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Morphometric analysis of premolars and its relevance to root canal anatomy

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

By

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Bachelor of Science, 2015

Doctor of Dental Surgery, 2018

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Abstract

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By: James DeGracie, DDS

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Introduction: Premolars are especially challenging to treat endodontically due to their small size and often-intricate anatomy. While the majority of premolars present with one or two root canals, the presence of three root canals has been reported. Failure to locate, clean, and obturate all root canals can result in the failure of endodontic therapy. The aim of this study was to investigate the correlation between the root-to-crown width ratio (RCWR) and number of root canals in maxillary and mandibular premolars.

Methods: Data was retrieved from the electronic health records of patients evaluated or treated at Virginia Commonwealth University School of Dentistry. A total of 100 premolars which had both periapical radiograph (PA) and cone beam computed tomography scans (CBCT) were identified and used for this study. The maximum mesial-distal crown width (MCW) and the widest mesio-distal width of the root (MRW) of each premolar were measured by two examiners using both PAs and CBCTs. The root-to-crown width ratio (RCWR) was calculated by dividing the MRW by the MCW. Statistical analysis was performed to determine the correlation between RCWR and the number of root canals as confirmed by CBCTs (significance set at 0.05).

Results: Premolars with three root canals had a RCWR significantly higher than premolars with one or two root canals ($p<0.0001$). Based on the logistic regression model, RCWR of at least 0.83 as determined from a PA or RCWR of at least 0.70 from a CBCT were associated with three root canals (predicted probability of 90%).

Conclusion: A larger root-to-crown width ratio (RCWR) indicates a significantly higher probability of three root canals in maxillary and mandibular premolars. This study highlights the importance of a thorough preoperative radiographic assessment to predict aberrant root canal anatomy.

Introduction

The field of endodontics is a specialized branch of dentistry that focuses on the dental pulp and tissues surrounding the root structure. The primary goal of endodontic treatment is to prevent and heal periradicular pathosis and to preserve the natural dentition (1). The practice model of dentistry and endodontic treatment in the United States relies on general dentists having the knowledge and experience to perform the majority of root canal treatment procedures (1). According to a survey conducted in 2007, 68% of endodontic treatment was conducted by general practitioners (GPs) (2). However, there has been an upwards trend in the number of GPs performing endodontic treatment. A more recent survey conducted in 2014 revealed that approximately 75% of endodontic treatment is completed by GPs (3). This can be attributed to the incorporation of technological advancements by general dentists such as high magnification loupes and advanced Ni-Ti rotary files to navigate the complex root canal system (3). Interestingly, the survey further revealed that 84% of general dentists who opt to perform root canal therapy treat anteriors 99%, premolars 95%, and molars only 62% percent of the time (3).

As an aid for treatment planning and referrals, the American Association of Endodontists (AAE) has created a "case difficulty assessment form" (4). This form evaluates several patient and tooth specific factors that are sorted into low, moderate, and high difficulty levels (4). Based on the different parameters, the form can aid clinicians in the preoperative workup of endodontic cases and establish a baseline difficulty level. This can help a practitioner anticipate the possible complications that may be encountered during treatment and aid in decision-making. Several reports in the literature have advocated the use of this AAE form as it has shown to reduce the number of endodontic mishaps and number of visits (5, 6). Even though premolars are listed as “low difficulty” scenarios on the AAE form, special attention should be taken to evaluate the parameters “Canal Morphology " and/or “Radiographic Appearance of Canal(s)” (4). A case that may appear to fall under the low difficulty category may rapidly jump to high difficulty if complex root canal morphology is present. An excerpt from the AAE Endodontic Case Difficulty and Assessment Form and Guidelines (2020) can be seen below (4).

Figure 1: AAE Endodontic Case Difficulty and Assessment Form and Guidelines Excerpt

