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Radiographic Comparison Using CBCT-PAI and Volumetric Analysis of Endodontically Treated Teeth: A Retrospective Cohort Study

Jeremy Hargrove
Virginia Commonwealth University

Radiographic Comparison Using CBCT-PAI and Volumetric Analysis of Endodontically Treated Teeth: A Retrospective Cohort Study

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

Jeremy Hargrove, DMD

University of Arizona, 2014

Midwestern University College of Dental Medicine - Arizona, 2018

Thesis advisor: Garry L. Myers, DDS

Program Director, Advanced Education Program in Endodontics

Virginia Commonwealth University

Richmond, Virginia

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Abstract

A RADIOGRAPHIC COMPARISON USING CBCT-PAI AND VOLUMETRIC ANALYSIS OF ENDODONTICALLY TREATED TEETH: A RETROSPECTIVE COHORT STUDY

By: Jeremy Hargrove, DMD

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Purpose: To assess the changes in CBCT-PAI score as well as 3-D volume of periapical findings associated with endodontically treated roots and to see how these findings change over time.

Methods: Retrospective chart review with the following inclusion criteria: 1. At least one tooth was endodontically treated at the endodontic private practice; 2. Patient had a recall examination and the treated tooth was asymptomatic, functional and a CBCT was exposed; 3. CBCT interpretation found a periapical finding associated with the treated tooth; 4. A follow-up recall examination was completed and CBCT exposed. Cases that fulfilled the inclusion criteria had the CBCT volumes evaluated by an oral radiologist and an endodontic resident. Each CBCT had a CBCT-PAI score assigned and 3-D volume of the periapical finding was determined in the initial recall and follow-up recall CBCT images in a randomized and blinded fashion.

Results: At total of 38 roots with periapical findings were included with average time elapsed from treatment to initial recall of 7.9 years and an average of 2.88 years between recalls. The change in CBCT-PAI score was not significant (p-value=0.6505). CBCT-PAI score improved in 36%, unchanged in 40% and increased in 24%. The median change in 3-D volume was 0.80mm^3 smaller at recall and was not statistically significant (p-value=0.2859). There was a total of 16 cases with volume less than 3.0mm^3 at initial recall and 93% of those remained less than 3.0mm^3 at follow-up recall. The correlation between volume change and time elapsed since treatment was not statistically significant (r=0.06, p-value=0.7020).

Conclusion: Clinicians may consider active surveillance as a treatment option for endodontically treated teeth with periapical findings, especially those that are small in size, as long as the patient is immunocompetent, clinically free of pathologic signs and symptoms and the tooth is functional. Further long-term recall examination is warranted to see how asymptomatic periapical findings change over time.

Introduction

Evaluation of endodontic treatment, both long and short-term, is multi-factorial and includes subjective and objective interpretation of clinical testing and radiographic imaging. The goal of endodontic treatment is to prevent pulpal and periapical pathology, and when needed, diagnose and correct the disease process with an emphasis on maintaining the natural dentition. As part of a clinical examination of the patient with suspected pathology of endodontic origin, the clinician will utilize objective and subjective tests such as thermal stimulus, electronic pulp testing, periodontal probing, percussion, palpation and biting tests to assess the pulpal and periapical tissues. Additionally, the clinician will utilize radiation imaging to visualize the crown and root of the tooth in question and surrounding anatomical structures. The radiographic imaging is analyzed by assessing the appearance of the peri-radicular bone, lamina dura, any existing root filling material and any radiographic changes from prior imaging that may be available. The collection of these data and imaging are used to create a pre-operative diagnosis of both the pulpal and periapical regions. With a diagnosis established a treatment plan can be developed. With the aim to resolve the pulpal and periapical pathology, the treatment options may include no treatment, extraction of the offending tooth, non-surgical root canal therapy, non-surgical root canal retreatment or surgical treatment among others. The process of informed consent to provide the patient with the information needed to make an informed decision must be undertaken. Part of this process is to provide the clinician's recommendation based on anatomical considerations, contra-indications as well as evidence based prognostic factors to allow for the greatest potential for a successful outcome.

The topic of outcome success has been thoroughly investigated throughout the literature. A distinction has been made from survival of the endodontically treated tooth and the success of the endodontically treated tooth. Much of this distinction comes from the definitions used by researchers when classifying the tooth and status. Strindberg, in 1956, evaluated outcomes and developed a very strict criterion for success (1). Strindberg established that for endodontic treatment to be a success, the following criteria had to have been met: absence of pain or swelling, no loss of function, absence or resolution of a sinus tract and the complete resolution of any radiolucency associated with the treated tooth (1). In 1966, Seltzer and Bender questioned the reliability of complete radiographic healing as a pre-requisite to success (2). This article raised concerns about the relevance of the radiographic appearance as it relates to the histologic reality of the periapical tissue and found that there was no significant correlation with the clinical symptoms and the histology of the tissue (2). This article suggested modifying the radiographic evaluation for success to include "radiographic evidence of an eliminated or arrested area of rarefaction six months to two years after obturation" and noted that failures will generally be found within the first few months following treatment and should only be considered a failure if clinical signs and symptoms of pathology persist or develop (2). In a 1967 publication, Seltzer suggested that endodontically treated teeth should be considered successful regardless of the radiographic interpretation as long as there are no adverse signs or symptoms and the tooth is functioning adequately (3).

