CLINICAL RESEARCH

Effect of Orthodontic Treatment on the Outcomes of Endodontically Treated Teeth: A Cone-Beam Computed Tomography Analysis

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ABSTRACT

Introduction: Often there is the need of moving endodontically treated teeth. Orthodontic movement may have no effect on the prognosis of teeth with root canal treatment (RCT). To verify this subject, we evaluated the effect of orthodontic movement on the prognosis of RCT teeth using cone-beam computed tomography (CBCT) and further explored the influence of orthodontic movement on the prognosis of RCT teeth with and without apical periodontitis (AP). **Methods:** This retrospective study was conducted by evaluating 169 RCT teeth of 100 patients who had undergone fixed orthodontic treatment. AP was assessed and classified using the CBCT periapical index. Univariate analysis of RCT outcome was performed for the total RCT group, RCT without AP group and RCT with AP group. Multivariate logistic regression was performed for the total RCT group and RCT without AP group, respectively, but not for the RCT with AP group. Variables related to the prognosis of RCT were included, such as age, gender, tooth position, RCT quality, coronal restoration quality, periodontal condition, orthodontic traction distance, and orthodontic rotation angle. **Results:** The orthodontic traction distance and rotation angle were not significantly correlated to the RCT outcomes, regardless of the presence of AP. Among the total RCT group, teeth with unqualified RCT (odds ratio = 3.42, P = .004) and inadequate coronal restoration (odds ratio = 4.40, P = .031) had a lower success rate. Of the 97 RCT teeth without AP, unqualified RCT was a risk factor for treatment failure (odds ratio = 3.55, P = .041). Of the 72 RCT teeth with AP, the univariate analysis showed that RCT quality were significantly related to the outcome (P = .042). **Conclusions:** Orthodontic movement had no effect on the prognosis of RCT teeth regardless of the presence of AP. *(J Endod 2024;50:1091–1099.)*

KEY WORDS

Apical periodontitis; cone beam computed tomography; orthodontic treatment; root canal treatment

SIGNIFICANCE

Orthodontic movement had no effect on the outcome of RCT teeth regardless of the presence of AP. The quality of RCT and coronal restoration before orthodontic treatment should be emphasized for the long-term successful healing of periapical tissue.

Recent improvements in economic conditions have led to an increased demand for orthodontic treatment by adults to improve dental esthetics. Orthodontic movement of endodontically treated teeth in adults is increasingly more common.

Although endodontically treated teeth can be orthodontically moved like untreated teeth[1,2], many uncertainties remain about the relationship between orthodontics and root canal treatment (RCT) during the treatment planning stage. Most recent studies have focused on whether root resorption of RCT teeth is more likely to occur during orthodontic movement. However, relatively few histological and clinical research studies have assessed the effects of orthodontic treatment on the prognosis of RCT teeth with apical periodontitis (AP). A previous histological study found no significant change in the extent of AP during orthodontic movement[3], while a second found that orthodontic movement delayed, but not prevented, healing of AP[4]. Moreover, a retrospective clinical study using panoramic radiography found that there was no significant change in the periapical index (PAI) scores after orthodontic treatment[5].

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As compared to conventional panoramic radiography, cone-beam computed tomography (CBCT) produces 3-dimensional (3D) images that do not overlap with anatomic structures[6,7] and, therefore, are more accurate for diagnosis of AP lesions and evaluation of RCT outcomes[8,9]. However, the usefulness of CBCT to assess the impact of orthodontic treatment on the prognosis of RCT teeth with AP remains unclear. In addition, there are notable differences in the healing processes of pulp disease and AP. Hence, it is necessary to separately analyze the prognosis of RCT teeth without AP to clarify the effects of orthodontic treatment.

Therefore, the aims of this retrospective study were to investigate the effects of orthodontic movement on the prognosis of RCT teeth with and without AP using CBCT.

MATERIALS AND METHODS

Study Approval and Patient Consent

The study protocol was approved by the Ethics Committee of Peking University Third Hospital (approval no. 2020/142-03) and conducted in accordance with the ethical principles for medical research involving human subjects described in the Declaration of Helsinki. Prior to inclusion in this study, written informed consent was obtained from all subjects.

Study Cohort

The cohort of this retrospective study was limited to patients who underwent orthodontic treatment at the Department of Stomatology of Peking University Third Hospital from January 2016 to September 2022. CBCT scans were used for diagnosis, treatment planning, and evaluation of the outcomes of orthodontic treatment. No patients underwent CBCT scanning specifically for this study, and all scans were performed in compliance with the Dental and Maxillofacial Radiological CBCT Guidelines[10]. All patients met the following inclusion criteria: at least one RCT tooth that remained during orthodontic treatment. Exclusion criteria were age <18 years, CBCT images with poor quality of specific parts of RCT teeth, no RCT teeth, extraction of RCT teeth during orthodontic treatment, and incomplete orthodontic treatment. Finally, 169 RCT teeth of 100 orthodontic patients (48 men and 52 women) were included for analysis.