Criteria and Subcriteria	LOW DIFFICULTY	MODERATE DIFFICULTY	HIGH DIFFICULTY
B. DIAGNOSTIC AND TREATMENT CONSIDERATIONS			
DIAGNOSIS	☐ Signs and symptoms consistent with recognized pulpal and periapical conditions	☐ Extensive differential diagnosis of usual signs and symptoms required	☐ Confusing and complex signs and symptoms: difficult diagnosis ☐ History of chronic oral/facial pain
RADIOGRAPHIC DIFFICULTIES	☐ Minimal difficulty obtaining/interpreting radiographs	☐ Moderate difficulty obtaining/interpreting radiographs (*e.g.*, high floor of mouth, narrow or low palatal vault, presence of tori)	☐ Extreme difficulty obtaining/interpreting radiographs (*e.g.*, superimposed anatomical structures)
POSITION IN THE ARCH – TOOTH TYPE	☐ Anterior/premolar	☐ 1st molar	☐ 2nd or 3rd molar
POSITION IN THE ARCH – INCLINATION	☐ Slight inclination (<10°)	☐ Moderate inclination (10-30°)	☐ Extreme inclination (>30°)
POSITION IN THE ARCH – ROTATION	☐ Slight rotation (<10°)	☐ Moderate rotation (10-30°)	☐ Extreme rotation (>30°)
TOOTH ISOLATION	☐ Routine rubber dam placement	☐ Simple pretreatment modification required for rubber dam isolation	☐ Extensive pretreatment modification required for rubber dam isolation
CROWN MORPHOLOGY	☐ Normal original crown morphology	☐ Full coverage restoration ☐ Porcelain restoration ☐ Bridge abutment ☐ Moderate deviation from normal tooth/root form (*e.g.*, taurodontism microdens) ☐ Teeth with extensive coronal destruction	☐ Restoration does not reflect original anatomy/alignment ☐ Significant deviation from normal tooth/root form (*e.g.*, fusion dens in dente)
CANAL MORPHOLOGY	☐ Slight or no curvature (<10°) ☐ Closed apex (<1 mm in diameter)	☐ Moderate curvature (10-30°) ☐ Crown axis differs moderately from root axis. ☐ Apical opening 1-1.5 mm in diameter	☐ C-shaped morphology ☐ Extreme curvature (>30°) or S-shaped curve ☐ Mandibular premolar or anterior with 2 roots ☐ Maxillary premolar with 3 roots ☐ Canal divides in the middle or apical third ☐ Very long tooth (>25 mm) ☐ Other anomalies such as radix ento/para molaris ☐ Open apex (>1.5 mm in diameter)
RADIOGRAPHIC APPEARANCE OF CANAL(S)	☐ Canal(s) and chamber visible and not reduced in size	☐ Canal(s) and chamber visible but reduced in size ☐ Pulp stones	☐ Indistinct canal path ☐ Canal(s) and chamber not visible

It is critical for a clinician to be cognizant of the root canal morphology and its variations when performing endodontic therapy. The complexity of the root canal system was highlighted by Vertucci in 1984, wherein the number and configuration of root canals in human permanent teeth were reported (7). While each tooth type presents its own set of challenges to overcome to complete successful endodontic therapy, premolars are known to be particularly difficult to treat due to their small size and often intricate anatomy. Both maxillary and mandibular premolars are typically reported to have one or two root canals (7). However, the presence of extra roots or canals have been reported in the literature (8, 9, 10, 11). In a small percentage of cases, presence of three root canals have been reported, along with a root form which make them look like "small molars" or "radiculous" (8). A classic review paper by Cantatore highlighted that risk of missing a canal in premolars is always present (8). Presence of extra canals in premolars is further complicated when it presents as a deep split within the root or as a "C" shaped root canal system, reported in mandibular premolars (7,11). Interestingly, mandibular premolars have been reported to be the most difficult teeth on which to perform endodontic treatment (12). A summary of the literature on the number and incidence of root canals in premolars can be seen below in Table 1.

Table 1: Literature Review of the Incidence of Root Canals in Premolars

Tooth Type	Author, Year	1 Canal	2 Canal	3 Canal
Max 1st	Vertucci, 1979 (9)	26%	69%	5%
	Olczak, 2022*(13)	1.70%	95.4	2.90%
Max 2nd	Vertucci, 1974 (10)	75%	24%	1%
	Olczak, 2022* (14)	88.90%	11%	0.10%
Man 1st	Zillich, 1973 (11)	69.30%	22.70%	0.40%
	Kottoor, 2013** (15)	73.55%	23.55%	2.90%
Man 2nd	Zillich, 1973 (11)	84.50%	11.70%	0.40%
	Wolf, 2021** (16)	89.50%	8%	0.10%

Note: * signifies the study was conducted utilizing CBCT. ** signifies the study was a systematic review.