Survival based epidemiological studies completed in 2001 and 2004 found a survival rate of endodontically treated teeth to be 95-97% at a follow-up time of 2-8 years (4,5). These insurance-based studies reviewed insurance records and deemed the treated tooth to be successful if there was no subsequent record of retreatment, surgery or extraction. More recently, a study from a South Korean cohort found survival of nearly 91% over a 5-year period (6). Essentially, this type of survival-based outcome indicates only that treatment was rendered and no subsequent indicator of failure, such as retreatment or extraction, was recorded. This type of outcome metric makes no consideration for functional status, whether signs or symptoms of pathology were present as well as radiographic healing. Outcome studies as a whole have varied from very strict healing criteria to the less stringent survival-based criteria. There is an informal consensus amongst clinicians that the best measure of outcome lies somewhere between each of those extremes. The 1966 article by Seltzer and Bender references the metric of "healing" by interpreting the changes in the rarefaction as a positive response to treatment (2). It is suggested that the metric of success should include those categorized as healing. By including those that are healing in the success category we account for those cases where radiographic and clinical indicators show a positive trend toward healing and accounts for the significant healing and remodeling variations that can occur within patient sub-populations.

It is accepted by the current literature that success be determined based on both the radiographic analysis and the clinical evaluation using the categories of healed, healing and non-healing. During a recall examination of an endodontically treated tooth, the clinical signs and symptoms of pathology will be assessed via biting tests, percussion tests, periodontal probing, clinical evaluation of the surrounding soft tissues and the patients report of symptoms and pain. Furthermore, a periapical radiograph will be taken, which historically and currently is the imaging modality recommended by the American Association of Endodontists (AAE) to assess radiographic signs of pathology (7). Using the results of the recall examination, a judgement on outcome and potential treatment recommendations are made. As discussed, to be considered healed in a success-based outcome study there must be complete resolution of the clinical signs and symptoms as well as complete healing of the periapical tissues as assessed by a periapical radiograph. The radiographic feature of the presence and uniformity of the lamina dura, which is the radiographic interpretation of the periodontal ligament, will be evaluated for signs of destruction and inflammation. To be considered healing, the patient must have no clinical signs and symptoms as well as demonstrable periapical healing that is visualized when compared to the pre-operative or historical radiographs. It is accepted that the bony healing that is occurring is a natural progression of the periapical healing process and should not be considered a failed treatment as additional time may lead to complete periapical healing. The third category is that of non-healing. This classification will have either persistent signs and symptoms of periapical pathology or the radiograph may indicate that the radiolucent lesion has not changed or may have increased in size.

When standards of success by these general guidelines are examined the success of primary endodontic treatment using modern endodontic materials and methods is still quite high ranging from 81-89% (8–11). Several studies have identified pre-operative, peri-operative and post-operative prognostic factors that tend to be associated with higher or lower rates of success in endodontics. Most notably, the presence of a pre-operative lesion of endodontic origin associated with the tooth in question has repeatedly been associated with a lower success rate than teeth without a pre-operative lesion. In the studies referenced, the distinction between pre-operative lesion present and no pre-operative lesion present corresponded to a variation in success rate of 79% and 94% respectively (9,11,12).

Since the distinction of healing is a subjective interpretation of the radiograph, a standardized approach to evaluate these radiographs was developed. Ørstavik, in 1986, established what is known as the “Periapical Index” (PAI) where a score was assigned to the tooth based on the periapical status in an effort to quantify the presence and severity of periapical inflammation and disease (13). The scoring system as described by Ørstavik was meant to be a simplified form of the interpretation made by Brynolf in 1967. The PAI generalized a score of 1 to be healthy or non-diseased, a score of 2 represented small bony changes, a score of 3 represented bony changes with apparent mineral loss, a score of 4 represented well defined bony changes and a score of 5 represented severe apical periodontitis with expansion and destruction of the periapical bone (13). Upon establishment of these scores the teeth were subsequently evaluated histologically and a significant correlation was found with the PAI score and an increasing inflammatory process and disease. The PAI has become an accepted method of scoring for comparison of pre-treatment and post-treatment disease processes with regard to endodontic treatment when comparing periapical radiographs.

Research has been conducted regarding how much bony destruction must occur before being visualized on a two-dimensional radiograph. In the classic study done in 1961 it was found that evaluators could only identify a lesion when the lesion was near perforation of the cortical plate and that cancellous bone destruction alone was insufficient to visualize on a film type radiograph (14,15). Furthermore, bone loss evaluation at the alveolar crest found similar findings in that cancellous bone loss alone was unable to be detected when the dense cortical plate remained intact (16). Further research from 1982 found that the cortical plate, due to the increase in calcium content, would require 7.1% of the mineral content to be lost before the lesion was detected via traditional film radiographs (17). In contrast however, Shoha concluded that lesions confined to areas where the cortical plate is naturally thinner, such as the mandibular premolar and anterior regions, that a cancellous lesion could be visualized despite no corresponding cortical plate involvement (18). This research did not demonstrate the actual bony destruction that accompanies a naturally occurring periapical lesion, more specifically, a periapical lesion of endodontic origin will have a corresponding loss of the lamina dura surrounding the apical region of the tooth. This lamina dura appears as a distinct radio-opaque line of dense bone surrounding the root of the tooth. Using conventional film as well as digital radiography, it was found that when the apical 2-3mm of lamina dura surrounding the apical tooth structure was removed, there was a significant improvement in the accurate detection of an artificial lesion even when cortical plate remained (19). Using periapical radiography as well as CBCT imaging, Liang found that cancellous lesions in areas where the cortical plate is thickest, namely the posterior mandible, were detected only 50% of the time compared to premolar and anterior regions which were accurately detected 95% of the time (20). The methodology of this study reinforces that loss of lamina dura plays a role in whether a cancellous lesion will be detected on periapical radiography (20).

