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Evaluation and Comparison of Periapical Healing Using Periapical Films and Cone Beam Computed Tomography: Post-Treatment Follow Up

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Evaluation and Comparison of Periapical Healing Using Periapical Films and Cone Beam Computed Tomography: Post-Treatment Follow Up

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

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Table of Contents

List of Tables

List of Figures

Abstract

ASSESSMENT OF PERIAPICAL HEALING USING PERIAPCAL RADIOGRAPHS AND CONE BEAM COMPUTED TOMOGRAPHY: POST-TX FOLLOW UP

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Purpose: The purpose of this study was to assess the radiographic changes in periapical status and analysis of healing determined using periapical radiographs (PA) versus cone beam computed tomography (CBCT) pre-operatively and at 3-64 months following endodontic treatment.

Methods: Pre/post treatment radiograph and CBCT scans of patients who had NSRCT, NSReTx, or SRCT from July 2011-December 2018 at VCU Graduate Endodontic clinic were included in this study. Volumetric and linear measurements of periapical lesions on initial and recall PA and CBCT images were performed using three calibrated examiners. Changes and differences in the estimated area from PA to CBCT were compared using the Wilcoxon signed-rank test. McNemar's chi-squared test was used to determine agreement in the proportion of lesions that were absent (0x0) between the PA and corresponding view of CBCT. This data was used to calculate the sensitivity, specificity, positive predictive value (PPV), and negative predicative value (NPV).

Results: A total of 51 patients with a median healing time of 13 months were included in the analysis. Significant healing was observed on both PA and CBCT images (p-value<0.0001). CBCT images detected significantly larger lesions and observed greater changes in healing. PA images had very low negative predictive value (40%) but were moderately strong in terms of sensitivity (71%), specificity (80%), and positive predictive value (94%).

Conclusion: Assessment using CBCT revealed a lower healing rate for all treatment categories compared with periapical radiographs. CBCT was more likely to detect the presence of a PARL, whereas a periapical radiograph would be less sensitive to detection of a PARL. Significant healing cannot be detected at an earlier point in time with PA radiographs or CBCT.

Introduction

The main goal of endodontic therapy is the prevention or elimination of apical periodontitis. Apical periodontitis is an immune mediated inflammatory response due to the infiltration of bacteria and their endotoxins into the pulp space of the root canal system. This process induces pathologic changes at the root apex referred to as apical periodontitis.(1)(2) Previous studies have suggested nearly half of the population will encounter apical periodontitis by age 50. Root canals are the treatment of choice in treating these periapical lesions.(3)

Diagnosis of apical periodontitis is determined by radiographic appearance, endodontic tests such as percussion and pulp testing, and patient signs and symptoms. In 2009, the American Association of Endodontics classified the types of apical periodontitis.(4) This classification discerns between asymptomatic periodontitis which consists of the presence of a periapical radiolucency (PARL) in the absence of symptoms and symptomatic apical periodontitis which consists of clinical symptoms but a PARL may/ or may not be present. Proper diagnosis is important when determining the appropriate treatment modality.

After root canal therapy results in the elimination or reduction of bacteria, healing may begin. Inflammatory cytokines and mediators within the lesion transition from a pro-inflammatory, destructive to anti-inflammatory and proliferative nature. Osteoprogenitor cells undergo differentiation into osteoblasts which secrete bony matrix to replace bone destroyed due to apical periodontitis. (5)

Since 1956, criteria for successful endodontic therapy has been assessed according to Strindberg's criteria. This criteria includes complete healing of the periapical lesion.(6) Orstavik completed a study in 1996 comprising of 599 endodontically treated roots. He concluded the peak incidence for healing of apical periodontitis was one year following treatment, however some cases required more than four years for complete radiographic healing.(7) Shortly after the completion of this study, the European Society of Endodontology recommended a one year follow up and subsequent evaluation for up to four years if presence of a periapical radiolucency remained.(8)

Periapical radiography has been the main method of modality to evaluate the healing of apical periodontitis which is illustrated by a radiolucency at the apex of the tooth. (9) Pre-operative periapical radiographs are used to aid in the diagnosis and estimate the size of the periapical lesion prior to treatment. Upon completion of the root canal, post-operative periapical radiographs are taken to evaluate any change in size of the radiolucency. The absence or decrease in size of the radiolucency suggests healing. An increase in size of the periapical lesion suggests the lesion is not healing and disease is still present. However, if the size of the lesion is consistent or unchanged it is more difficult to discern the situation and subsequently how to proceed with treatment.(7)(10)(11)

Since, periapical radiography is only two-dimensional it limits the amount of information it provides. For instance, the bucco-lingual dimensions cannot be assessed in periapical radiographs. In addition, superimposition of adjacent anatomical structures such as the maxillary sinus may interfere with appropriate interpretation. Studies have shown that in some instances bone must be demineralized by 30-50% in order to visualize these lesions radiographically.(12) Bender and Seltzer stated periapical lesions are not detected by periapical radiographs if confined only to cancellous bone (13) or if less than 12.5% of bone loss exists in the area.(12) Many other authors have confirmed perforation of the cortical bone is necessary for radiographic detection of lesions. (14)(15)(16). These reasons contribute to why healing of periapical lesions may not be known for many years after treatment. A study completed in 1991 by Walter Murphy evaluated the healing of periapical radiolucencies after nonsurgical root canal treatment using periapical radiographs. This retrospective chart review evaluated 89 patients with a minimum of a 2mm periapical radiolucency measured on the pretreatment periapical radiograph. At the three-month recall, 41 (46.1%) of the periapical lesions had resolved completely and 43 (48.3%) had a decrease in size of the lesion. Murphy also discovered at the 12 month follow up after root canal therapy 70.6% of lesions had complete healing whereas only 17.6% of lesions had complete healing at 6 months. (11)

While cone beam technology has existed since the 1980s (17), the application of CBCT was developed for dental and maxillofacial use in the late 1990s. (18) The introduction of cone-beam computed tomography (CBCT) as a three- dimensional imaging technique has had a huge impact on the field of endodontics. CBCT has been shown to overcome many of the limitations attributed to periapical radiography.(19)(20)(21)(22) This imaging modality aids in the visualization of periapical lesions not seen otherwise due to small size or being confined in cancellous bone.(23)(24) In addition, CBCT allows the opportunity to assess and measure the periapical lesion in three orthogonal planes. (25) However, in a recent systematic review, Aminoshariae notes a few disadvantages of CBCT which include radiation exposure, high levels of scatter (metal posts) and increased costs to the patient. (26)

A joint position paper released by the American Association of Endodontics and the American Academy of Oral and Maxillofacial Radiology provided scientifically based guidance to clinicians for the use of CBCT in Endodontics. These guidelines included recommendations to use CBCT in situations such as complex anatomy, localization of a calcified canal, re-treatment assessment, trauma, pre-surgical planning, external/internal resorption, and implant placement.(27) However, it was also suggested that periapical radiographs be the imaging modality of choice for endodontic treatment. In addition, this position paper also recommends completing a CBCT with a limited field of view (FOV), which diameter ranges from 4-100mm. The limited FOV contains smaller voxel sizes which offer a higher resolution and decreased radiation dose to the patient.(28)

For these reasons, many people have suggested to use CBCT volumetric measurements of lesions to assess dimensional change. (25) It has been determined through studies that these volumetric measurements correlate accurately with physical volumes of artificially created bone lesions. (20)(29) Van der Borden was the first to assess 3-dimensional changes of periapical lesions after root canal treatment. His study included 50 teeth with 71 roots with evidence of periapical bone loss and compared initial lesion sizes on periapical radiographs and CBCT with post-operative radiographs recalled over 10-37 months after root canal treatment. At recall, 11 of 71 roots (15.5%) showed complete healing of the lesion on CBCT compared with 32 of 71 (45.1%) on periapical radiographs. Overall, 55 of 71 roots (77.5%) showed a reduction in size of the lesion on CBCT compared with 63 of 71 roots (88.7%) on periapical radiographs. Van der Borden illustrated that changes in the size of lesions were different when comparing 2D periapical radiographs and 3D volumetric CBCT. (30)