Intraoral periapical radiographs (PA) are considered the imaging modality of choice in the preoperative evaluation of the endodontic patient (17). However, there are specific drawbacks which can affect its diagnostic yield. Firstly, PAs are a two-dimensional representation of three-dimensional objects, which can result in root structure overlap that may hide or over-represent root canal anatomy (18). Secondly, overlapping anatomic structures (maxillary sinus, mental foramen, or zygomatic arch)) may obscure visualization of complex root canal anatomy and the periapical area, referred to as “anatomical noise” (18). In addition, PAs suffer from geometric distortion caused by incorrect angulations of the radiographic cone toward the teeth and the image receptor (18). Specific techniques have been reported in the literature to overcome the limitations of PAs in identifying root canal morphology. For example, changes in the horizontal angulation of PAs can help identify the number, location, and direction of root canals in a particular tooth (19). In addition, attention should be given to sudden changes in the density of the root canal space (fast-break appearance), suggestive of a split root canal (20). While conventional radiographic analysis can give insights and clues into root canal morphology, a study conducted by Sherwood found that 80% of general dentists missed extra roots and failed to identify root canal curvature (21). Cone beam computed tomography (CBCT) has steadily gained traction in the dental field as an alternative radiographic modality (17). CBCT provides clinicians the ability to scroll along the three anatomical planes, which helps overcome the major shortcomings of PAs mentioned above. While the use of CBCT can greatly aid a clinician's understanding of the root canal system, only 38% of GPs reported having one onsite (22).

Favorable outcomes in endodontic therapy require adequate cleaning, shaping and obturation of the root canal system (23). The reported success rate for endodontic treatment ranges from 81% to 83%. (24, 25). While the overall success and survival of root canal treatment is high there is still a reported incidence of failure of up to 20% (26). The most reported reasons for failure are leakage of the root canal material (30%), missed root canal(s) (20%), under filling (14%), anatomical complexity (9%), and overfilling (3%), amongst others (27). In a classic study by Hoen and Pink on failing root canal treatment, a missed root canal space was reported in 42% of the cases (28). A common factor amongst the reported reasons for failure of endodontic therapy is the presence of irritants and most importantly microbes that will not allow healing to occur (29). This highlights the importance of chemo-mechanical debridement in achieving predictable and successful endodontic outcomes. Unhindered access to the entire root canal system is an essential prerequisite for thorough root canal debridement, which is only possible with a thorough understanding of tooth morphology (30).

Morphometric analysis is the measurement of the external form of a structure and the use of statistical analysis to describe or compare organisms (31). In the field of dentistry, it involves external measurements of teeth to aid in detection and recognition of teeth type and even gender or age (32). Historically, this has been used in forensic dentistry to aid in the positive identification of those involved in trauma or accidents (33). Morphometric analysis when applied to endodontics may aid in the positive preoperative identification of complex root canal anatomy. Sieraski published a review article that proposed that three rooted maxillary premolars might be identified through use of paralleling PA radiographs (34). He introduced the idea that if the mesial-distal width of the mid-root area was equal to or greater than the mesial-distal width of the crown, the tooth would likely have three roots (34). To the best of our knowledge, this proposed empirical tool in identifying root or root canal morphology has never been verified. Therefore, there is a gap in knowledge with the application of morphometric analysis for the preoperative prediction of number of root canals in human premolars.

The aim of this study was to perform a morphometric analysis of maxillary and mandibular premolars to calculate and establish a root-to-crown width ratio (RCWR) to predict the number of root canals.

Methods

Sample Selection

The study protocol was approved by the Institutional Review Board at the School of Dentistry, Virginia Commonwealth University, Richmond, Virginia (HM20024233**)**. A retrospective search of the Virginia Commonwealth University School of Dentistry AxiUm (Henry Schein One, American Fork, Utah) database from January 2014 to December 2022 was conducted to identify maxillary and mandibular premolars. The radiographs collected were from patients that already had them taken during routine or emergency dental evaluations. A total of 100 images were collected from a pool of 94 patients.

The inclusion criteria during screening of teeth were as follows:

1. Maxillary or Mandibular Permanent Premolar teeth with complete root formation
2. Paralleling Periapical radiograph (PA) and limited field of volume cone beam computed tomography Scan (CBCT) for all teeth
3. Intact clinical crown or if restored, intact mesial and distal contacts were present.

Exclusion criteria:

1. Crown or root fracture
2. Scatter on CBCTs
3. Gross decay
4. Presence of root resorption
5. Radiographs with cone cut affecting visibility of the entire involved tooth

Image Acquisition

The PAs were exposed using a GX770 Gendex apparatus (Gendex Corporation, Milwaukee, Wisconsin) and captured on a Dexis sensor (Dental Imaging Technology Corporation, Quakertown, PA) with the following settings: 70kVp, 7mA, .13s exposure time. The CBCTs were captured using a CS 8100 3D Carestream 8100 with the following settings: 90kV, 5mA, 15.0s exposure time, 75 voxel size, and 665mGy.cm2. The slice thickness was set to 1.3mm.