Periapical healing and resolution of existing inflammatory processes is multi-variable. Several factors that contribute to periapical healing have been identified. Some of these factors include systemic conditions and diseases, severity of the periapical inflammatory disease process, bacterial virulence and quality of the subsequent endodontic and restorative treatment rendered (21). In a 2017 review, Holland describes conditions such as diabetes mellitus, hypertension, menopause and osteoporosis that can produce a change in the hosts immune response and thereby reducing the patients healing response following endodontic treatment (21). In contrast, a systematic review of systemic disease and their relationship to endodontic outcomes found conflicting evidence and further research in the topic is needed (22). The optimal recall period for periapical assessment of healing is also largely variable. Clinical outcome studies have reported that a significant portion of endodontically treated teeth will respond favorably within 12 months (23,24). Additionally, follow-up periods up to 7 years have been documented for periapical resolution (1). Strindberg's study on clinical and radiographic follow-up examination proposed a recall period of 4 years as the standard (1).

As use of CBCT becomes more prevalent in the dental practice, it is frequently used for diagnostic purposes as well as pre-operative, post-operative and follow-up examinations for endodontic treatment. The AAE has established recommendations regarding CBCT use. As with all forms of radiation, the clinician must consider the diagnostic and clinical benefit of the desired image as well as the risk associated with radiation exposure. The AAE recommendation for CBCT use as it pertains to post-operative evaluation reads as: if CBCT was the modality used for pre-operative diagnosis then CBCT may be used for subsequent follow-up imaging for evaluation of healing and bony changes (7). As the use of CBCT increases for post-operative evaluation it is important to understand the limitations that CBCT has when attempting to correlate what is seen radiographically and how that compares to histology.

De Paula-Silva researched the accuracy of detecting periapical lesion in dogs and then used histology as the gold standard to confirm the presence of true apical periodontitis (25). Periapical radiography detected apical periodontitis 71% of the time whereas the CBCT methodology was able to detect the presence of a lesion 84% of the time. These same teeth when evaluated histologically had true periapical inflammation in 93% of cases. De Paula-Silva demonstrated that periapical imaging is not as sensitive as CBCT in detection of periapical pathology and that periapical radiographs may lead to an under-diagnosis of periapical pathology (25). In 2016, Kanagasingam performed a similar study to evaluate the diagnostic accuracy of periapical radiography and CBCT when compared to histology on human cadavers (26). They found that utilizing two periapical images, namely a straight on view and an angled view, had a sensitivity of 0.27-0.39 in their ability to detect a lesion whereas CBCT had a sensitivity of 0.89 (26). They concluded that CBCT was significantly more accurate than periapical imaging when attempting to evaluate the periapical region for apical periodontitis (26).

Further research into comparing periapical radiography and CBCT done by Tsai in 2012 attempted to evaluate CBCT interpretation of artificially created lesions that were small in size to compare how the lesion size altered the evaluators ability to detect a rarefaction (27). It was found that two dimensional periapical radiography demonstrated poor diagnostic accuracy to detect periapical lesions of all sizes tested whereas CBCT demonstrated poor accuracy when lesion was <0.8mm diameter, fair to good accuracy when the lesion was 0.8-1.4mm, and excellent accuracy when lesion was larger than 1.4mm (27). This demonstrated that even small lesions are likely to be detected when CBCT imaging is utilized and can be of benefit to help better understand changes in the periapical region, especially when two-dimensional imaging and diagnostic testing produce inconclusive results.

In a 2016 systematic review and meta-analysis, artificial lesion detection via CBCT imaging had an accuracy of 0.96 whereas an accuracy of 0.73 and 0.72 were found for traditional PA film and digital PA radiographs respectively (28).

In an attempt to create an objective system to interpret a CBCT and periapical changes on a CBCT, Estrela established the “CBCT Periapical Index” (CBCT-PAI) similar to the PAI established by Ørstavik (29). This system uses a scale of 0-5 where each increasing number indicates an increased level of bony alterations as seen on the CBCT. A '0' indicates intact periapical bony structure, a '1' indicates a periapical radiolucency of 0.5-1.0 mm, a '2' indicates a periapical radiolucency of 1-2 mm, a '3' indicates a periapical radiolucency of 2-4 mm, a '4' indicates a periapical radiolucency of 4-8 mm and a '5' indicates a periapical radiolucency of >8 mm. Additional modifiers were established to denote expansion of the periapical cortical bone with an 'E' or destruction of the periapical cortical plate with a 'D'. This scoring system, when used in the context of tracking changes to periapical bone on CBCT will allow for a quantitative assessment of bony changes.

