30% of the overall assessments (n = 90), 74% of which were more aggressive therapy plans (p = 0.028). When decision-makers chose watchful waiting as a therapy before CBCT (n = 44), they changed 48% of those assessments (p = 0.005), most often (81%) to an endodontic treatment. It opposes to 10% of changes when they chose endodontic treatment before access to CBCT (n = 42, p = 0.705). When only considering the most prevalent option among decision-makers for each case, there were five changes in the 18 cases, four of which were more aggressive plans (p = 0.18). In the eight cases where the decision-makers chose watchful waiting ‘before’ CBCT, there were four changes in the therapy plan ‘after’ CBCT.

Discussion

This study investigated the effect of using CBCT as a complementary diagnostic tool in endodontic therapeutic decision-making of immature traumatized teeth with suspected pulp necrosis. The main finding is that endodontists were more likely to change their therapy plan after access to CBCT if they had chosen watchful waiting as a treatment plan before access to CBCT.

The ‘before’ and ‘after’ study design has been used by other researchers to investigate the effect of a diagnostic imaging test at the therapeutic efficacy level in endodontics and in other fields.26,27 The judgment of validity for the results and conclusions of this method can be based on a quality assessment tool.28 Thus, the population was chosen consecutively, clinical data were harvested prospectively, and a specific clinical indication was assessed. In addition, the patients were thoroughly examined by the same specialist and that information was used to make decisions. Meads and Davenport28 conclude that ‘therapeutic plans based on the before test results should not be known at the time of making therapeutic plans based on a combination of the before and after test results’. This conclusion justifies the choice for the 19 week lapse time between assessments as the decision-makers would not remember their previous answers. Studies that rely on decision-making based solely on the use of intraoral radiographs (i.e., without the addition of clinical examination) potentially exaggerate the frequency of changes in therapies after CBCT and lack clinical interest as there are many other clinical diagnostic tools that provide essential information that can circumvent the inaccuracy associated with conventional radiographs.

There are, however, some drawbacks to this method. The use of several decision-makers to assess the same cases presents a source of variation. It becomes difficult to distinguish from uncertainty in the assessment and variation between patients, despite the fact that the agreement in the present study can be interpreted as substantial for the 90 assessments and the descriptive analysis based on the majority of assessments for each case revealed the same proportions as the overall assessments.29 The choice of different decision-makers should increase external validity; however, the present study may or may not accurately represent endodontists, as no systematic recruitment process of the decision-makers was performed although our recruitment approach seems to be common.30–34 In addition, CBCT was not performed on the same day as the intraoral radiographs taken by the specialist, risking a maturation bias in favour of CBCT. Accordingly, patients need to be clinically and radiographically evaluated and referred to a radiology department before the CBCT evaluation.
However, the examinations were performed within an acceptable timeframe.

For practical reasons, only selected images were initially shown rather than the whole volume, and this might have introduced a bias, as pictures could potentially not be representative, or some important radiological details might have been missed. However, decision-makers were informed that the whole volume was available in case they needed further information at any time. None of the decision-makers asked for evaluation of the whole volume. One of the researchers was a specialist in endodontics with considerable experience in using CBCT (NRV). Researchers scrutinized the whole volume to select pictures considered representative for each case in a self-perceived objective fashion trying to mitigate potential bias. Moreover, radiologists evaluated the whole volume, and the relevant information was translated in a report that was used by the decision-makers, minimizing the risk of image selection and missed information and making available written data as it would be in the clinical practice in Sweden, where CBCT cannot be independently used by non-radiologists.

Because the decision-makers’ choices were anonymous, the authors were unable to follow changes individually. This arrangement could have resulted in the understatement of the results as we assumed changes were minimal. It was impossible to analyse the variation within the same individual over time and its effect on the results. The study had only four therapy plan choices, and the decision-makers desired more choices. They did not have any responsibility for the patient and their choices did not affect the actual chosen therapies for those patients. These issues weaken, to some degree, the validity.