Image evaluation

All images were reviewed and measured utilizing MiPACS Dental Enterprise Viewer (Medicor Imaging, Charlotte, North Carolina) for PAs and CS 3D imaging (Carestream Dental, Atlanta, Georgia) for CBCTs. A Dell Optiplex 7460 AIO Series desktop (Intel Core i7-8700 @3.2 GHz Windows 10 Pro 64-bit English) was used to process all imaging software.

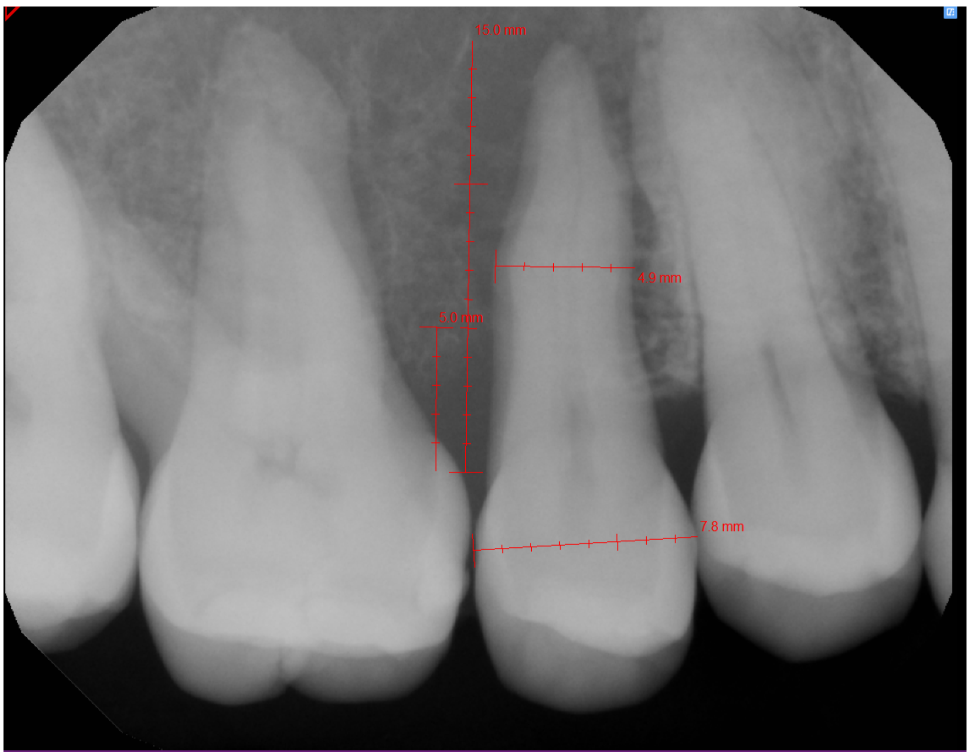
Two examiners (One endodontic resident and one board certified endodontist) independently reviewed and conducted measurements for all 100 cases. Prior to initiation of the study, 10 sample cases were utilized to conduct examiner calibration. Measurements were taken independently and reviewed together to ensure criteria were understood and proper measurements were recorded. Measurements were taken on PAs for all 100 cases and a two week interval was taken prior to CBCT measurements.

The following information was recorded for each PA:

- Maximum mesiodistal crown width (MCW) in millimeters
- Maximum mesiodistal root width (MRW) in the middle or apical third in millimeters

The middle and apical thirds of the root were determined by taking a measurement from the cemento-enamel junction (CEJ) to the root apex and dividing the root into thirds. The examiner would place a measurement one third the root length beginning at the CEJ extending apically to ensure the widest aspect of the root was measured in the middle and apical thirds. An example of how the measurements were taken can be seen below in Figure 2.

Figure 2: Sample PA Measurements



The following information was recorded for each CBCT:

- Number of root canals
- Number of roots
- Maximum mesiodistal crown width (MCW) in millimeters
- Maximum mesiodistal root width (MRW) in the middle or apical third in millimeters

The axial view of CBCTs were utilized to confirm and record the number of root canals and roots present in each premolar. A separate canal was defined as a separate orifice found on the pulp floor that could be instrumented to a depth of 3-4mm or to a depth of 16mm from the cusp tip or a treatable canal with a separate apical foramen (8).