Another proposed method for evaluating bony changes in the periapical region is via tracking changes to the three-dimensional volume of an associated rarefaction. By determining the volume of the area of interest one can track the volume changes over time in a quantitative way. Ahlowalia compared the accuracy of volumetric measurement of artificially created periapical lesions in bovine bone when using CBCT and micro-CT. It was found that both CBCT and micro-CT had a high degree of agreement (>0.9) when compared to the physical measuring of the lesion. They concluded that CBCT would be an accurate means to determine the volume of a periapical lesion and a valuable tool for the interpretation and monitoring of healing of the periapical tissue.

ITK-SNAP (v. 3.8.0), a computer-based software, that can be used for the segmentation of non-regular areas, has been found to be an accurate tool to determine the three-dimensional volume of a segmented model in CBCT imaging (30). Gomes, in a non-clinical setting, found ITK-SNAP to be highly accurate when compared to the known volume of the segmented areas (31). Further research has found this software to have high accuracy in determining the upper airway volume in CBCT volumes (32). Additionally, ITK-SNAP has been used to assess healing following endodontic periapical micro-surgery (33).

As stated previously, the goal of endodontic treatment is to prevent pulpal and periapical pathology, and when indicated, treatment to correct the disease process. This goal relies on the clinical examination, the radiographic interpretation and the clinicians training and experience to identify disease and prescribe treatment. Each individual clinical test and radiographic imaging modality provides information that when combined attempts to provide an assessment of the histological status of the pulpal and periapical tissue. Since histopathologic evaluation is not feasible or ethical in this clinical environment, the results of the clinical and radiographic evaluation must be interpreted to make a diagnosis. Clinicians rely on this data when evaluating endodontically treated teeth to assess the state of healed, healing or non-healing and then offer recommendations for further treatment if indicated.

In light of this, the aim of this study was to assess the changes in CBCT-PAI score as well as the volume of periapical findings associated with an endodontically treated and asymptomatic tooth and to see how these findings change over time. The information obtained will add to the existing research and may help a clinician interpret the presence of a periapical finding associated with an asymptomatic endodontically treated tooth and may influence any subsequent treatment or monitoring recommendations.

Methods

This research aimed to evaluate recall CBCT images by comparing the periapical findings of asymptomatic endodontically treated teeth from the initial recall CBCT to a follow up recall CBCT.

Patient records from an endodontic private practice were searched with the following inclusion criteria:

1. Patient had at least one tooth endodontically treated at the private practice.
2. Patient had recall examination completed which included clinical signs and symptoms and CBCT imaging was performed.
3. The treated tooth was asymptomatic to percussion, palpation and biting test and the tooth was functional for the patient.
4. CBCT interpretation indicated a periapical finding associated with the treated tooth.
5. A second recall examination was completed which included clinical signs and symptoms and CBCT imaging performed at least 1 year after the initial recall examination.

A periapical finding was defined as any deviation from “normal” apical anatomy and would include any size of periapical rarefaction as well as signs of widening of the periodontal ligament space (>0.5mm) associated with the endodontically treated tooth.

After identification of patient records that satisfied the above criteria, all patient identifiers were removed and each patient was assigned a number. A master spreadsheet was made with the assigned patient number and the corresponding treatment date, treated tooth number, initial recall examination date, follow-up recall examination date and the corresponding CBCT volumes were collected. The CBCT volumes were exported from the CBCT server in an anonymized multi-file dicom format.

A random number generator was used to assign the order in which the scans would be evaluated to ensure blinding. A master key was maintained so that the data could be analyzed and statistically evaluated after evaluation of scans was completed.

Both evaluators, an oral radiologist and an endodontic resident, met and reviewed the CBCT-PAI scoring system and measurements for calibration (29). Use of the software, ITK-SNAP, was reviewed as well as methods for segmentation of CBCT imaging, interpolation of the data and ultimately recording of the volume of any findings in the CBCT imaging. All CBCT volumes reviewed by the endodontic resident were reviewed on a computer monitor with a resolution of 1080x1920 in a room with a dimmed light source. All CBCT volumes evaluated by the oral radiologist were reviewed on a computer monitor designed for medical imaging with a resolution of 1080x1920 in a room with a dimmed light source.

The first 5 scans, which were randomly assigned, were reviewed in Carestream Software and CBCT-PAI score recorded independently by both evaluators. Subsequently, the same scans were evaluated in ITK-SNAP where any periapical finding was segmented, interpolated and the volume of the finding was recorded. The two evaluators then compared both the CBCT-PAI score as well as the volume of the periapical findings from ITK-SNAP to confirm inter-observer comparability and calibration.

Following this initial calibration, each evaluator proceeded to record a CBCT-PAI score and the calculated volume of the segmented finding for each scan in the randomly generated order. If a scan, upon review had multiple roots within the same endodontically treated tooth with a periapical finding, both findings were recorded as separate entities and CBCT-PAI and volume size was recorded for each respective root (ex #14 with findings on both palatal and mesiobuccal roots that were distinctly separate).

After the CBCT-PAI score and volume of the periapical finding were determined, the data was recorded in spreadsheet format as well as entered into a REDCap online form indicating the respective scan number, the evaluator name, the CBCT-PAI score and volume of the finding (34). Once data collection was complete, the time elapsed since initial treatment and the time between the initial recall examination and the follow-up examination were calculated.