The presented results seem to indicate that for immature central incisors with a suspicion of pulp necrosis in which an endodontic treatment is preliminarily planned after a thorough clinical examination, CBCT does not contribute to many therapy plan changes and, therefore, might not be routinely indicated in the first treatment phase. This might reflect that the patients included in the study were part of a parent study that asked for an initial CBCT, so in some teeth the degree of suspicion of necrosis was so high that CBCT did not contribute with additional information to change therapy. In a pure clinical situation, some of these children might not have an indication for CBCT, an important consideration in the present study. However, if watchful waiting is chosen instead by a particular clinician, the use of CBCT has a stronger potential to hasten treatment, avoiding, at least theoretically, eventual complications of delayed therapy. Therefore, the use of CBCT might be beneficial when clinicians consider a watchful strategy based on conventional examination. In the present study, the latter situation required only two CBCT examinations for a change in treatment plan to occur. Nevertheless, the use of CBCT should neither be a shortcut for sloppy examinations or lack of clinical discernment nor a stubborn quest for diagnostic certainty or defensive medicine.

In general endodontics, CBCT has the potential to change the course of actions, notably in highly selected and complex cases. There is some evidence that when cases are simpler, the impact is far less significant. This report also points in that direction: when decision-makers were confident enough to choose more definitive treatments other than watchful waiting (e.g., endodontic treatment), there were far fewer changes ‘after’ CBCT. Some studies have found that changes in treatment plans were more often more aggressive, a finding also evident in this present study. Changes are probably beneficial for the patient in a significant number of cases, but not all. Unfortunately, there are few well-designed controlled trials that randomize the use of CBCT to assess patient outcome.

Two studies have investigated more closely the effect of CBCT on therapy choices for teeth presenting external resorptions. CBCT information results in changes in therapies and assists in planning, but periapical radiographs might suffice if teeth are deemed unsalvageable. One explanation for our results could be that changes in therapy plans occur because CBCT is more accurate, especially for diagnosing apical periodontitis. The changes in therapy plans reported in two studies on the same material were strongly correlated with changes in diagnoses. Another aspect that should be highlighted is a possible increase in decision-makers’ confidence in CBCT as they see that it depicts the true nature of the case. CBCT seems to increase confidence in choosing diagnoses and therapy plans in endodontics, although Al-Salehi found the opposite. However, differences in inclusion criteria and who prescribes CBCT in relation to who plans treatments might help explain the different results.

Trauma complications can emerge early – days to weeks later or years after the incident. There is a general agreement that early diagnosis and treatment of traumatic injuries can prevent posttraumatic complications giving a better chance for the preservation of the tooth and its surrounding tissue. Nevertheless, the assessment of pulp vitality is one of the major challenges in dental traumatology due to the temporary loss of sensitivity after trauma and because of the limitations of conventional pulp sensibility tests. In addition, pulp testing is more difficult when assessing immature teeth in young patients considering the technical and psychological challenges. The clinician must then be aware of additional signs of pulp necrosis such as crown discoloration and radiographic changes before initiating endodontic treatment. This can delay diagnosis and may affect tooth prognosis.

The use of ionizing radiation in the target population (i.e., young individuals) should be more judicious as they are more sensitive to radiation exposure. In addition to optimizing protocols, CBCT use should
primarily be justified. The principle of ‘as low as diagnostically acceptable’ (ALADA) should be followed, and the use of various other diagnostic tests should have previously been considered. The European Commission has recommended the use of CBCT only in complex cases and only after adequate anamnesis and clinical and basic radiological examination if these have not provided sufficient information to tackle the case. Applying the European Commission guidelines, the vast majority of endodontic problems, diagnoses, and treatment plans can be established in specialist practices without the need for more advanced diagnostic tests such as CBCT. The cases presented here were all referred from a selected population and posed a somewhat more difficult clinical problem. However, the authors ignored the proportion of non-referred cases. In an earlier study conducted in Sweden and with very robust data, a majority of the traumatic dental injuries to permanent teeth in young people affected central upper incisors, and trauma occurrences peaked before the age of 11, when these teeth might still not have fully matured apices. Only 4% of young patients with traumatic dental injuries were treated by different specialists (oral surgeons, pedodontists, and endodontists).

Conclusion

CBCT use changed the assessments in 30% of the patients with traumatized central incisors who were referred to a specialized clinic for treatment with a clinical suspicion of pulp necrosis and the changes in treatment were more often more aggressive. CBCT had the most impact in helping change therapy plans when endodontists chose watchful waiting as a treatment plan before access to CBCT.