The sagittal view was used to record the widest aspect of the crown in a mesial-distal dimension and again at the widest aspect of the root in the middle or apical thirds. The same method of determining the middle and apical thirds on the PAs was utilized on the CBCTs. Examiners were able to scroll in buccal and lingual dimension within the scan to ensure the measurements were taken at the widest mesiodistal aspect.

Statistical Methods

The root-to-crown width ratio (RCWR) was calculated by dividing the MRW by the MCW. Interclass Correlation Coefficient (ICC) was calculated to determine consistency of the two independent raters. Average paired differences between measurements on PAs and CBCTs were compared using paired t-tests. Associations between RCWR and number of root canals was conducted using a one-way ANOVA with post hoc pairwise comparisons adjusted with Tukey's adjustment. Logistic regression was utilized to determine how accurately the RCWR predicted the number of canals through calculation of a Receiver Operating Characteristic (ROC) curve and to determine a RCWR value for which the probability of a third canal was at least 90%. A 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 100 premolars were evaluated by two independent reviewers. The Interclass Correlation Coefficient (ICC) for measurements with periapical radiographs (PA) was 0.989 and 0.990 for cone beam computed tomography scan (CBCT) measurements. The distribution of the included teeth was almost evenly split amongst maxillary and mandibular premolars. One-third of the sample size were first premolars with the remaining two-thirds being second premolars. There was a nearly even split in terms of number of root canals present in the sampled teeth: one root canal (38%), two root canals (33%), and three root canals (29%). A complete summary of the characteristics of the sampled teeth is presented in Table 2.

Table 2: Characteristics of Included Teeth

	n	**%**
Tooth		
Maxillary First Premolar	15	15%
Maxillary Second Premolar	29	29%
Mandibular First Premolar	18	18%
Mandibular Second Premolar	38	38%
Number of Roots		
1	73	73%
2	18	18%
3	9	9%
Number of Canals		
1	38	38%
2	33	33%
3	29	29%

The root-to-crown width ratio (RCWR) was directly associated with predicting the number of root canals for both PAs (p-value<0.0001) and CBCTs (p-value<0.0001). For the PAs, premolars with one root canal had a RCWR on average 0.15 smaller than those with three root canals (95% CI: 0.10- 0.20, p-value<0.0001) and premolars with two root canals had a ratio that was on average 0.13 smaller than those with three root canals (95% CI: 0.08-0.18, p-value<0.0001). The difference between premolars with one or two root canals was not statistically significant (p-value=0.7048). For the CBCTs, premolars with three root canals had a ratio that was, on average, 0.15 units larger than those with one root canal (95% CI: 0.11-0.19, p-value<0.0001) and two root canals (95% CI: 0.11-0.19, p-value<0.0001). Again, the difference in ratio was not statistically significant between premolars with one or two root canals (p-value=0.9992). Results are presented in Table 3.

Table 3: Average Root-to-Crown Ratio by Number of Root Canals

	Mean, SE	
Canals	**PA RCWR**	**CBCT RCWR**
1	0.58, 0.01[a]	0.55, 0.01[a]
2	0.59, 0.02[a]	0.55, 0.01[a]
3	0.72, 0.02[b]	0.70, 0.01[b]
P-value	**<0.0001**	**<0.0001**

*P-value from ANOVA; levels connected by the same letter are not statistically significantly different based on Tukey's adjusted post hoc pairwise comparisons.

The comparison of the average PA and CBCT RCWR based on the number of root canals tended to be the same for each tooth type. The average RCWR sorted by the number of root canals and each tooth type are presented in Table 4.

Table 4: Average Root-to-Crown Ratio by Number of Root Canals and Tooth Type

Number of Canals	Maxillary First	Maxillary Second	Mandibular First	Mandibular Second
		PA RCWR		
1	--	0.56	0.57	0.58
2	0.52	0.59	0.64	0.68
3	0.67	0.78	0.68	0.77
P-value	0.0125	0.0016	0.0454	<0.0001
		CBCT RCWR		
1	**--**	0.51	0.57	0.56
2	0.49	0.56	0.61	0.56
3	0.68	0.79	0.66	0.71
P-value	<0.0001	<0.0001	0.0325	<0.0001

Note: There were no cases of maxillary first premolars with 1 root canal.

The area under the curve (AUC) for the logistic regression model to predict the presence of three root canals (versus one or two) was AUC=0.8482 for the PA RCWR and AUC=0.9534 for the CBCT RCWR. Receiver Operating Characteristic (ROC) curves are presented in Figure 3. Based on the logistic regression model, a PA RCWR value of 0.83 predicted the probability of three root canals with 90.4% accuracy (95% CI: 70.7-97.4%) while a CBCT RCWR value of 0.70 predicted the probability of three root canals with 91.6% accuracy (95% CI: 71.7-97.9%). Estimated logistic regression curves are presented in Figure 4.