Statistical Methods

Agreement between two independent raters was assessed using Kappa Statistic for CBCT-PAI scores and ICC for volume. Change in CBCT-PAI score was evaluated with McNemar's Chi-squared test. Change in lesion size was evaluated with Wilcoxon signed-rank test. Associations with the age of the treatment (time from treatment to first follow-up) were assessed with Kruskal Wallis test (CBCT-PAI score) and Pearson's correlation (volume). Significance level was set at 0.05. SAS EG v.8.2 (SAS Institute, Cary, NC) was used for all analyses.

Results

A total of 38 cases were included in the analysis although 40 were reviewed. Exclusions were made for those that had a CBCT-PAI score of 0 at the initial recall as judged by the radiologist. All CBCT images, both initial recall and follow-up recall, were taken using the same Carestream CS 9000 unit using limited field of view and 75 micron resolution.

Agreement between the two raters was very high for the volume (ICC=0.98). Agreement was substantial for CBCT-PAI score (k=0.69) (35). The average time elapsed from treatment to initial recall was 7.9 years and an average of 2.88 years between recalls.

Based on CBCT-PAI ratings from the radiologist, 36% of the cases had improvement based on the CBCT-PAI scores, 40% remained the same, and 24% were worse. Overall, the CBCT-PAI scores did not change significantly between the two time periods (p-value=0.6505). Although the median number of years since treatment was lowest for those who had an improvement in CBCT-PAI scores (4.54 years; IQR: 3.82-8.10 years) it wasn't significantly different from those that remained the same (5.25; IQR: 3.06-13.69) or those that got worse (8.25; IQR: 2.35-14.69) (p-value=0.7842).

Volume measures were averaged between the two raters for subsequent analyses. The median change in volume was 0.80mm^3 smaller at follow-up (IQR: -2.28-1.06). The distribution of the periapical volume size and the associated age of treatment (years elapsed from initial treatment to follow-up treatment) is given in Table 1.

The change in the volume was not statistically significant (p-value=0.2859). The correlation between change in finding volume and time since treatment was not statistically significant (r=0.06, p-value=0.7020). There were 16 cases that had a volume of less than 3.0mm^3 at the initial recall. Of those 16 cases, 93% of them remained less than 3.0mm^3 at the follow-up recall. The one case that got larger was referred for extraction due to a suspected vertical root fracture.

The median CBCT-PAI score for both evaluators is represented in Table 2. The lesion size is graphically compiled in Figure 1 where the lesion size of each case along with its respective years since original treatment to follow-up recall examination are represented. The percentage change of the volume of the periapical finding are represented graphically in Figure 2. In both figures the green dot represents that the periapical finding decreased in size, gray dot indicated the volume increased from 0.01-10.0% and the red dot indicates the volume increased greater than 10.01%. The distal extent of the black bars seen in Figure 1 represent the initial recall volume.

Table 1: Volume of Periapical Finding Distributed by Time Elapsed Since Treatment

		Median Volume		
	n	**Initial Volume (mm^3)**	**Follow-up Volume (mm^3)**	**Paired Change (mm^3)**
1 to 5 Years	9	1.35	0.62	-0.52
6-7 Years	9	5.57	5.37	-1.75
8-9 Years	4	7.22	13.91	7.19
10-15 Years	6	2.64	2.23	-0.65
16-20 Years	10	14.92	15.77	-0.44

Table 2: Median CBCT-PAI Scores

	Endo Resident	**Oral Radiologist**
Initial Recall CBCT-PAI	2	2
Follow-up Recall CBCT-PAI	1	1