Other studies have shown similar results. Garcia de Paula-Silva examined 83 treated or untreated roots of dogs using periapical radiographs, CBCT, and histology. He discovered periapical radiographs detected periapical radiolucencies in 71% of teeth while CBCT detected periapical radiolucencies in 84% of teeth. He concluded a CBCT scan was more sensitive in detecting apical periodontitis compared with periapical radiographs, which was more likely to miss apical periodontitis when it was still present.(21) In 2013, Liang evaluated 84 single-rooted teeth associated with periapical lesions 10-19 months after root canal treatment. He discovered CBCT detected significantly greater post treatment periapical lesions than periapical radiographs. Overall, the absence of periapical lesions on CBCT was observed in 16/84 teeth (19%) and a decrease in size in 61/84 teeth (72.6%). (31) Zhang looked at 61 single rooted teeth with residual periapical lesions on a CBCT after one year of treatment. A second CBCT one year later showed a decrease in lesion volume in 38/61 teeth (63%), unchanged volume in 20/61 teeth (33%) and an increased volume in 2/61 teeth (3%). (32) Lastly, in 2012 Patel discovered an absence of periapical radiolucenies 92.7% of the time with periapical radiographs and 73.9% for CBCT. He summarized that CBCT revealed a lower healed and healing rate for root canal treatment than periapical radiographs. (26)(33)

As these studies show, apical periodontitis is a dynamic process that takes time and can necessitate many years before showing indications of complete healing.(7) The aim of this study was to compare the volumetric changes in sizes of periapical lesions pre-operatively and post operatively after recall examinations for NSRCT, NSReTx, or endodontic periapical surgery with PA radiographs and CBCT. A comparison between these two modes of radiography was also assessed.

Methods

This study utilized a review of data using a retrospective cohort design to determine the dimensional changes that occur in periapical radiolucencies using periapical radiographs and comparing these changes to dimensional changes seen in CBCT scans following endodontic treatment. The VCU Institutional Review Board approved this study (IRB #HM20012563). Eligible for inclusion were all patients referred to the Graduate Endodontic Practice at Virginia Commonwealth University School of Dentistry for non-surgical root canal therapy (NSRCT), non-surgical retreatment (NSReTx), or endodontic periapical surgery from 2010 through 2018.

The study population comprised patients who presented for endodontic treatment in the Graduate Endodontic Practice at VCU School of Dentistry (Richmond, VA). Patients were referred for evaluation and treatment from the VCU School of Dentistry undergraduate student clinics as well as the Advanced Education in General Dentistry residency, Faculty Practice, and Richmond metropolitan area private dental practices.

Graduate endodontic residents completed the initial evaluations of all patients. Evaluations included subjective and objective information, clinical findings, diagnostic test results and pulpal and periapical diagnoses. This information was recorded in the electronic patient record (Axium©). Treatment options were reviewed with the patients and included: 1) Perform NSRCT, NSReTx, or periapical surgery, 2) Extraction of the tooth and replacement with other prosthesis (i.e.: fixed partial denture, implant and crown, or removable partial denture), and 3) No further treatment. The advantages, disadvantages, risks, benefits, and cost of these treatment options were discussed with the patient.

Specifically, the following data was recorded:

Subjective Symptoms: Pain to Cold, Pain to Heat, Pain on Biting or Release, Localizable or Diffuse Pain

Diagnostic Testing: Cold test, Bite test (Biting and Release), Percussion test, Transillumination, Mobility, and Periodontal Probing Depths

Radiographic Evaluation: Presence or Absence of a Periapical Radiolucency, Size of the Periapical Radiolucency, Periodontal Defects present (Isolated, Generalized, or Vertical)

Diagnosis:

Pulpal: Symptomatic Irreversible Pulpitis, Asymptomatic Irreversible Pulpitis, Pulpal Necrosis, Previously Treated

Periapical: Normal Periapical Tissues, Symptomatic Apical Periodontitis, Asymptomatic Apical Periodontitis, Acute Apical Abscess, Chronic Apical Abscess

For NSRCT and NSReTx, treatment sequences followed standard clinical protocol. Instrumentation was performed using stainless steel hand files and a variety of different nickel titanium rotary systems. Irrigation included 5.25% Sodium Hypochlorite and 17% Ethylenediaminetetraacetic acid (EDTA) for all cases. In some cases, 2% Chlorhexidine was also used. All canals were cleaned and shaped to a minimum of a 30/.04 final apical diameter. Obturation was performed using gutta percha with either cold lateral condensation or a continuous wave warm vertical technique. Roth's 401 sealer or Tubliseal was used. Following obturation, the access opening was occluded using a provisional material (Interim Restorative

Material or Cavit) or definitively restored (resin composite or amalgam). Surgical treatment was also performed in accordance to a standard clinical protocol. Reflection of a full-thickness mucoperiosteal flap preceded osteotomy and root resection in all included surgical cases. In most, but not all surgical cases, roots were ultrasonically retroprepared prior to placement of a retrofill material. Intra-operative hemostasis was achieved with the use of standard cotton pellets, epinephrine-impregnated cotton pellets (Racellets®), and/or ferric sulfate. Flap closure was achieved via monofilament suture materials. All cases were performed using a Zeiss OPMI Pico microscope or a Global microscope.

Patients were included in the study if (A) documentation of their clinical records was complete, (B) NSRCT, NSReTx, or periapical surgery was completed on at least one of their teeth, (C) a pre-treatment, or intra-treatment, PA and CBCT showed a periapical radiolucent lesion (PARL) around the apex of at least one root of the tooth in question, (D) and a periapical radiograph and CBCT scan were taken at a subsequent follow up appointment (no less than 3 months after treatment was completed). An area of low density (or radiolucency) periapically was defined as a lesion if it measured at least twice the width of the normal periodontal ligament space on an adjacent healthy tooth.

Patients who were pregnant, had a history of receiving therapeutic radiation to the head or neck, were younger than 18, or older than 89, were excluded from the study. Any teeth that had a history of a previous endodontic surgery were excluded. There was no restriction for race, ethnicity, or gender.

All of the CBCT scans, both initial and follow-up, were taken with the Carestream 9300 system (Carestream Health; Rochester, NY). All CBCT images were taken using a limited field of view (5 x 5 cm) and a voxel size of 0.090 mm. Operating parameters were set at 2-10mA, 60-

90 kV, and 12 seconds. CBCT images were analyzed using a Dell Optiplex 990 computer (Dell SA, Geneva, Switzerland) and a 22-inch LCD monitor with a resolution of 1680 x 1050 pixels (Dell SA, Geneva, Switzerland). All preoperative images were taken to aid the resident in diagnosis and treatment of these cases.

Two board-certified endodontists and an endodontic resident performed linear measurements on each periapical radiolucency using MiPACS software for PA radiographs and CS 3D Imaging software (Carestream Health; Rochester, NY) for CBCT scans. Using the MiPACS software, the evaluator located and measured the PA radiolucency at the area of the widest dimension on the PA radiograph. A second measurement was then made at 90 degrees to the initial measurement thus giving both dimensions of the PARL on the PA radiograph. Linear measurements for CBCT scans were completed using orthogonal slicing. The evaluator located the slice that appeared to demonstrate the largest size of the lesion and made a measurement of the lesion at what appeared to be the widest dimension. A second measurement of the widest dimension was then made at 90 degrees to this initial measurement. These measurements were to be made from a bone landmark to another bone landmark. If the lesion did not have clearly demarcated boney borders, (for example if the cortical plate was perforated by the lesion or if the sinus was perforated by the lesion) the evaluator was asked to estimate the lesion boundary based upon the bone that could be observed on either side of the bone defect. These measurements were performed in the axial, coronal, and sagittal planes for each lesion. A calibration between examiners was performed by comparing the measurements made on the first 5 lesions in the study and calculating the intraclass correlation coefficient (ICC). The overall ICC among the three raters was high, at 0.80. Among the PAs, it was 0.83 and for CBCT scans it was 0.78. Since calibration demonstrated consistent ability to measure, the remaining images were divided among the three evaluators and each examiner measured seventeen periapical lesions. Data from each measurement was compiled using Microsoft Excel (Microsoft Corp. Redmond, WA).

Area of periapical radiolucency was estimated from PAs using area of ellipsoid (pi*1/2width*1/2height). For CBCT images, the area was calculated in the same manner but was dependent on the tooth. For anterior teeth, the area was calculated from the size on the coronal view on the CBCT (Figure 2) and for posterior teeth, the sagittal view was used. Changes in area before and after treatment and differences in estimated area from PA to CBCT were compared using the Wilcoxon signed-rank test due to skewness in the data. McNemar's chi-squared test was used to determine if there was agreement in the proportion of lesions that were absent (0x0) between the PA and corresponding view of CBCT. This data was also used to calculate the sensitivity, specificity, positive predictive value (PPV), and negative predicative value (NPV) of the PA. Significance level was set at 0.05 for all analyses. SAS EG v.6.1 (SAS Institute; Cary, NC) was used for all analyses.