Figure 3: Receiver Operating Characteristic Curves for PA and CBCT RCWR for Predicting Teeth with Three Root Canals

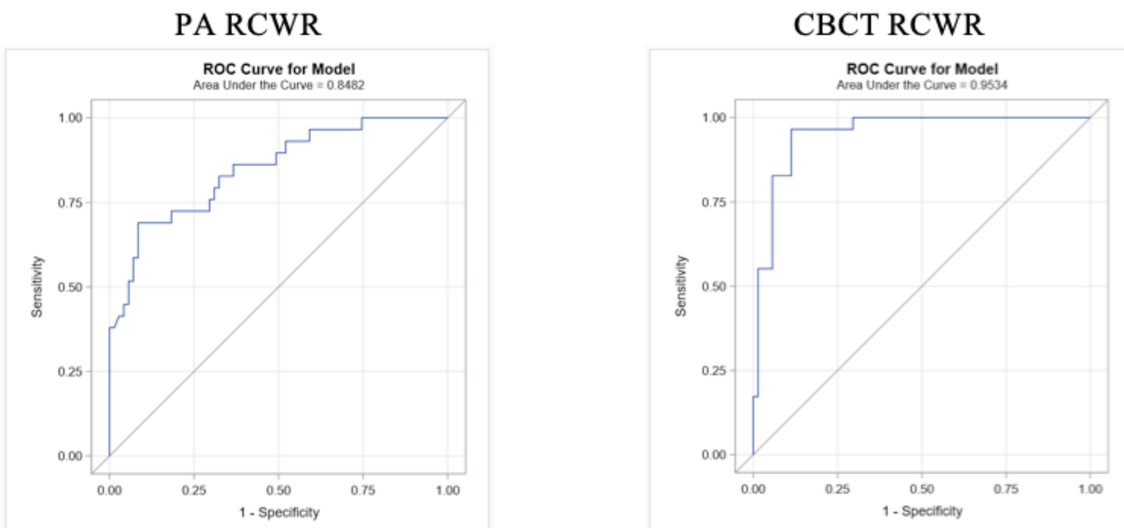
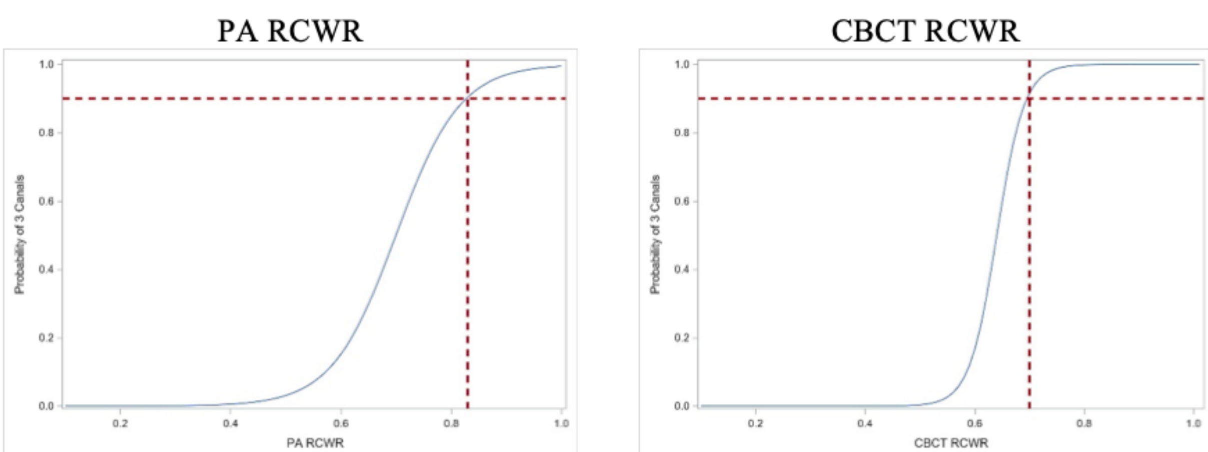


Figure 4: Logistic Regression Models for Probability of Three Root Canals by PA and CBCT RCWR



Discussion

A thorough preoperative radiographic assessment is essential for successful endodontic therapy (19). Based on paralleling radiographic examinations, Sieraski published a paper for identification and management of three canalled premolars (34). According to the proposed guideline, if the mid root mesial-distal width was equal or greater to the mesial width of the crown, the premolar likely had three roots (34). However, as the anecdotal evidence was based on few case examples, there was a need for a methodical investigation in order to evaluate the validity of the guideline. As a result, our study aimed to establish and evaluate the correlation between the root-to-crown width ratio (RCWR) and number of root canals in maxillary and mandibular premolars. This study demonstrated that an increased RCWR was associated with a higher presence of three root canals in premolars.