Radiographic Evaluation

All CBCT scans were conducted with the KaVo 3D eXam cone beam dental imaging system (KaVo Dental GmbH, Biberach, Germany). Radiologic measurements were conducted with eXam Vision postprocessing software (Imaging Sciences International, Inc, Hatfield, PA) in a dark room on a 19-inch monitor (Lenovo LT1913pA; Lenovo Co, Ltd, Beijing, China) with a resolution of 1280 $\times$ 1024 pixels. The following information was recorded for each patient: gender, start and end dates of orthodontic treatment, and locations of RCT teeth. Periapical status, RCT, coronal restoration, periodontal condition, and traction distance and rotation angle during orthodontic treatments were evaluated for all RCT teeth.

Periapical Status

The size of the apical lesion was measured before and after orthodontic treatment using eXam Vison software and graded with the CBCT periapical index as proposed by Estrela et al[11], where the absence of AP (intact periapical bone structure) was assigned a score of 0, while the presence of AP (periapical radiolucency >0.5 mm) was assigned a score of 1 to 5 based on severity. In addition, 2 variables, expansion of cortical bone (E) and destruction of cortical bone (D), were recorded according to the scoring system. The most severe periapical condition of multi-root teeth was recorded.

RCT Teeth

Teeth with opaque materials in the pulp chamber and/or root canal were considered RCT teeth. Adequate filling was defined as filling within the root of the tooth, no more than 2 mm from the radiographic apex, and no visible void. Inadequate filling was defined as filling present in the pulp chamber only or (slightly) beyond, ending more than 2 mm beyond the radiographic apex, or showing severe overfilling (eg, uneven filling, voids, inadequate density, and/or poor condensation). Multiroot teeth were classified according to the most adequately filled root canal[12].

Coronal Restoration

The types of coronal restorations (intact tooth, nonrestored/cavity, restoration, crown/post-core crown) were recorded. Restoration was defined as restorations of the coronal portion of teeth that were consistent with amalgam, glass-ionomer, or composite fillings, whereas crowns were defined as the coronal restorations of teeth that had an appearance correlating with cast restorations[9]. If secondary caries, open margins, or overhangs, or temporary coronal fillings were detectable, the quality of the restoration was assessed radiographically and classified as inadequate[13].

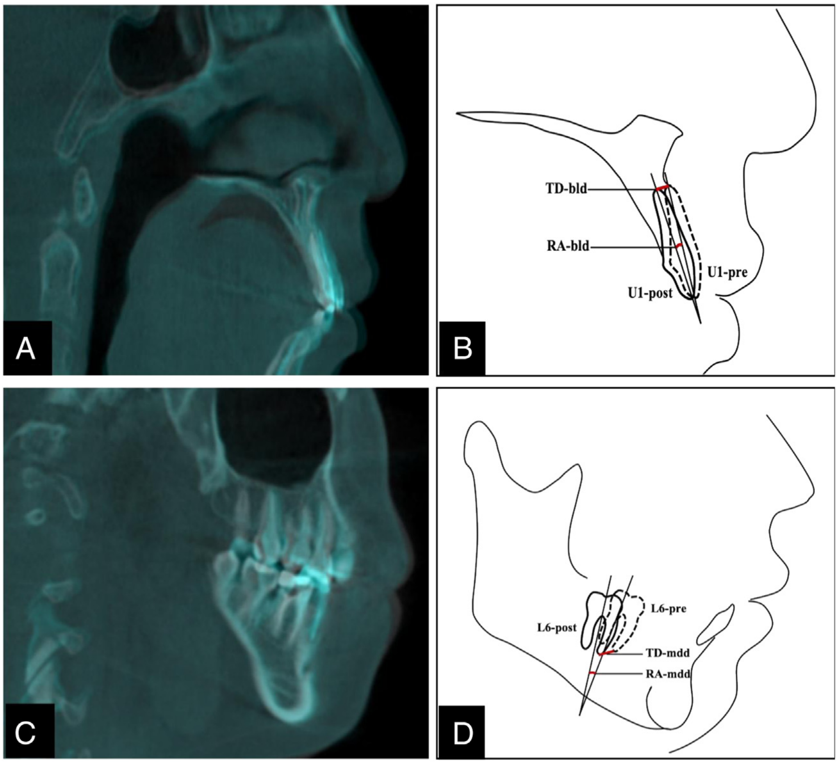

FIGURE 1 – Measurements from the InVivo 5.2.4 software. (*A* and *C*) Superimposition of pre- and post-orthodontic CBCT. (*B*) Measurements of the tooth movement in buccal-lingual direction (bdd). TD (traction distance), distance between pre- and post-orthodontic anatomic root apex; RA (rotation angle), angle between pre- and post-orthodontic long axis. (*D*) Measurements of the tooth movement in mesial-distal direction (mdd).