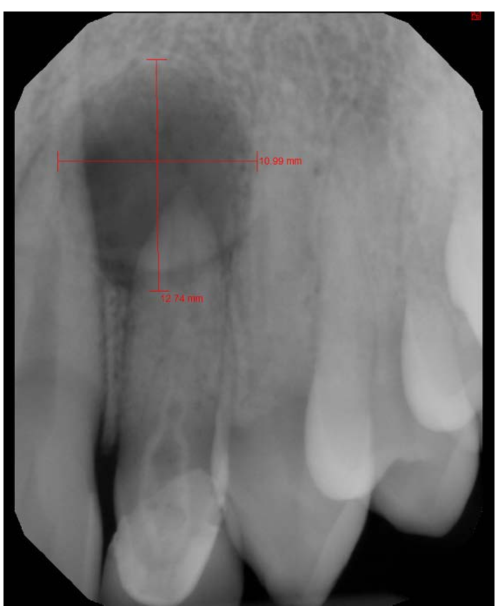

Figure 1 Example of PA radiograph measurements

Figure 2 Example of CBCT measurement of area of low density

Results

Thirty-five patients were identified to meet the inclusion criteria. The participants (n=35) had an average age of 61.5 years (range= 23 to 81). They had a total of 46 treated teeth with 51 separate periapical radiolucent lesions.

The distribution of the tooth type is described in the Table 1:

Table 1 Tooth Type (n)

Tooth Type	Maxillary	Mandibular	# Total
Incisor	11	1	12
Canine	3	1	4
Premolar	13	1	14
Molar	7	9	16

The distribution of treatment type is described in Table 2:

Table 2 Treatment Type (n)

Treatment Type	NSRCT	NSReTx	SRCT
Maxillary CI/LI	5	0	6
Maxillary Canine	0	0	3
Maxillary Premolar	4	2	7
Maxillary Molar	1	5	1
Mandibular CI/LI	0	0	1
Mandibular Canine	0	0	1
Mandibular Premolar	1	0	0
Mandibular Molar	1	4	4

Average healing time

The median time between pre-operative and post-operative PA was 390 days and ranged from 90 days to 1,974 days. The median time between pre-operative and post-operative CBCT was 397 days and ranged from 90 to 1,939 days (Figure 3). The amount of days between was not significantly different between the two image types (initial PA vs CBCT and recall PA vs CBCT), with a median difference of 0 days (Wilcoxon signed-rank test p-value=0.4860).

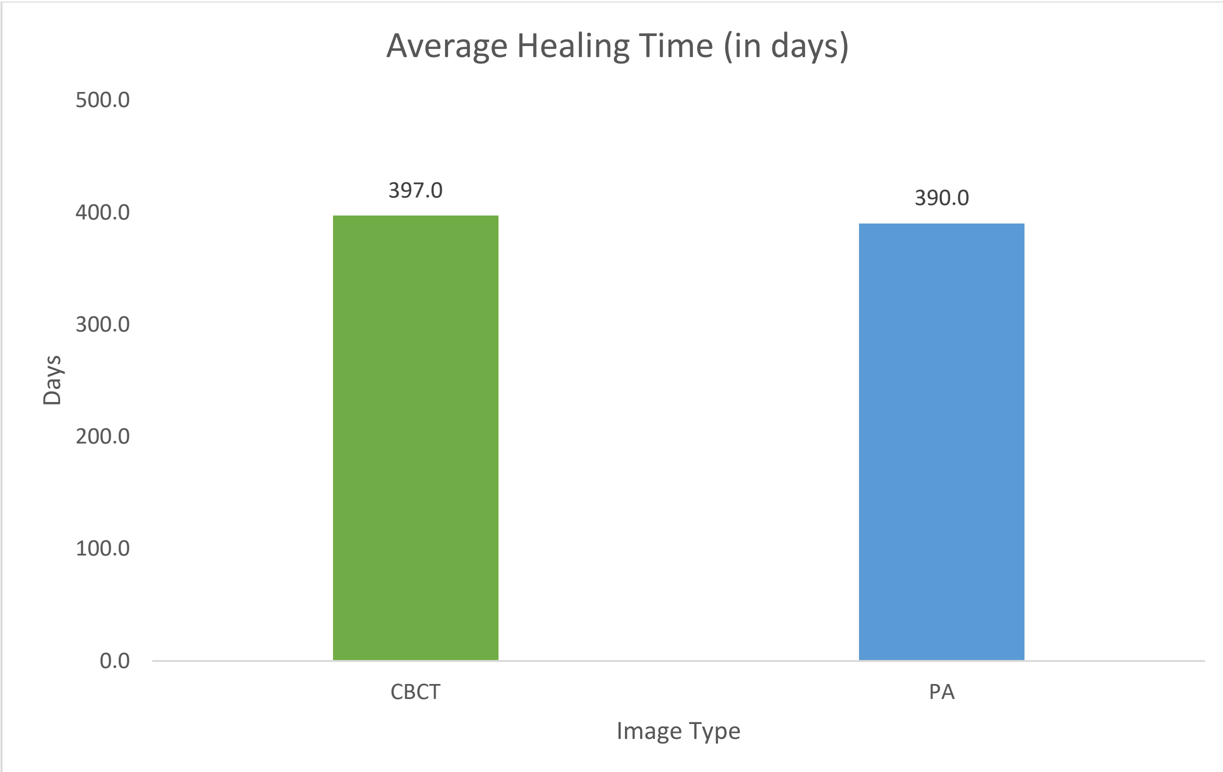

Figure 3 Average Healing Time (days)

Lesion Size

Pre-operative lesions had a median area of 10.8 mm^2 on PA and 16.4 mm^2 on CBCT. Post-operative lesions had a median area of 2.4 mm^2 on PA and 5.8 mm^2 on CBCT (Table 3, Figure 4).

Table 3 Summary Statistics on Lesion Size, Healing, and Difference Between Images

		Median (mm^2)	Q1	Q3
Pre-Operative	PA	10.8	4.9	24.6
	CBCT	16.4	8.2	31.6
Post-Operative	PA	2.4	0.0	7.1
	CBCT	5.8	1.5	12.7
Healing				
	PA: Pre-Post	5.9	2.8	17.6
	CBCT: Pre-Post	7.4	3.5	18.4
Difference (CBCT-PA)	Pre-Operative	3.4	-1.3	7.5
	Post-Operative	2.6	0.0	5.8

*IQR= Range from Q1 (25th percentile) to Q3 (75th percentile)