Figure 1: Volume Change of Periapical Finding

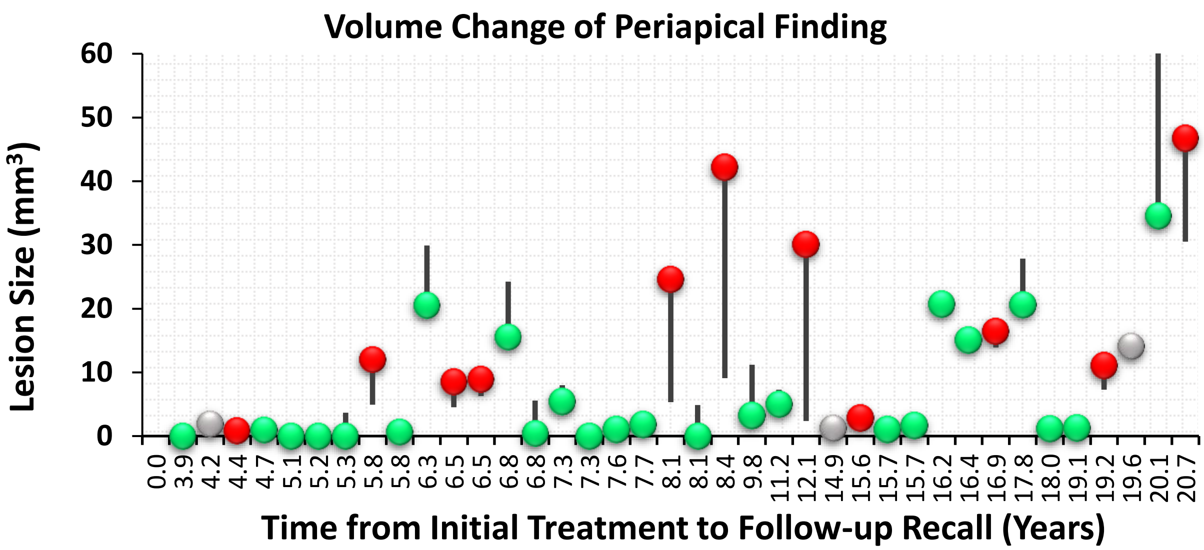
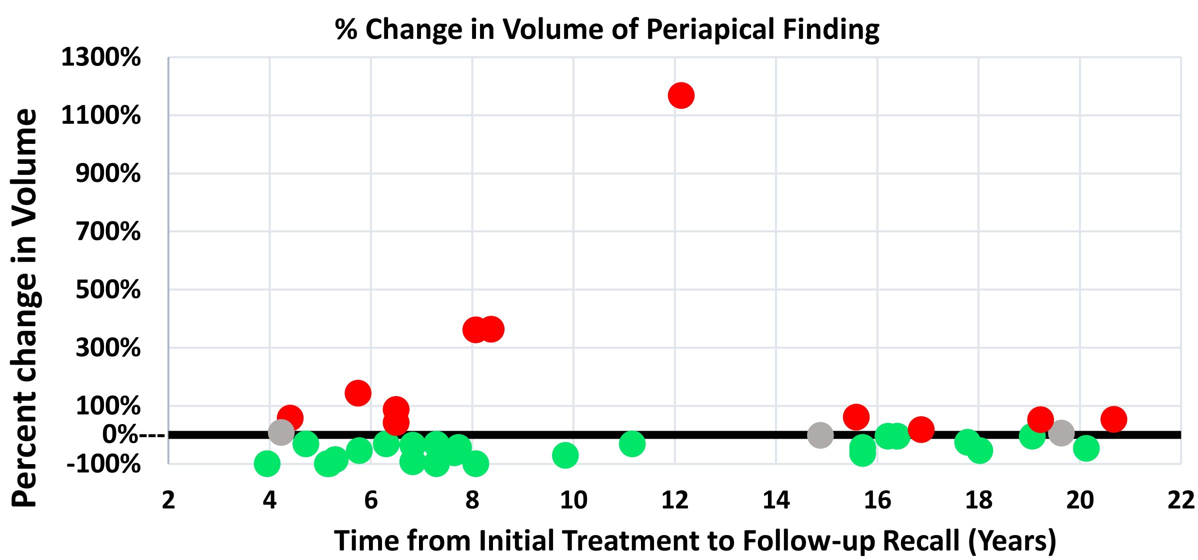


Figure 2: Percent Change in Volume of Periapical Finding



Discussion

The primary purpose of this retrospective study was to evaluate periapical findings associated with asymptomatic endodontically treated teeth and compare how they changed over time using CBCT-PAI and three-dimensional volume changes on CBCT imaging. This assessment of how these findings change over time may help clinicians make clinical judgements and treatment recommendations when a periapical finding is visualized without the presence of associated clinical signs or symptoms of pathology.

It is appropriate and understood that a clinician would utilize all the available data to formulate a diagnosis and an appropriate treatment plan. Furthermore, clinicians are taught that rarefactions present on a radiograph are indicative of some grade of inflammation indicating pathology which is backed up by historical research of periapical lesion pathology, etiology and how subsequent treatment leads to resolution of the periapical lesion (8,9,36–38). Periapical radiography is the gold standard for evaluation of the periapical region but has limitations in its ability to detect periapical rarefactions (7). The matter of subjectivity comes into question with regard to evaluation of radiographs and the inherent "human" error factor. Radiographic evaluation is highly dependent on the clinician. In 1972, Goldman illustrated the subjectivity present in conventional film-type periapical radiographic analysis (39). In his study, conventional post-treatment and recall periapical radiographs were presented to a radiologist, endodontists and endodontic residents and they were tasked to evaluate for the presence or absence of a periapical lesion. Goldman's research found the interpretation of a radiograph to be widely varied. Agreement of success and failure between the evaluators only occurred 47% of the time and agreement whether a lesion was present only 42% of the time. Additionally, the intra-observer agreement was 75% which indicated that even the same evaluator only agreed with their own assessment 75% of the time upon a second evaluation at a later date (39). More recently, a similar study with digital radiography by Tewary, found similar results with inter-observer agreement of all evaluators to be only 25% with an intra-observer agreement ranging from 41%-85% (40). This research demonstrated the subjective nature of radiographic interpretation to evaluate the presence of disease. Despite large technological advancements in dental radiography between the referenced studies, the human subjectivity factor still varies widely and should be taken into consideration when evaluating the radiograph for success versus failure determination. The advent of CBCT has provided an additional diagnostic tool for assessment of the periapical region but still contains the same challenges of subjectivity when interpreting the CBCT volume. A recent CBCT study by Chogle found that when evaluating periapical radiographs and CBCT by three different examiners, there was inter-observer agreement of apical diagnosis 65% of the time using periapical radiograph and 72% of the time when using CBCT (41). This indicates that despite the increase in information that can be obtained by CBCT there still is varying subjectivity when evaluating the CBCT images.