Periodontal Condition

The degree of bone loss along the coronal and sagittal planes of the mesiodistal and buccolingual surfaces of each tooth was assessed radiographically to evaluate the periodontal tissues before orthodontic treatment[14]. Bone loss >50% of the normal alveolar bone height on at least one surface was regarded as severe, 25%–50% on at least one surface was regarded as moderate, and <25% on both surfaces was regarded as mild. Normal alveolar bone height was defined from the junction of the enamel and cementum to the apex of the tooth.

Tooth Movement and Rotation During Orthodontic Treatments

The CBCT data before and after orthodontic treatment were imported into InVivo 5.2.4 software (Anatomage, Inc, San Jose, CA). After overlapping the CBCT images of preorthodontic and postorthodontic treatment, the traction distance and rotation angle of the affected tooth were measured according to the following criteria (Fig. 1*A–D*).

1. Traction distance: The traction distance of the anatomic root apex in the mesiodistal and buccolingual directions before and after orthodontic treatment was measured. The anatomic apex of the mesial, buccal, or mesiodistal root of multiroot teeth was measured.
2. Rotation angle: The rotation angle of the long axis of the tooth in the mesiodistal and buccolingual directions before and after orthodontic treatment was measured.

Outcome Assessment

The changes to the measured diameter of periapical lesions were used as outcome assessment.

For teeth with preorthodontic CBCT-PAI = 0, the healing status was classified as successful if the postorthodontic periapical radiolucency diameter was <0.5 mm or classified as failed if the postorthodontic periapical radiolucency diameter was >0.5 mm.

For teeth with preorthodontic CBCT-PAI ≥1, the healing status was classified as successful if the periapical lesion diameter had decreased or classified as failed if the periapical lesion diameter remained unchanged or had increased.

For teeth with multiple roots, if one of the roots was classified as failed, the tooth was classified as failed healing.

Evaluator Calibration

Two observers with endodontic experience independently screened all CBCT scans. When there were differences between the observers, the images were reevaluated by both observers to reach a consensus. Before the investigation, for calibration purposes, Cohen's kappa values of 10 CBCT scans that were not included in this study were calculated to determine the degree of agreement between the observers.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY). Numerical variables are presented as the median and interquartile range, while categorical variables are presented as the frequency and percentage. Univariate statistical analyses included the chi-square, Fisher's exact, and Mann–Whitney U tests. A multivariable logistic model was used to identify statistical differences among independent variables (event: unsuccessful healing after orthodontic treatment). Stratified subsamples were analyzed separately when appropriate. All statistical tests were 2-tailed and interpreted at a significance level of 5%.

RESULTS

Description and Prognostic Factors of Overall RCT Teeth

The cohort included 169 RCT teeth. The median age at the start of orthodontic treatment was 27 (range, 23–33) years and the median duration of orthodontic treatment was 2.6 (range, 2–3.2) years.

As AP size, more than half of cases before (97, 57.4%) and after (89, 52.7%) orthodontic treatment resulted in CBCT-PAI = 0.

The univariate analysis (Table 1) results revealed that of the 169 cases, the healing status of 107 (63.3%) was considered successful, while that of 62 (36.7%) was considered failed.

Multiple logistic regression analysis (Table 1) further confirmed that success rate was greater for teeth with adequate RCT (odds ratio [OR] = 3.42; 95% confidence interval [CI] = 1.48–7.94) and adequate coronal restoration (OR = 4.40; 95% CI = 1.15–16.87).

Prognostic Factors of Samples with Preorthodontic CBCT-PAI = 0

In total, 97 teeth had a preoperative CBCT-PAI = 0. The median age at the start of orthodontic treatment was 27 (range, 23–33.5) years and the median duration of orthodontic treatment was 2.35 (range, 1.9–3.1) years.

As AP size, more than half of cases after orthodontic treatment (64, 66%) had no AP and only 3 cases (3.1%) exhibited cortical bone destruction, with 1 case (1%) showing cortical bone expansion.

The univariate analysis (Table 2) results revealed that among the 97 cases without AP before orthodontic treatment, the healing status of 63 (64.9%) was considered successful, while that of 34 (35.1%) was considered failed.

The results of multiple logistic regression analysis are shown in Table 2. The treatment results of teeth with a preoperative CBCT-PAI = 0 were significantly related to RCT quality (OR = 3.55; 95% CI = 1.05–11.99).