Premolars have been known to present with varying root anatomy and root canal morphology (7). Interestingly, maxillary second premolars are the only tooth type to display all eight root canal configurations described in the Vertucci classification system (7). Developmentally, the specific number and shape of roots is determined by the Hertwig's Epithelial root sheath (HERS) (35). This phenomena occurs mid-way through tooth growth with the proliferation of epithelial cells at the inferior border of the enamel organ (35). The shape of HERS will vary across different teeth, which results in a distinct number and size of roots (35). For a single root and accompanying root canal, the dentin will develop in a round, circumferential layout (15). This happens when the diaphragm remains in the shape of a collar (15). However, if two or three epithelium outgrowths converge towards each other to bridge the gap and fuse, two or three diaphragms are formed, which in turn can either fuse to form a single rooted tooth with multiple canals or remain separate, forming a multi-rooted tooth (36).

In this study morphometric analysis was used to identify complex anatomy in premolars. Morphometric analysis is a non-invasive quantitative technique which includes analysis of lengths, widths, and ratios to predict a specific parameter (31). More recently it has been used in dentistry to correlate and identify age, gender, aberrant tooth anatomy, etc (32, 33). According to a morphometric analysis conducted by Peiris, a direct relationship was demonstrated between the tooth primordia or crown size and the root canal morphology in maxillary premolars (37). This can be explained by taking into consideration the evolutionary development of teeth. The purpose of a root structure is to provide adequate support to the crown to withstand masticatory forces (38). As the size of the crown increases, the accompanying root correspondingly becomes larger or splits into multiple roots to provide a firm foundation (38). It has been reported that a larger overall primordium results in an increased amount of foci of signaling centers and interradicular processes (39). The depth and penetration of the interradicular processes and accompanying radicals eventually determine the root structure formation (40). In premolars with seperated roots, radicals are completely devided by the inter-radicular process resulting in formation of two or more roots (40). In cases with incomplete division of the radicals, superficial developmental grooves delimt the boundary of the radicals (40). There is some evidence that the number of roots may correlate to the density of the bone (40). An example of this can be seen in the higher prevalence of maxillary three rooted premolars compared to mandibular premolars as there is a higher density of bone found within the mandible (9, 10, 11, 41).

The guideline proposed by Sieraski and colleagues specifically evaluated the presence of three roots in contrast to our study wherein the focus was on a more clinically relevant question i.e. to identify the number of root canals (34). In addition, the current study included teeth with all forms of root canal anatomy such as one, two, and three canals. The sample size of this study was significantly larger when compared to the case series by Sieraski et al in which only 5 cases were shown (34). Strict criteria were outlined to define the landmarks on the radiographic images to reduce the subjectivity in interpretation and improve reproducibility of the findings, which helped establish the RCWR . We included both middle third and apical thirds to determine the MRW. This was in contrast to the study by Sieraski et al where only mid-root dimension was observed (34). This was done as some of the root splits have been reported in the apical third which corresponds to an increased mesial distal dimension in said third (34). Finally, this study had an added benefit as it utilized both periapical radiographs (PAs) and cone beam computed tomography scans (CBCT) for assessing the tooth morphology.

The RCWR was established by dividing the maximum mesiodistal root width (MRW) over the maximum mesiodistal crown width (MCW) and was demonstrated to be statistically significant when comparing one and two versus three root canaled premolars. However, there was no significant difference between one versus two root canals. This finding can be further understood with a more in depth understanding of premolar anatomy. Premolars develop with round or oval shaped roots extending in a buccal and lingual dimension (15). Premolars with only one root and root canal typically have a “conical appearance” on PA radiographs (19, 20). In addition, the majority of premolars in a two root canal configuration (the one root variant or as separate buccal and lingual roots) demonstrate similar radiographic appearance as the roots/root canals are superimposed in a buccal and lingual dimension (15). In this study, both measurements (MRW and MCW) utilized to establish the RCWR were taken in a mesial-distal dimension. This might explain why there was no difference in the RCWR between one canaled and two canaled premolars. However, teeth with three root canals often presented in two forms: A) Two separate buccal root canals and one palatal root canal in maxillary and mandibular premolars B) Three canals in a “C” shape configuration for mandibular premolars. These configurations resulted in increased mesial-distal dimensions of the root structure, thereby increasing the RCWR value. As a result, the RCWR for three canaled premolars was significantly higher than RCWR of one and two canaled variants. Our study adds to the previous findings of Sieraski et al and Peiris et al to further highlight the use of morphometric analysis of crowns to predict the root form and root canal morphology (34, 37).