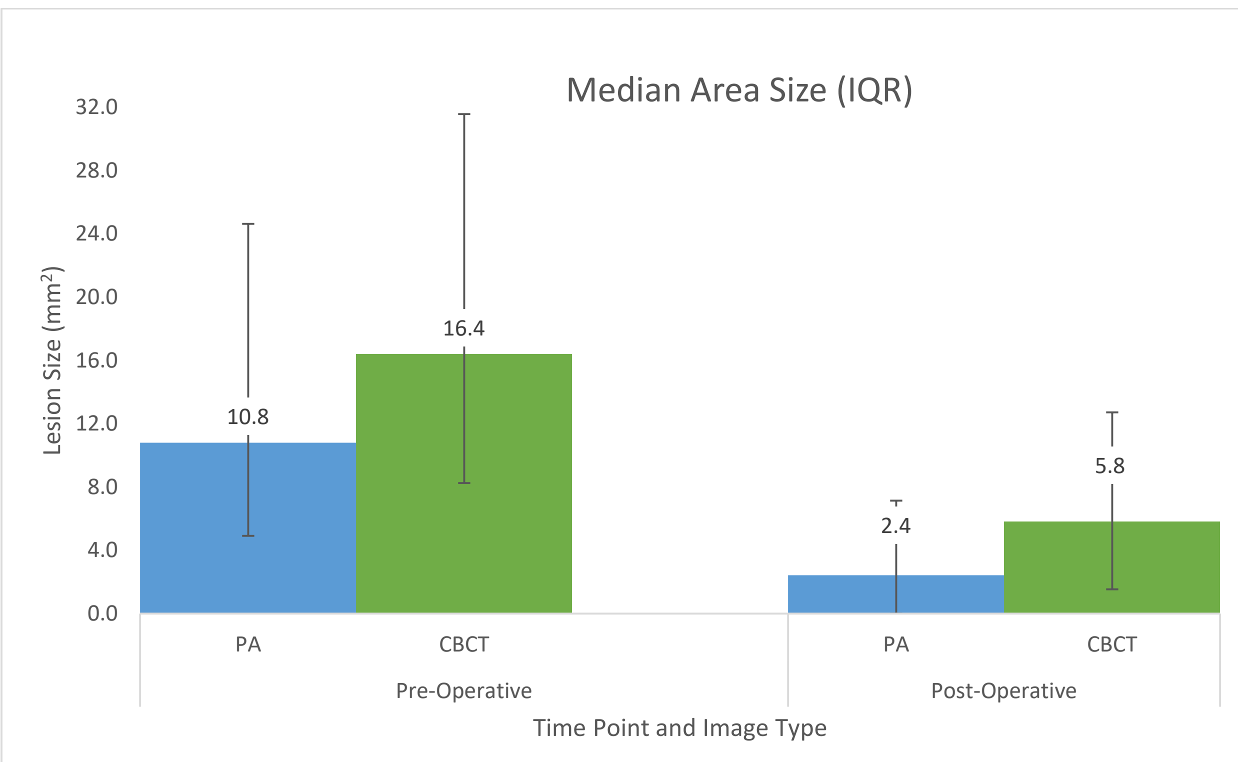

Figure 4 Median Area Size

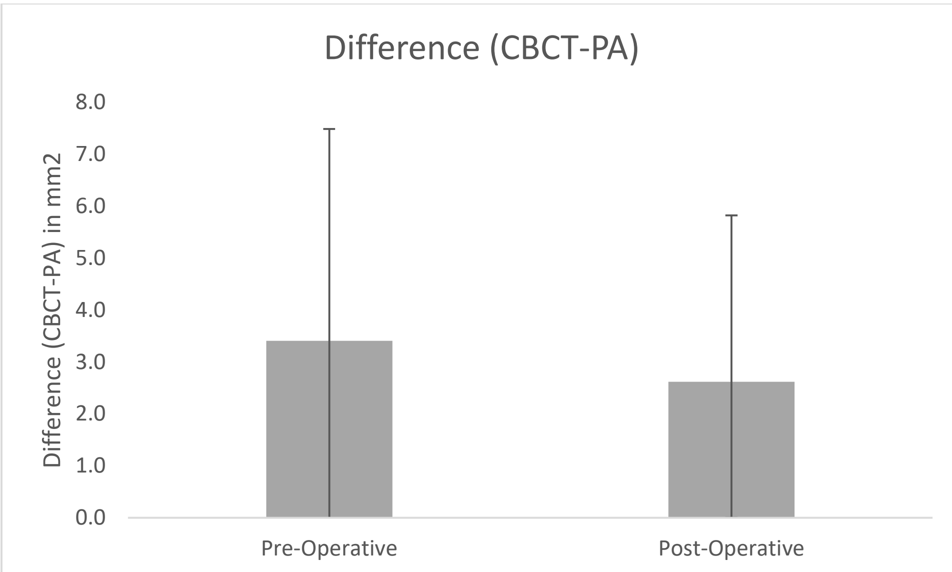

Figure 5 Difference in Median Area Size (CBCT-PA)

Change in Lesion Size

Based on PA radiographs, post-operative lesions had a median difference of 5.9 mm^2 smaller than pre-operative (Wilcoxon signed-rank test p-value<0.0001). Based on the CBCT images, post-operative lesions had a median difference in size of 7.4mm^2 smaller than pre-operative lesions (Wilcoxon signed-rank test p-value<0.0001). Results are given in Table 3.

Change in lesion size was not significantly associated with treatment type (NSRCT, NSReTx, SRCT), gender, or patient age (Table 4).

Table 4 Patient Demographics and Amount of Healing

	PA: Change in Area Size			CBCT: Change in Area Size		
	Median	**IQR**	**P-value***	**Median**	**IQR**	**P-value***
Surgery Type			0.8149			0.3475
NSRCT	5.44	-0.95, 17.22		8.97	7.07, 15.93	
NSReTx	5.72	4.29, 11.31		5.15	-0.68, 17.47	
SRCT	6.96	2.64, 20.11		7.73	2.78, 25.34	
Gender			0.9656			0.4124
Female	5.67	3.23, 12.76		6.25	3.48, 16.49	
Male	7.40	1.48, 17.79		8.63	3.57, 21.65	
	Spearman Correlation	**95% CI**	**P-value***	**Spearman Correlation**	**95% CI**	**P-value***
Age	-0.20	-0.45, 0.08	0.1632	-0.05	-0.32, 0.23	0.7472

*P-value from Kruskal-Wallis Test for Surgery Type and Gender and from Spearman rank correlation for Age