Acknowledgment

The authors would like to express their gratitude to Robert Lundqvist for assistance with the statistical analysis and to Eleonor Fowler for help with patient registers. The authors acknowledge the staff of the Endodontics department and the Oral and Maxillofacial Radiology department at the Umeå University Hospital for their support during the study.

Funding

The authors declare no conflicts of interest. This study was supported by the Region of Västerbotten, the Swedish Dental Society, and the Knut and Alice Wallenberg Foundation.

Ethics

Ethical approval was obtained by the Umeå Regional Ethical Board, Sweden (Dnr. 2016/520-31) and the Swedish Radiation Safety Authority (Dnr. 1632) for the project. All included patients consented to participate in the study. Older children (215 years) and parents signed an informed consent.

REFERENCES

1. Borsén E, Källestål C, Holm A-K. Treatment time of traumatic dental injuries in a cohort of 16-year-olds in northern Sweden. Acta Odontol Scand 2002; 60: 265–70. doi: https://doi.org/10.1080/00016350262042229
2. Andreasen JO, Munksgaard EC, Bakland LK. Comparison of fracture resistance in root canals of immature sheep teeth after filling with calcium hydroxide or MTA. Dent Traumatol 2006; 22: 154–6. doi: https://doi.org/10.1111/j.1600-9657.2006.00419.x
3. Mendoza AM, Reina ES, García-Godoy F. Evolution of apical formation on immature necrotic permanent teeth. Am J Dent 2010; 23: 269–74.
4. Yang J, Yuan G, Chen Z. Pulp regeneration: current approaches and future challenges. Front Physiol 2016; 7: 58. doi: https://doi.org/10.3389/fphy.2016.00058
5. Bantos JV, Goulart EM, Cortes deS.. . Pulpal response to sensibility tests after traumatic dental injuries in permanent teeth. 2014; 30: 188–92M I.
6. Mejáre IA, Axelson S, Davidson T, Frisk F, Harryberg M, Kvist T, et al. Diagnosis of the condition of the dental pulp: a systematic review. Int Endod J 2012; 45: 597–613. doi: https://doi.org/10.1111/j.1365-2591.2012.02016.x
7. Gopikrishna V, Pradeep G, Venkateshababu N. Assessment of pulp vitality: a review. Int J Pediatr Dent 2009; 19: 3–15. doi: https://doi.org/10.1111/j.1365-263X.2008.00955.x
8. Sigurdsson A, In: Ørstavik D. Clinical Manifestations and Diagnosis. In: (ed). Essential endodontology: prevention and treatment of apical periodontitis. Hoboken: NJ: Wiley-Blackwell; 2019. pp. 211–36.
9. Andreasen FM. Histological and bacteriological study of pulps extirpated after luxation injuries. Endod Dent Traumatol 1988; 4: 170–81. doi: https://doi.org/10.1111/j.1600-9657.1988.tb00317.x
10. Andreasen JO. Luxation of permanent teeth due to trauma. A clinical and radiographic follow-up study of 189 injured teeth. Scand J Dent Res 1970; 78: 273–86. doi: https://doi.org/10.1111/j.1600-0722.1970.tb02074.x
11. Sundqvist G. Bacteriological studies of necrotic dental pulps. Umeå: Umeå University; 1976.
12. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am 2008; 52: 707–30. doi: https://doi.org/10.1016/j.dden.2008.05.005
13. Leonardi Dutra K, Haas L, Porporatti AL, Flores-Mir C, Nascimento Santos J, Mezzomo LA, et al. Diagnostic Accuracy of Cone-beam Computed Tomography and Conventional Radiography on Apical Periodontitis: A Systematic Review and Meta-analysis. J Endod 2016; 42: 356–64. doi: https://doi.org/10.1016/j.joen.2015.12.015
14. Kruse C, Spin-Neto R, Evamar K, Kreijsvang L-L. Diagnostic accuracy of cone beam computed tomography used for assessment of apical periodontitis: an ex vivo histopathological study on human cadavers. Int Endod J 2019; 52: 439–50. doi: https://doi.org/10.1111/iej.13020
15. Kanagasigam S, Lim CX, Yong CP, Mannocci F, Patel S. Diagnostic accuracy of periapical radiography and cone beam computed tomography in detecting apical periodontitis with histopathological findings as a reference standard. *Int Endod J* 2017; 50: 417–26. doi: https://doi.org/10.1111/iej.12650