Limited field of view CBCTs were used as the definitive modality to confirm the number of root canals and to verify MRW and MCW measurements. Examiners were able to view each case from different angles that were not achievable on the PAs. Unfortunately, some scans were excluded from the study due to beam hardening or scatter. Larger MRW and MCW measurements were noted on the majority of PAs in comparison to CBCTs, which could be attributed to the geometric distortion observed in PA radiographs (17). Despite this shortcoming, there was no significant difference observed in the RCWR ratios between PA and CBCT evaluations. This could be attributed to strict inclusion of high-quality paralleling radiographs. During the screening of paralleling PA images many cases had to be excluded due to improper angulation or overlap. As first premolars are located anatomically further around the curvature of the arch, it is more difficult to get paralleling radiographs or radiographs with no overlap (42**)**. This may give insight into why the majority (2/3rds) of the teeth were second premolars.

The received operating characteristics (ROC) curve was formed by calculating the sensitivity and specificity based on different cutoffs for the RCWR. This demonstrated how well variable RCWRs can predict the presence of a third root canal. If the RCWR was a perfect predictor of three root canals, then the area under the curve (AUC) would be 1.0 or demonstrated as a horizontal line along the y-axis. If the RCWR were equal to random guessing with no predictive power for detecting the presence of three root canals, this would be demonstrated as a 45-degree line as shown by the black tangent in Figure 3. As the AUC approaches 1.0 this demonstrates high predictive power. The results of this study show the AUC's were of 0.85 and 0.95 for PAs and CBCTs respectively and therefore a good predictor of detecting the presence of three root canals. The logistic regression model seen in Figure 4 plots the probability of three root canals based on the RCWR. A PA RWCR of 0.83 or a 0.70 CBCT RCWR will have an approximate 90% accuracy for detecting the presence of three root canals. A clinician that is assessing the difficulty of a premolar prior to initiating endodontic therapy can calculate the RCWR pre-operatively and gain insight into the possibility of a third root canal.

The clinical implication of this study may result in increased detection of premolars with three root canals during the preoperative examination. This is particularly suited for general practitioners (GPs) who perform the majority of root canal therapy. They may not have access to in house advanced CBCT imaging which would shed light on the number of root canals present within a particular case (22). Based on the findings of this study, preoperative measurements taken on a paralleling PA can be utilized to calculate the RCWR. If the RCWR of a PA is equal to or greater than 0.80 there is around a 90 percent chance of three root canals being present. This enables the GPs to properly gauge case difficulty before initiating endodontic therapy. This may guide a clinician to order a CBCT scan to investigate further or refer to an endodontic specialist for evaluation and treatment.

There were a few limitations of this study. Firstly, all the included samples were from the greater Richmond, Virginia area, which can affect the generalizability of the results to other geographic areas. Another limitation was seen with regards to the spread of the sampled data. Approximately 2/3rds of the included samples were maxillary and mandibular second premolars. Many of the first premolars reviewed to include in the study did not meet the inclusion criteria. One major issue encountered during screening was the lack of a paralleling radiographs that showed both the entirety of the root and crown structure. This may have occurred due to the anatomic location of the premolar within the arch form. Furthermore, no attempt was made to distinguish the configuration of the root canal anatomy and correlate it with the RCWR.

Conclusion

The use of morphometric analysis and the application of the root-to-crown width ratio (RCWR) demonstrated a high predictive power to identify root canal anatomy in premolars. As the RWCR increased, the probability of identifying premolars with three root canals was significantly higher. While the use and implementation of cone beam computed tomography scans (CBCT) play an important role in endodontic therapy, it is not accessible to all clinicians. Therefore, the successful implementation of the RCWR on periapical radiographs, specifically by general dentists, could lead to an increased preoperative identification of premolars with three root canals. This in turn will enable the clinician to properly assess case difficulty prior to initiating endodontic therapy. Future studies should be conducted with a larger sample size from a more heterogeneous population to further evaluate the application of morphometric analysis in predicting root canal morphology of premolars.

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