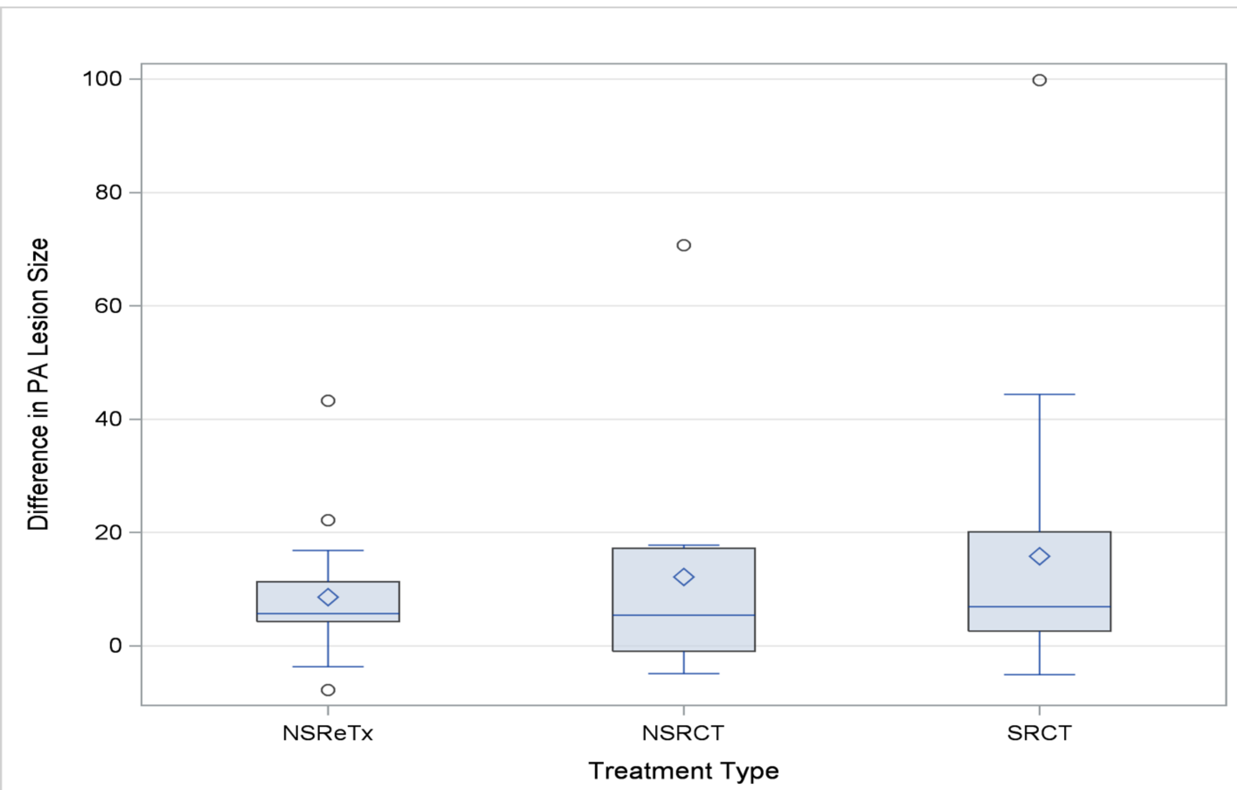

Figure 6 Difference in PA Lesion Size vs Treatment Type

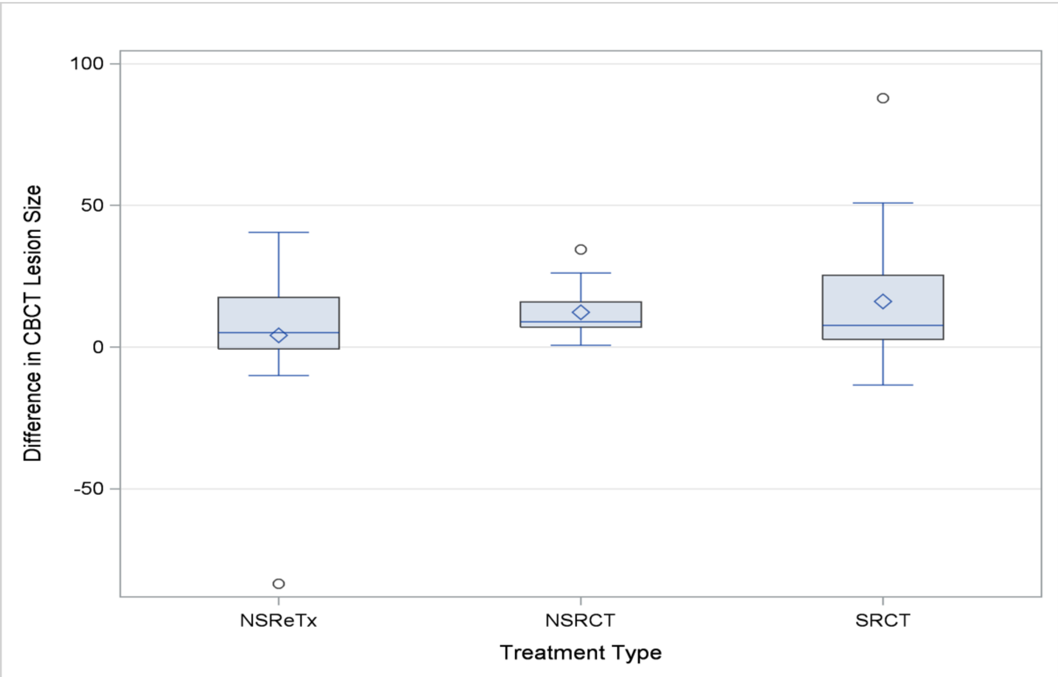

Figure 7 Difference in CBCT Lesion Size vs Treatment Type

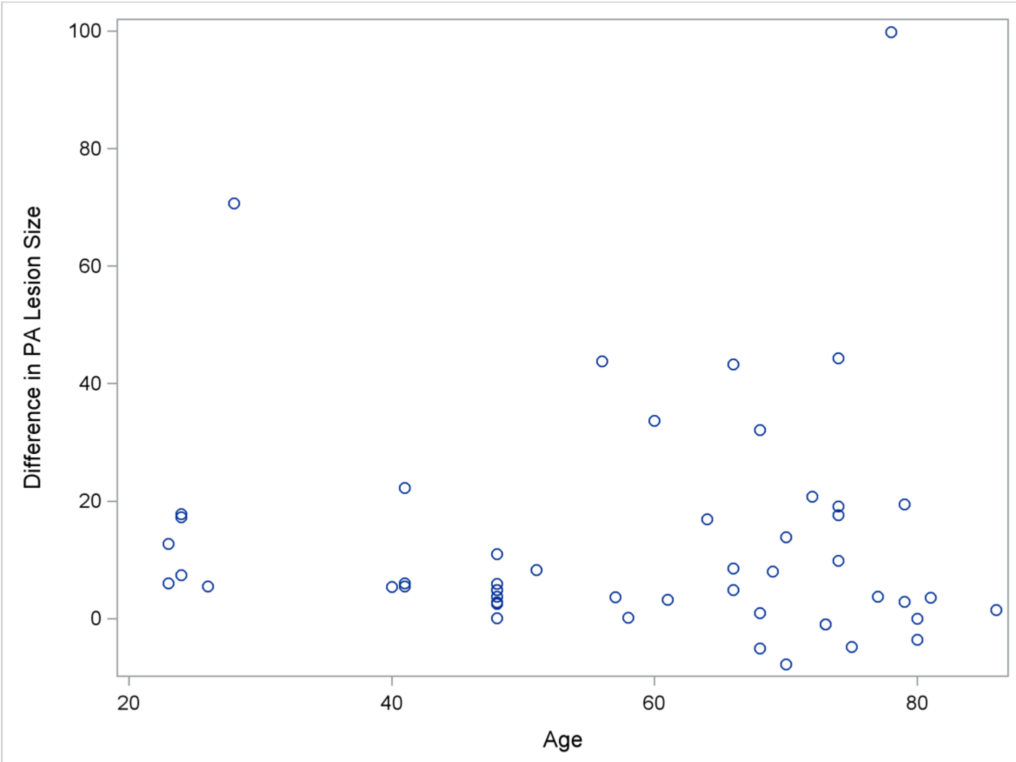

Figure 8 Difference in PA Lesion Size vs Age

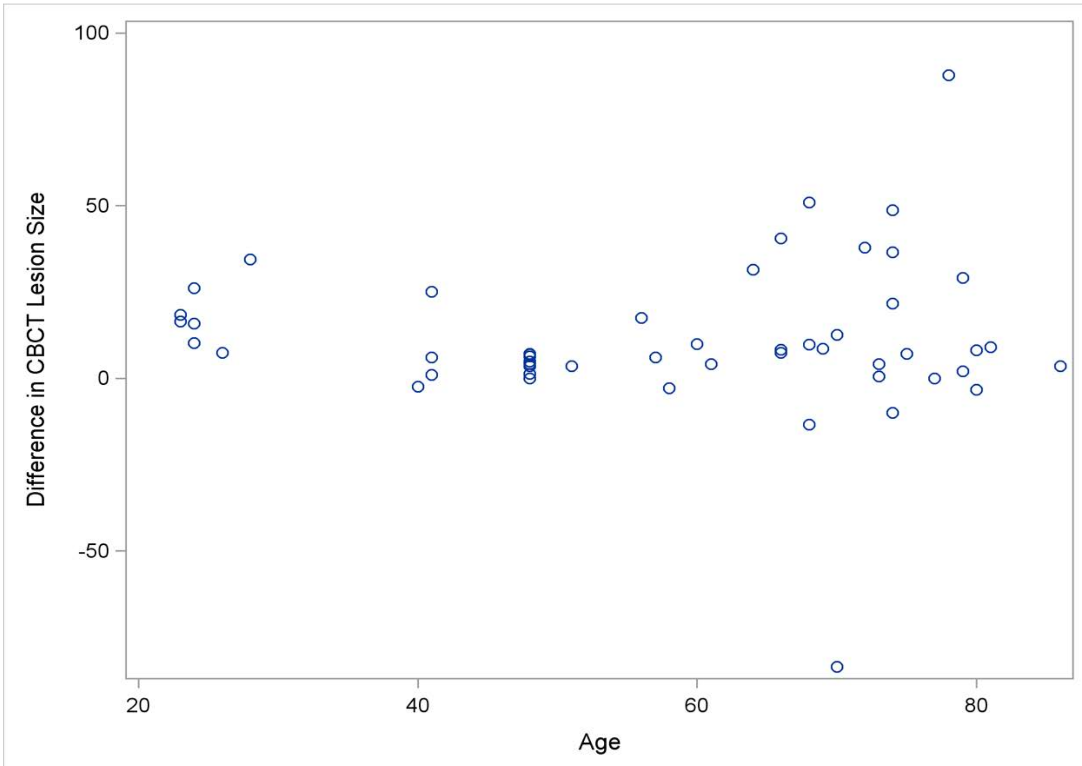

Figure 9 Difference in CBCT Lesion Size vs Age

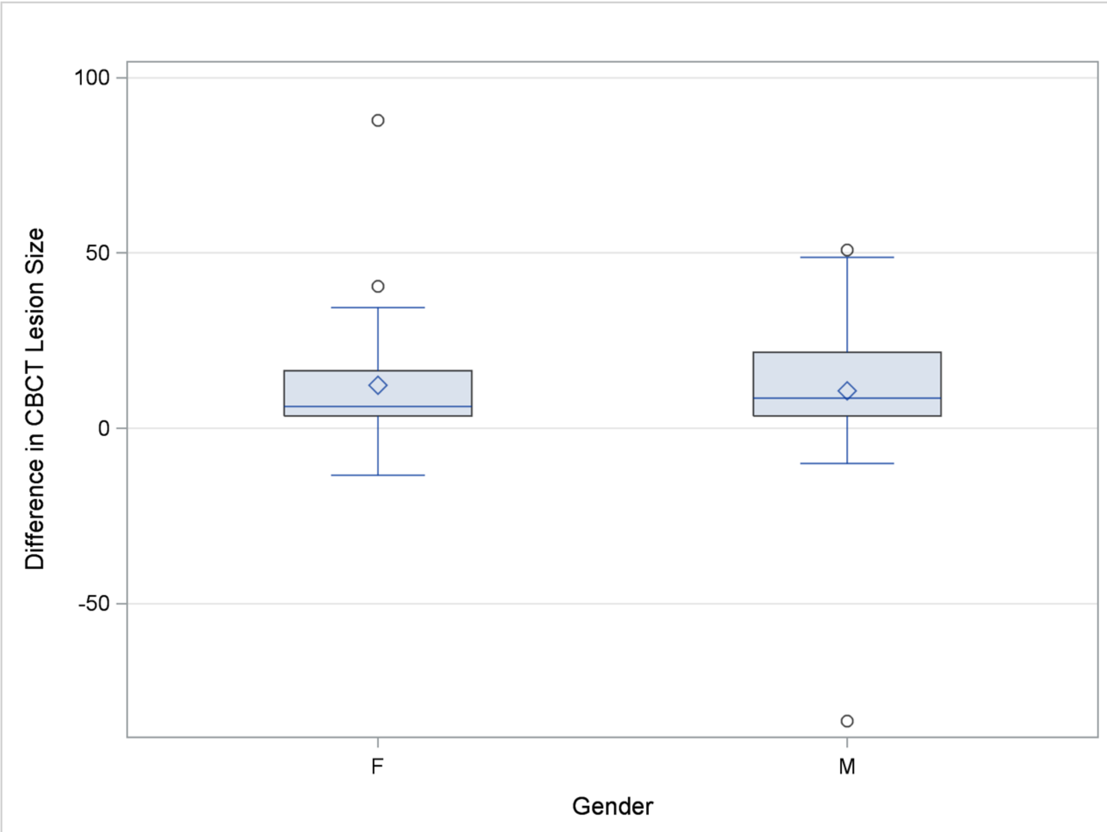

Figure 10 Difference in CBCT Lesion Size vs Gender

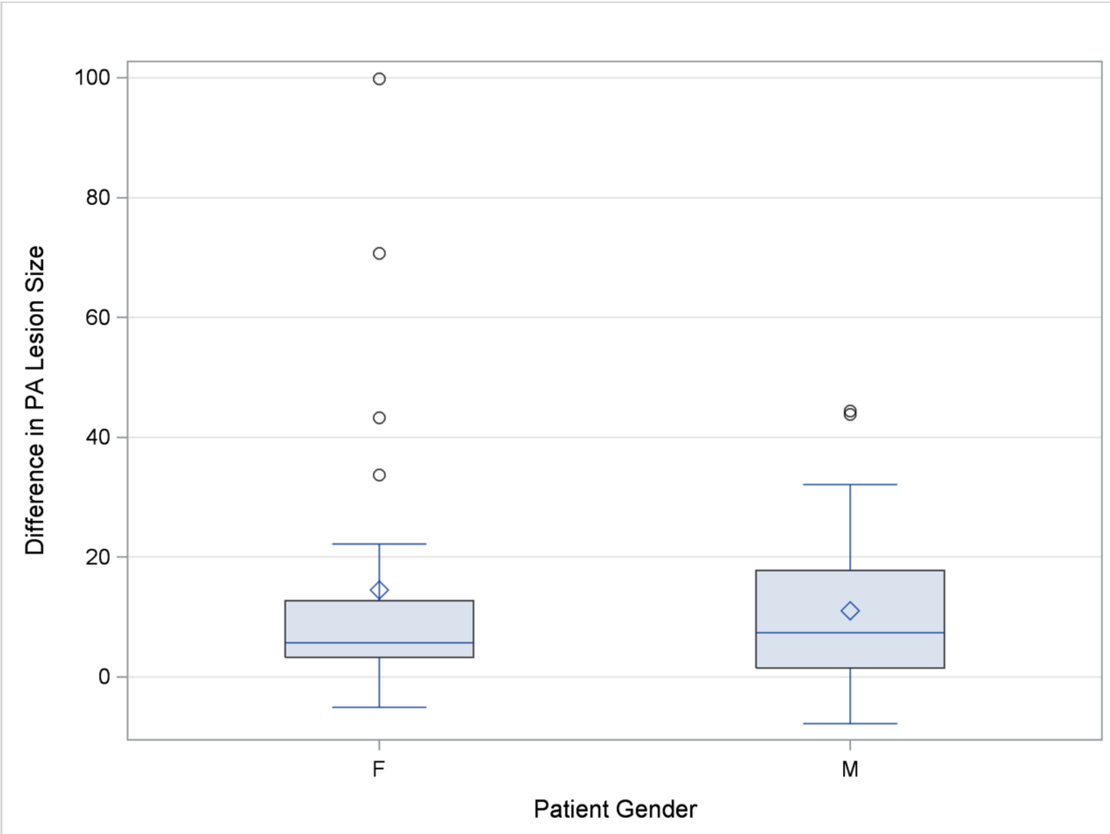

Figure 11 Difference in PA Lesion Size vs Gender

Change in lesion size on a PA radiograph vs CBCT scan was also not significantly associated with the amount of healing time (6 months or less, 6-12 months, 12+ months).

Table 5 Number of Cases by Healing Time (n)

PA Healing	n	%
6 months or less	12	24%
6-12 months	11	22%
12+ months	28	55%
CBCT Healing	**n**	**%**
6 months or less	12	24%
6-12 months	10	20%
12+ months	29	57%

Table 6 Change in Area Size Based on Healing Time

	Change in Area Size		
Healing Time	Median	IQR	P-value*
PA			0.8089
6 Months or less	5.46	4.26, 7.14	
6-12 Months	7.40	-0.95, 17.22	
12+ Months	6.96	2.64, 20.11	
CBCT			0.5448
6 Months or less	6.74	2.3, 12.33	
6-12 Months	5.62	3.48, 15.93	
12+ Months	8.63	3.57, 29.04	

*P-value from Kruskal-Wallis Test

Difference between PA and CBCT

When comparing pre-operative lesion sizes between PA and CBCT using the comparable CBCT view (i.e. coronal view for anterior teeth and sagittal view for posterior teeth), the lesion sizes had a median difference of 3.4 mm^2 larger on CBCT than PA (Wilcoxon p-value=0.0145). For post-operative lesions, the CBCT measurements were again larger, this time with a median difference of 2.6 mm^2 (Wilcoxon p-value=0.0005). Results are given in Table 3/ Figure 5.

Additionally, measurable lesions were detected on CBCT on 12 of the 20 cases where lesions were found to be absent on the PA. There were also 2 that were found on the PA but were absent in the comparable view of the CBCT. For both cases, the PA and CBCT were taken on the same recall day and the lesion was absent on all three CBCT views. These results indicated a significant difference in the distribution of absent lesions between PA and CBCT (p-value=0.0075). Assuming the CBCT is the gold standard, the PA's ability to detect lesions can be described using sensitivity, specificity, positive predictive value and negative predictive value. These results are given Table 7. While the positive predictive value is high for the PA

(94%), the negative predictive value is low (40%). Sensitivity and specificity are moderate at 71% and 80%, respectively.