16. Talwar S, Umeja S, Nawal RR, Kaushik A, Srivastava D, Oberoy SS. Role of cone-beam computed tomography in diagnosis of vertical root fractures: a systematic review and meta-analysis. *J Endod* 2016; 42: 12–24. doi: https://doi.org/10.1016/j.joen.2015.09.012

17. Yi J, Sun Y, Li Y, Li C, Xi X, Zhao Z. Cone-Beam computed tomography versus periapical radiograph for diagnosing external root resorption: a systematic review and meta-analysis. *Angle Orthod* 2017; 87: 328–37. doi: https://doi.org/10.2319/061916-481.1

18. European Commission. Radiation protection no. 172. Evidence-based guidelines on cone beam CT for dental and maxillofacial radiology. Luxembourg: Office for Official Publications of the European Communities; 2017.

19. Cohenca N, Silberman A. Contemporary imaging for the diagnosis and treatment of traumatic dental injuries: a review. *Dent Traumatol* 2017; 33: 321–8. doi: https://doi.org/10.1111/detr.12339

20. Van Acker JW, Martens LC, Aps JKM. Cone-Beam computed tomography in pediatric dentistry, a retrospective observational study. *Clin Oral Investig* 2016; 20: 1003–10. doi: https://doi.org/10.1007/s00784-015-1592-3

21. Fryback DG, Thornbury JR. The efficacy of diagnostic imaging. *Med Decis Making* 1991; 11: 88–94. doi: https://doi.org/10.1177/0272989X9101100203

22. Kruse C, Spin-Neto R, Wenzel A, Kirkevange L-L. Cone beam computed tomography and periapical lesions: a systematic review analysing studies on diagnostic efficacy by a hierarchical model. *Int Endod J* 2015; 48: 815–28. doi: https://doi.org/10.1111/iej.12388

23. Rosen E, Taschieri S, Del Fabbro M, Beitzlum I, Tsesis I. The diagnostic efficacy of cone-beam computed tomography in Endodontics: a systematic review and analysis by a hierarchical model of efficiency. *J Endod* 2015; 41: 1088–14. doi: https://doi.org/10.1016/j.joen.2015.02.021

24. Kurt SN, Üstüen Y, Erdogan Özgüre, Evlice B, Yoldas O, Öztune H. Outcomes of periradicular surgery of maxillary first molars using a vestibular approach: a prospective, clinical study with one year of follow-up. *J Oral Maxillofac Surg* 2014; 72: 1049–61. doi: https://doi.org/10.1016/j.joms.2014.07.004

25. Estefan BS, El Batoumy KM, Nagy MM, Diogenes A. Influence of age and apical diameter on the success of endodontic regeneration procedures. *J Endod* 2016; 42: 1620–5. doi: https://doi.org/10.1016/j.joen.2016.06.020

26. Wittenberg J, Fineberg HV, Black EB, Kirkpatrick RH, Schaffer DL, Ikeda MK, et al. Clinical efficacy of computed body tomography. *AJR Am J Roentgenol* 1978; 131: 5–14. doi: https://doi.org/10.2214/ajr.131.1.5

27. Rodriguez G, Abella F, Durán-Sindreu F, Patel S, Roig M. Influence of cone-beam computed tomography in clinical decision making among specialists. *J Endod* 2017; 43: 194–9. doi: https://doi.org/10.1016/j.joen.2016.10.012

28. Meads CA, Davenport CF. Quality assessment of diagnostic before-after studies: development of methodology in the context of a systematic review. *BMC Med Res Methodol* 2009; 9: 3. doi: https://doi.org/10.1186/1471-2288-9-3

29. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33: 159–74.