The findings of this study further reinforce the subjectivity present in the interpretation of CBCT imaging. Similar to Goldman and Tewary, this study found that there were varying levels of agreement between the oral radiologist and the endodontic resident. This was more evident in the CBCT-PAI score between the two evaluators where there was 77% agreement between the two evaluators. The results of this study could be strengthened if the same scans were reviewed by the same examiners again at a later date to compare the intra-observer agreement. Demarcation of the radiolucent finding depended on several factors including orientation of the CBCT image in the viewer, contrast adjustment and experience of the evaluator. Demarcation of the radiolucent border of a periapical finding is highly dependent on the evaluator's judgement. Many of the CBCT volumes reviewed represented only mild widening at the periapex and thus a well-defined or corticated border was not visualized and resulted in variation of the three-dimensional volume determination. Additionally, due to the generally small size of the periapical findings being evaluated, even small discrepancies in lesion demarcation may result in significant inter-observer volume disparities.

The time between recalls, while it did not indicate any statistical difference in CBCT-PAI score change or periapical finding volume size in this study, showed interesting results for one case that was treated 16 years prior and then recalled at 20 years post treatment. This case in particular, at 16 years had a periapical finding volume of $64mm^3$ and then at 4 years later had a periapical finding volume of $34mm^3$. This represented a significant decrease in periapical finding volume of 46%. Other studies have demonstrated cases that had long-term healing up to 7 years as well as a study evaluating PA changes at 10-17 and 17-27 years post endodontic treatment (1,42).

Periapical radiography has been demonstrated to underestimate the size of a rarefaction in part due to a thickened cortical plate, variation in anatomy, superimposition of anatomical structures and the fact that it is a two-dimensional representation of a three-dimensional object (14,15,18). To overcome some of these limitations, additional angulated radiographs may be taken to further help interpret the periapical status as well as localization of pathology (26,43,44). Due to these limitations, clinicians often will recognize the value that CBCT offers to provide additional information regarding the periapical status of the tooth in question and prescribe such imaging for their patients. CBCT has been shown to be more sensitive and accurate while detecting periapical rarefactions and its value in clinical practice can influence the treatment options presented as well as treatment approach (26,45,46). However, Kruse challenged the diagnostic validity of periapical radiographs and CBCT to accurately detect true apical periodontitis (47). Patients that had undergone apical surgery and upon recall, the periapical radiographs and CBCT indicated a “unsuccessful healing” status, underwent an additional surgical procedure and histopathologic examination of the periapical tissue was completed. Of those cases, 42% showed no histologic signs of periapical inflammation despite evidence of it on the periapical radiograph and CBCT. These cases underwent additional treatment due to an inaccurate diagnosis of apical periodontitis. The data from this research finds that 76% of cases, over the recall time period, had either no change or a reduction in CBCT-PAI score. The initial CBCT-PAI score would indicate evidence of periapical pathology, however given additional time the cases examined either remained unchanged or the score decreased. This finding may be clinically analogous with the cases where Kruse reported that no periapical inflammatory disease process was found despite the appearance of it on the CBCT (47).

Subjectivity of the radiograph was also examined by Strong where the periapex of a normal healthy non-root filled tooth was digitally manipulated to include poor endodontic treatment or a poor quality coronal restoration (48). Evaluators were tasked to evaluate the periapical region before the digital manipulation and then other evaluators reviewed the same radiograph but with digitally manipulated coronal restoration or endodontic treatment. They found that the evaluators had a significantly higher tendency to rate the apex as “definitely abnormal” or “probably abnormal" despite no changes within the periapical region on the manipulated image. This study demonstrated that once a tooth becomes endodontically treated and has either a poor restoration or poor endodontic treatment, the evaluators became significantly more critical of the periapical region. The concept of confirmation bias occurs when the evaluating clinician begins to gather evidence to makes an initial diagnosis but then selectively places more or less weight on evidence that may strengthen or contradict their original diagnosis (49). In Strong's study, evaluators saw either a poor-quality restoration or endodontic treatment and may have become biased to conclude that periapical changes were occurring when in fact only the obturation and restoration was manipulated. This is relevant to the results of this study because many of the periapical findings that resulted in the CBCT being included in this study were quite small. Furthermore, one of the main objectives of the recall examination is to critically evaluate the periapical region of the treated tooth and despite the findings often being small, any deviation from what the examining clinician deemed to be a "normal" CBCT appearance resulted in the periapical status of the tooth to be called into question and thus being included in this study.

While CBCT has been proven to be an asset, one must consider the limitations of the imaging modality. The diagnostic accuracy using CBCT to evaluate true apical periodontitis, in non-root filled teeth is very accurate but has been shown to drop significantly when the tooth is endodontically treated (50). Kruse found that when evaluating non-root filled teeth in human cadavers using CBCT, the clinical diagnosis as compared to histology had a sensitivity of 0.95 when detecting apical periodontitis and 1.00 when detecting no apical periodontitis (50). In root filled teeth however the sensitivity decreased to 0.63 in detecting apical periodontitis and 0.91 when detecting no apical periodontitis. This demonstrates that the presence of root filling materials decreases our ability to accurately diagnose apical periodontitis via CBCT. Kruse proceeded to suggest that CBCT interpretation alone should not be used to determine if apical periodontitis is present in root filled teeth and that clinical signs and symptoms must be accounted for when attempting to interpret all the clinical and diagnostic data when evaluating an endodontically treated tooth (50). The data from this research found that 71% of the periapical findings got smaller in volume or remained within +10% of its initial size. This may indicate that despite the CBCT appearance being consistent with that of asymptomatic apical periodontitis the true histologic status may have been that of the normal healing process or normal apical tissue.