Table 7 Predictability of PA When Compared to CBCT (Post-Op) Predictability of PA when compared to CBCT (Post-op)

		CBCT	
		Present	Absent
PA	Present	29, 57%	2, 4%
	Absent	12, 24%	8, 16%

Sensitivity	71%
Specificity	80%
PPV	94%
NPV	40%

*Percent adds to more than 100% due to rounding

Discussion

Many previous studies have attempted to quantify changes in size of periapical lesions on periapical radiographs and CBCT. In 1986, Orstavik created the periapical index for interpretation of periapical lesions on radiographs. (34) This index paved the way for Estrela to develop a similar 6-point system for CBCT scans. (35) However, there has still been confusion as to what constitutes a periapical radiolucency. Pope stated a healthy, vital tooth may have PDL space widening of 0-1mm on a periapical radiograph but may demonstrate significant variation when viewed with a CBCT. (36) Most studies have agreed that a periapical radiolucency is defined as two times the width of the healthy periodontal ligament space on any adjacent healthy tooth. (32)

In 2018, Aminoshariae et al completed a systematic review comparing and quantifying endodontic outcomes using CBCT imaging versus intraoral periapical radiography. Six articles were included in this systematic review which consisted of NSRCT outcome cohort studies with a CBCT recall of greater than one year and a periapical radiograph as a control. They found the odds of CBCT imaging locating a lesion were twice more than the odds of periapical radiography locating the same lesion. Thus, it was concluded CBCT imaging may provide more clarity to establish an accurate diagnosis in complex cases. She warns even though CBCT can be utilized to overcome shortcomings of two-dimensional radiography, clinicians must still consider limitations such as radiation dose, high levels of noise/scatter, variations in dose distribution within a volume of interest, and cost. For these reasons, it is advised only to use CBCT imaging when potential benefits outweigh the risks. If CBCT imaging is used, always follow the ALARA (As Low As Reasonably Achievable) principle as well as utilization of the smallest possible field of view and voxel size, the lowest mA, and shortest exposure time. (26)

Many previous similar studies have looked at the diagnostic sensitivity, specificity, positive predictor value (PPV), and negative predictor value (NPV) of various radiographic methods in the detection of AP. Dutra et al completed a systematic review and meta-analysis regarding the diagnostic accuracy of CBCT and conventional radiography on apical periodontitis in 2016. This systematic review and meta-analysis included nine studies, in which only five compared digital periapical radiography with CBCT. These five studies were completed by Liang et al (2014), Patel et al (2009), Sogur et al (2009), Sullivan et al (2000), and Wallace et al (2001). In these studies, AP was induced in skeletal material by drilling holes or applying acid to the periapical bone tissue. Digital radiography was compared to a gold standard of histologic examination for confirmation of actual AP. (37) They found the accuracy values were 0.96 for CBCT imaging and 0.72 for digital periapical radiography. These studies also reported sensitivity, specificity, PPV, and NPV for digital radiography. Sensitivity ranged from 24% (38) to 80% (39) while specificity ranged from 42% (40) to 100% (38) (20). The reported PPV ranged from 81% (40) to 100% (38) (20) and the NPV ranged from 21% (40)(41) to 64% (20). As you can see, these studies displayed a wide range of results.

In 2009, Garcia de Paula-Silva examined treated or untreated roots of dogs' teeth using periapical radiography, CBCT, and histology. AP was diagnosed as follows depending on the method utilized: 71% periapical radiography, 84% CBCT, 93% histologically. Periapical radiography had a 100% specificity, 77% sensitivity, 100% PPV, and 25% NPV. Once, again these results were compared to a histological gold standard. (21) Estrela completed a similar study examining 1508 human teeth with endodontic infection using PA radiographs and CBCT. Contrary to the previous study, CBCT was used as the comparison for periapical radiography, instead of histology. They observed a 55% sensitivity, 98% specificity, 98% PPV, and 55% NPV for periapical radiographs. (42)

In this study, 35 patients with a total of 46 treated and 51 separate periapical radiolucent lesions were treated with either NSRCT, NSReTx, or SRCT and returned for recall within a span of 3 months to approximately 5 years. For the most part, both pre-operative and recall periapical radiographs and CBCT were taken within a few days of each other. In a few instances, the periapical radiograph and CBCT were taken further apart from each other but no significant difference was found that would affect the healing.

CBCT showed a significantly larger lesion size on both pre-operative and recall scans compared to periapical radiographs taken at the same time. However, 25% of the lesions were interpreted as larger on the PA radiograph both pre-operatively and at recall. This highlights the difficulty in correctly interpreting periapical radiographs as opposed to CBCT.

In general, both recall periapical radiographs and CBCT scans showed a significant decrease in the sizes of periapical lesions in comparison to pre-treatment measurements. In some cases, the periapical radiolucency got larger and was interpreted as such on both imaging modalities. Overall, CBCT showed a greater total reduction in periapical lesion size. This may be because CBCT periapical lesion were generally interpreted larger initially, giving the opportunity to have a more significant reduction in size at recall.

Similar to Estrela, CBCT was used as the comparison for periapical radiography in this study, instead of histology. Periapical radiographs in this study had a sensitivity of 71% and a specificity of 80%. Sensitivity is the accuracy in identifying disease in people who truly have the disease. Alternatively, specificity focuses on the accuracy in correctly classifying truly non-diseased people. Out of the periapical lesions detected by CBCT at recall, periapical radiographs agreed and found a periapical lesion 71% of the time (true positive). Furthermore, when a periapical lesion was absent at recall on the CBCT, the periapical lesion was also absent on the periapical radiograph 80% of the time (true negative). This sensitivity value determined in this study was smaller compared to Garcia de Paula Silva et al (21) but much larger than that discovered by Patel et al (38) and Estrela et al (42). This study found a similar specificity of 77% reported by Stavroupoulous and Wenzel (43) but less than that determined by Patel et al (38), Estrela et al (42), and Garcia de Paula Silva et al (21) in their respective studies. The discrepancy in findings could be attributed to having multiple examiners interpreting and measuring the radiographs. Tewary et al concluded that the interpretation of dental radiographs are subjective, irrespective of the type of imaging modality used.(44) Additional discrepancies may be attributed to these studies using histopathological findings as the gold standard to diagnose AP, instead of CBCT, as recommended by Kanagasingam.(45)