30. Al-Salehi SK, Horner K. Impact of cone beam computed tomography (CBCT) on diagnostic thinking in endodontics of posterior teeth: a before- after study. *J Endod* 2016; 53: 57–63. doi: https://doi.org/10.1016/j.jdent.2016.07.012

31. Kruse C, Spin-Neto R, Wenzel A, Vaeth M, Kirkevange L-L. Impact of cone beam computed tomography on periapical assessment and treatment planning five to eleven years after surgical endodontic retreatment. *Int Endod J* 2018; 51: 729–37. doi: https://doi.org/10.1111/iej.12888

32. Chogle S, Zaatari M, Sarkis R, Saadoun M, Mechem A, Zhao Y. The recommendation of cone-beam computed tomography and its effect on endodontic diagnosis and treatment planning. *J Endod* 2020; 46: 162–8. doi: https://doi.org/10.1016/j.joen.2019.10.034

33. Viana Wanzeler AM, Montagner F, Vieira HT, Dias da Silveira HL, Arus NA, Vizzotto MB. Can cone-beam computed tomography change Endodontists’ level of confidence in diagnosis and treatment planning? A before and after study. *J Endod* 2020; 46: 283–9. doi: https://doi.org/10.1016/j.joen.2019.10.021

34. Balasundaram A, Shah P, Hoen MM, Wheeler MA, Bringas JS, Gartner A, et al. Comparison of cone-beam computed tomography and periapical radiography in predicting treatment decision for periapical lesions: a clinical study. *Int J Dent* 2012; 2012; 920815. doi: https://doi.org/10.1155/2012/920815

35. Levin DC, Rao VM. Turf wars in radiology: other causes of overutilization and what can be done about it. *J Am Coll Radiol* 2004; 1: 317–21. doi: https://doi.org/10.1016/j.jacr.2003.12.024

36. Mota de Almeida FJ, Knutsson K, Flygare L. The effect of cone beam CT (CBCT) on therapeutic decision-making in endodontics. *Dentomaxillofac Radiol* 2014; 43: 20130137. doi: https://doi.org/10.1259/dmfr.20130137

37. Goodell KB, Mines P, Kersten DD. Impact of cone-beam computed tomography on treatment planning for external cervical resorption and a novel axial Slice-based classification system. *J Endod* 2018; 44: 239–44. doi: https://doi.org/10.1016/j.joen.2017.10.001

38. Patel K, Mannocci F, Patel S. The Assessment and Management of External Cervical Resorption with Periapical Radiographs and Cone-Beam Computed Tomography: A Clinical Study. *J Endod* 2016; 42: 1435–40. doi: https://doi.org/10.1016/j.joen.2016.06.014

39. Mota de Almeida FJ. Computed tomography in endodontic decision making. Malmö: Malmö University, Faculty of Odontology, Holmbergs; 2019.

40. Mota de Almeida FJ, Flygare L, Knutsson K, Wolf E. 'Seeing is believing': a qualitative approach to studying the use of cone beam computed tomography in endodontics in Sweden. *Int Endod J* 2019; 52: 1519–28. doi: https://doi.org/10.1111/iej.13144

41. Lin S, Pilosof N, Karawani M, Wigler R, Kaufman AY, Teich ST. Occurrence and timing of complications following traumatic dental injuries: a retrospective study in a dental trauma department. *J Clin Exp Dent* 2016; 8: e429–36. doi: https://doi.org/10.4177/feecd.53022

42. Andreasen FM, Pedersen BV. Prognosis of luxated permanent teeth—the development of pulp necrosis. *Endod Dent Traumatol* 1985: 1: 207–20. doi: https://doi.org/10.1111/1600-9657.1985.tb00583.x

43. Andreasen FM, Andreasen JO. Treatment of traumatic dental injuries. *Shift in strategy: Int J Technol Assess Health Care* 1990; 6: 588–602.

44. Jaju SP, Jaju SJ. Cone-Beam computed tomography: time to move from ALARA to ALADA. *Imaging Sci Dent* 2015; 45: 263–5. doi: https://doi.org/10.5624/isd.2015.45.4.263

45. Borsén E, Holm AK. Traumatic dental injuries in a cohort of 16-year-olds in northern Sweden. *Endod Dent Traumatol* 1997; 13: 276–80. doi: https://doi.org/10.1111/1600-9657.1997.tb00555.x

46. Borsén E, Holm AK. Treatment of traumatic dental injuries in a cohort of 16-year-olds in northern Sweden. *Endod Dent Traumatol* 2000; 16: 276–81. doi: https://doi.org/10.1034/j.1600-9657.2000.016006276.x