Furthermore, the introduction of artifacts from metals or other radio-opaque materials present in the CBCT volume can negatively impact the ability to accurate visualize the area of interest (51). CBCT, since it is a three-dimensional representation of the dental and alveolar structure, is able to remove some of the limitations of two-dimensional imaging such as superimposition but does introduce new challenges. Patient movement during CBCT imaging, distortions, streaking, sun bursting, beam hardening are all forms of artifacts that can contribute to the challenges encountered when interpreting a CBCT image. These distortions may come from dental restorations such as metal alloy fillings, adjacent implants, root filling materials such as gutta percha, extruded sealer or posts present in the canal system (51,52). Additionally, materials used in surgical repair from facial trauma or orthognathic surgery may create distortions and artifacts in the area of interest making interpretation difficult or unreliable (52). When interpreting the CBCT and the diagnostic yield that it provides, the clinician should consider these limitations to avoid over interpretation of the CBCT volume. Kruse demonstrated how existing root filling material alters the evaluators ability to accurately detect apical periodontitis (50). This may be in part due to the close proximity of the root filling material to the area of interest which is generally the apical most portion of the root surface just adjacent to gutta percha as well as potentially extruded sealer material present in the periapical bone. This distortion may contribute to the decreased diagnostic accuracy of the apical tissue and lead to over interpretation of the periapical region.

As has been described, CBCT is more likely to detect a periapical finding compared to periapical radiography. As CBCT use increases, periapical findings associated with endodontically treated teeth will also likely increase. Regardless of the reason the CBCT was taken, the clinician must use evidence-based recommendations to the patient when these findings are discovered. In a recent editorial by Patel the process of disease identification, treatment recommendation and outcome determination is discussed (53). Patel addresses how CBCT has complicated the way that endodontic success is determined. Since more radiolucent findings associated with endodontically treated teeth are seen with CBCT, cases that may have been deemed clinically and radiographically successful by two-dimensional radiography are now called into question due to the increased sensitivity of CBCT. A new diagnosis of asymptomatic apical periodontitis may be established in these cases. From the perspective of the patient the endodontic treatment is deemed successful despite the new periapical diagnosis. Friedman addressed how the disease centered measure of success, specifically resolution of disease, is often lower when the patients perception of success is compared (54). A patient will likely deem treatment to be successful when there is resolution of pain, restoration of masticatory function and ultimately retention of the treated tooth. In a patient centered treatment ideology, a diagnosis of asymptomatic apical periodontitis may lend itself to an active surveillance type of recall interval (53). When choosing to monitor rather than pursue treatment in these cases the risk of increased pain, swelling or systemic complications has to be assessed. Patel describes that certain sub-populations of patients are likely not suitable for a monitoring approach such as organ transplant recipients, patients undergoing chemotherapy or patients that are otherwise considered immune-compromised (53). More research regarding the potential adverse events occurring due to monitoring of asymptomatic apical findings of endodontically treated may be pursued to better evaluate any potential risks.

In the daily practice of medicine and dentistry, clinicians are faced with the task of evaluating the patient, performing diagnostic testing, establishing a diagnosis and then prescribing a treatment which is then monitored to determine success. The determination of success, in the field of endodontics, has clearly evolved over the years. Donabedian, a prominent figure in the medical community, discussed how we define quality of care and how we assess it (55). Donabedian describes that outcomes are multi-factorial and how an outcome of success or failure may differ depending on the perspective taken when evaluating the disease, treatment and value of the outcome (55). A 2016 manuscript from the Journal of the American Medical Association described a shift from disease centered outcomes to a patient centered or patient goal based outcome ideology (56). The disease centered ideology aims to provide treatment recommendations to resolve the disease and then make diagnostic and examination-based determinations that the disease process has been altered or eliminated. A patient centered outcome measurement will take into account the cost and benefit of further treatment for the patient as well as the quality of life that continued treatment, alteration of treatment or continued monitoring would have for the patient (56). As it would apply to endodontics, there is an increase in frequency of discovery of periapical findings associated with endodontically treated teeth that were likely to remain undetected on periapical radiographs. In these cases, the treating clinician will need to make a treatment recommendation based on the discovery of the new periapical finding. This study may provide insight at the long-term changes that a clinician may expect to see as it relates to periapical findings associated with asymptomatic endodontically treated teeth. When considering treatment recommendations upon the discovery of such a finding, there is an increase in evidence that an active surveillance approach may be warranted (53,57).

Conclusion

This study found that 76% of the periapical findings had unchanged or improved CBCT-PAI scores and 71% had a change in volume that decreased or stayed within +10% of the initial volume. Periapical findings associated with these teeth had an overall decrease of $0.80mm^3$ throughout the recall period. Of the cases that presented with a periapical finding volume less than $3.0mm^3$ at the initial recall examination, 93% had a periapical finding volume of less than $3.0mm^3$ at the follow-up recall examination. The present study includes teeth that were treated up to 20 years previously, and despite the presence of a periapical finding has provided many years of function for these patients and all, except 2, remained asymptomatic. Based on this study, clinicians may consider active surveillance as a treatment option for endodontically treated teeth with periapical findings, especially those that are small in size, as long as the patient is immunocompetent, clinically free of pathologic signs and symptoms and the tooth is functional.

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