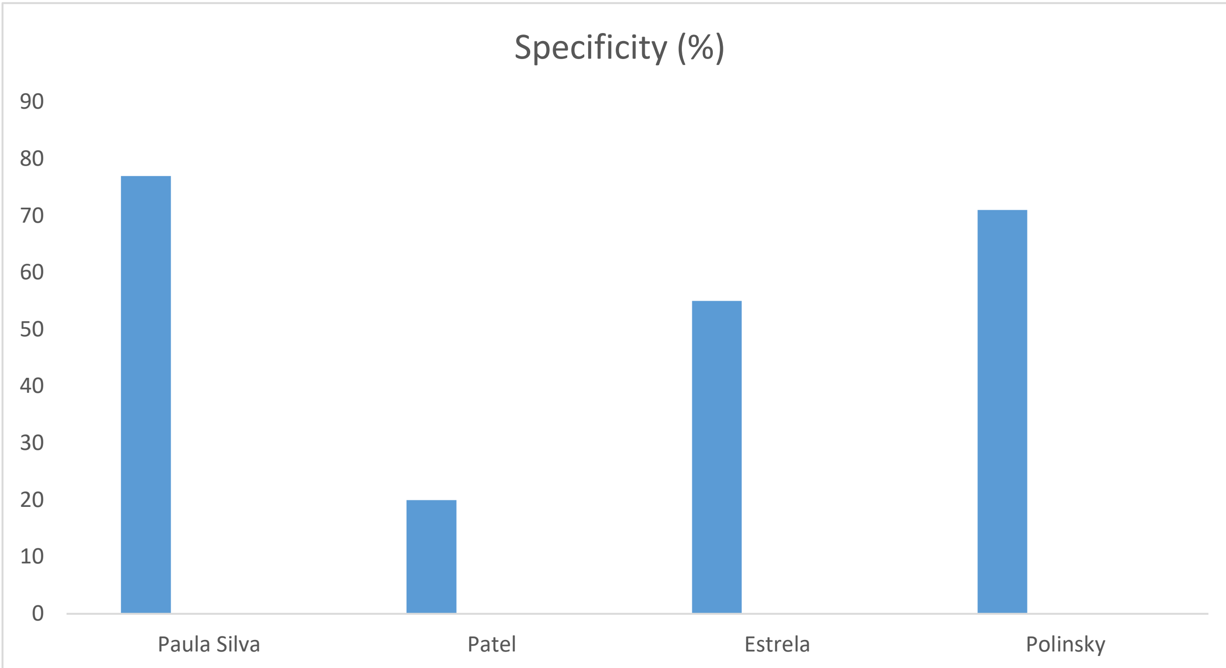

Figure 12 Comparison of Specificities of Previous Studies

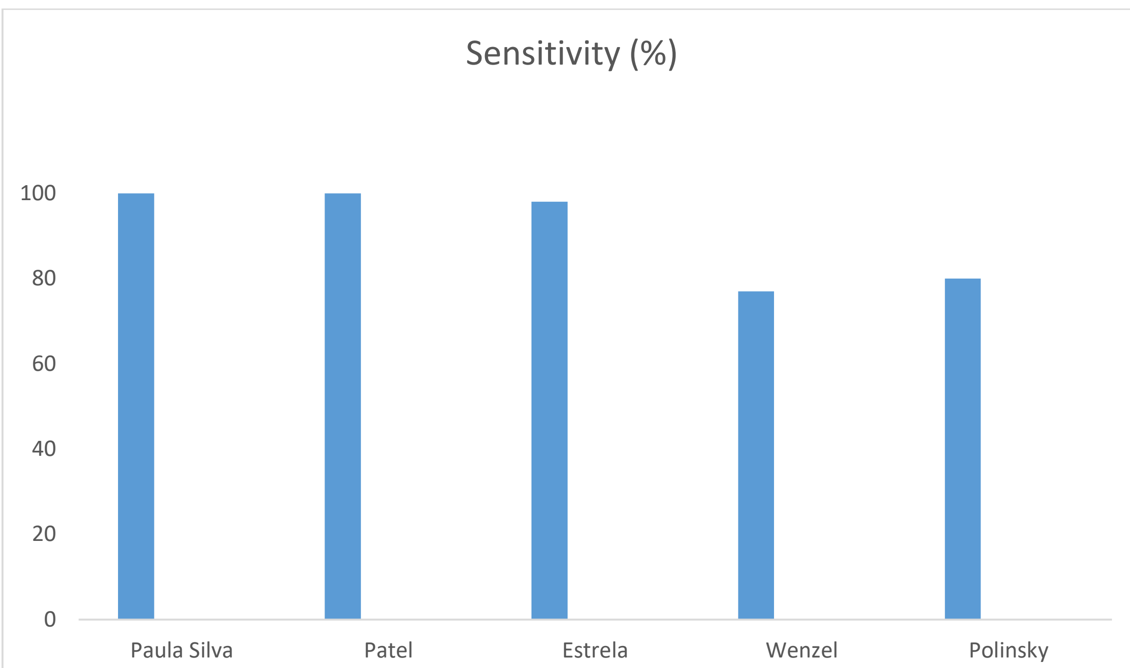

Figure 13 Comparison of Sensitivities of Previous Studies

The PPV (positive predictor value) is the probability that subjects with a positive screening test (PA lesion) truly have the disease (PA lesion confirmed by CBCT scan). The PPV for PA's was discovered to be 94% in this study. This means that if a periapical radiograph shows a periapical lesion present, a CBCT will also detect a periapical lesion 94% of the time. In this study, an evaluator detected a periapical radiolucency on a PA radiograph that did not correspond to an area of low density on the corresponding CBCT scan. Most likely, due to reasons stated previously about the limitations of periapical radiography, the periapical area may have been misinterpreted and may not have existed. Alternatively, the negative predictor value (NPV) is the probability that subjects with a negative screening test (no PA lesion) truly do not have the disease (no PA lesion confirmed by CBCT scan). The NPV was 40% in this study. This value indicates if a periapical radiograph does not identify a periapical lesion, there still is a 60% chance a periapical lesion will be identified on a CBCT. These values are comparable to previous studies completed by Patel et al(38) and Sogur et al (39). CBCT imaging is more effective at detecting periapical lesions that cannot be detected by periapical radiography, particularly in the maxillary incisor/canine and molar areas due to the influence of structural noise. (46) Clinicians must be aware of the possibility of false negatives when using conventional radiography for the detection of AP. (42)

In general, healing is a very dynamic process and may be affected by many factors. Countless prior studies have explored many of these factors such as sex and age. In 2008, Ng looked at many preclinical factors of NSRCT to see if any had an influence on healing and the outcome of root canal treatment. She established only pre-operative periapical lesions, root fillings with no voids, root filling length, and coronal restoration had an influence on the treatment outcome. (33) Comparable to his study, patient sex and age were not found to have a significant effect on the healing of these periapical lesions after NSRCT, NSReTx, or SRCT. It should be noted, there was not an even distribution of age and gender type represented in this study.

In 2018, Kruse completed a study evaluating the accuracy of periapical radiography and CBCT in diagnosis of AP compared to a histopathologic gold standard. He examined both root filled and non-root filled teeth. He concluded all diagnostic parameters were lower for root filled teeth. He attributed this finding possibly due to artifact interference, continued healing, and possible decreased bacterial load. (47) This study did not have the same findings. This study illustrated there was no significant difference in the median healing rates between the type of treatment performed (NSRCT, NSReTx, or SRCT) whether visualized with periapical radiographs or CBCT. This reinforces clinicians should not select which type of imaging modality to utilize for subsequent recalls based off of the procedure performed. For instance, one would not have to complete a CBCT to visualize healing of a NSReTx case rather than a periapical radiograph. This confirms periapical radiographs are still the primary imaging modality for all types of treatment at recall.

Lastly, this study investigated the differences in the amount of healing of a periapical lesion when viewed with either PA radiography or CBCT at the same point in time. Recall times were categorized as followed: <6months, 6-12 months, or >12 months. No significant difference was found between the amount of healing detected with a periapical radiograph or CBCT at the same point in time. However, there was a trend for a greater range of healing on both imaging modalities as the recall time increased. It should be noted, this study had a much higher *n* in the >12-month recall category that may affect the results. It can be concluded from this study significant healing cannot be detected at an earlier point in time when using a CBCT as opposed to a PA radiograph. Therefore, clinicians can utilize solely periapical radiographs at any time frame to analyze changes in healing and it will reveal similar findings as if using CBCT scan.

Alternatively, many people believe CBCT is overestimating the frequency of periapical lesions, (49) and in return leading to possible overtreatment of otherwise asymptomatic radiolucencies and patients. Torabinejad evaluated 120 endodontically treated roots on asymptomatic and functional teeth. All of these teeth had no apparent radiolucent findings with periapical radiographs and follow up from 2-15 years. He discovered 20% (1 out of 5) of teeth with successful root canal treatment based on conventional periapical imaging had CBCT radiolucencies measuring greater than 1mm. Since one cannot determine the histologic diagnosis of the periradicular radiolucency, he states despite the presence of a lesion using CBCT, no further treatment is warranted if the patient is asymptomatic. He warns these radiolucencies may not be pathologic changes and therefore clinical decision making must not be solely based on radiographic interpretation. (50)

Similarly, Kruse followed 74 teeth with previous endodontic surgery with persistent apical lesions detected with CBCT. Twenty of these teeth were re-operated and histopathology was used as a reference to determine inflammation. They found 8/20 (40%) of these teeth had no periapical inflammation and in turn did not benefit from further treatment. It was emphasized not all lesions observed on a CBCT represent inflammation. (47) It is important that clinical testing and patient signs and symptoms be taken into consideration when making treatment decisions. Further clinical studies with long term follow up are needed to differentiate this findings from disease entities assist in establishing the proper course of action in these cases.(50)

There were several limitations to this study. To begin, this study did not compare periapical radiography to the histopathologic gold standard to identify AP. This would improve clinical relevance and reduce the risks of false positives and false negatives. As we know, histological diagnoses may not always agree with periapical radiography or CBCT findings. Secondly, this study may reveal slightly different results since previous related studies evaluated AP in mechanically induced bone which does not produce the diffuse boarders of natural AP. (40) In addition, measurements of periapical lesions were calculated using the area of an ellipsoid, yet once again natural AP has diffuse boarders and is irregularly shaped. Since measurements were taken at the areas of greatest dimension, this may overestimate the actual areas of these periapical lesions. (40) Lastly, the subjectivity of periapical lesion measurements by the three evaluators may affect the results even though a calibration examination was completed. In particular, due to the relative similarities in radiodensity of the maxillary sinus or space outside the cortical plate to periapical radiolucencies, it may be difficult to determine a clear boundary for perforating lesions on CBCT scans. In these cases, the evaluator had to approximate the approximate the extent of the periapical lesion edge which may differ based on the evaluator's interpretation and experience.

Conclusion

In conclusion, CBCT had a higher probability of detecting the presence of a periapical lesion, while a periapical radiograph had a higher probability of missing a periapical lesion even though it may be present. Furthermore, significant healing cannot be detected at an earlier point in time with periapical radiographs or CBCT. This study revealed there was no difference in median healing rates between these two modalities. Despite the advantages of CBCT, clinicians must still consider the higher costs and potentially greater radiation dose to patients. The AAE & AAMOR still recommend periapical radiography as the imaging modality of choice both pre-operatively and at recall with CBCT aiding in more complex scenarios. (27) Further long-term studies are needed to classify what may be defined as “normal” appearance on a CBCT and when further treatment may not be necessary as opposed to what may be defined as “disease” and should require further intervention

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