Prognostic Factors of Samples with Preorthodontic CBCT-PAI ≥1

In total, 72 teeth had a preoperative CBCT-PAI ≥1. As compared to teeth with a preoperative CBCT-PAI = 0, the patient age range at the start of orthodontic treatment was basically the same, with a slightly shorter median duration of orthodontic treatment of 2.76 (range, 2.14–3.25) years.

As AP size, cases before (31, 43.1%) and after (27, 37.5%) orthodontic treatment resulted in a CBCT-PAI = 2. In addition, the AP diameter before and after orthodontic treatment was 1.22 (range, 0.9–2.05) mm and 1.2 (range, 0–1.8) mm, respectively. Cortical bone destruction before and after orthodontics, without cortical bone expansion, was observed in only 9 (12.5%) and 8 (11.1%) cases, respectively.

By univariate analysis (Table 3), among the 72 cases in the sample, the healing status of 44 (61.1%) was considered successful, while that of 28 (38.9%) was considered failed. The cure rate was greater for cases with adequate RCT than inadequate RCT (69.4% vs 43.5%, respectively, *P* = .042).

Consistency Between Observers

We determined the consistency between observers and calculate Cohen's kappa for different parameters. These results indicate a lower Cohen's kappa for coronal restoration quality (Table 4). The consistency between observers for CBCT-PAI (D/E) is higher (Table 4).

DISCUSSION

Orthodontics had No Effect on the Prognosis of RCT Teeth

The relationship between endodontics and orthodontics at the treatment planning stage and the effect of orthodontic treatment on RCT teeth with or without AP remain unclear.

TABLE 1 - Univariate and Logistic Regression Analysis Identifying Influencing Factors on RCT Outcome in Overall Teeth

	RCT outcome		Univariate analysis		Multivariate analysis	
Variables	**Success**	**Failure**	**χ^2/z**	***P* value**	**Odds ratios (95% CI)**	***P* value**
Gender			2.345	.183	0.53 (0.20, 1.42)	.208
Male	13 (50.0%)	13 (50.0%)				
Female	94 (65.7%)	49 (34.3%)				
Age group, y			3.851	.429		
<20	6 (85.7%)	1 (14.3%)			Ref.	.495
20–29	65 (62.5%)	39 (37.5%)			2.89 (0.30, 27.56)	.357
30–39	22 (57.9%)	16 (42.1%)			5.31 (0.52, 54.48)	.148
40–49	7 (87.5%)	1 (12.5%)			1.23 (0.054, 28.01)	.897
50–59	7 (58.3%)	5 (41.7%)			3.33 (0.20, 54.55)	.4
Tooth position			1.254	.335	0.79 (0.31, 2.02)	.617
Mandibular tooth	63 (67.0%)	31 (33.0%)				
Maxillary tooth	44 (58.7%)	31 (41.3%)				
Tooth type			3.374	.193		
Anterior	27 (64.3%)	15 (35.7%)			Ref.	.408
Premolar	37 (72.5%)	14 (27.5%)			0.62 (0.21, 1.84)	.388
Molar	43 (56.6%)	33 (43.4%)			1.14 (0.34, 3.86)	.833
Orthodontic movement						
TD-mdd[‡]	1.5[§] (0.8∼2.5)[‖]	1.9[§] (1.0∼2.7)[‖]	−1.365	.172	1.27 (0.95, 1.68)	.102
RA-mdd[‡]	4.0[§] (1.5∼7.1)[‖]	3.4[§] (2.1∼6.1)[‖]	−0.113	.91	1.01 (0.94, 1.08)	.804
TD-bld[‡]	1.8[§] (0.9∼2.7)[‖]	2.1[§] (1.1∼3.0)[‖]	−0.938	.348	1.06 (0.84, 1.38)	.7
RA-bld[‡]	4.6[§] (2.6∼7.7)[‖]	4.3[§] (2.6∼8.9)[‖]	−0.162	.872	1.02 (0.94, 1.09)	.692
RCT quality			11.127	.001[†]	3.42 (1.48, 7.94)	.004[†]
Adequate	90 (70.3%)	38 (29.7%)				
Inadequate	17 (41.5%)	24 (58.5%)				
Coronal restoration quality			9.518	.004[†]	4.40 (1.15, 16.87)	.031[*]
Adequate	103 (66.9%)	51 (33.1%)				
Inadequate	4 (26.7%)	11 (73.3%)				
Periodontal bone loss			7.07	.065		
Normal	67 (65.0%)	36 (35.0%)			Ref.	.357
Mild	30 (66.7%)	15 (33.3%)			0.99 (0.41, 2.39)	.98
Moderate/Severe	10 (47.6%)	11 (52.4%)			2.32 (0.69, 7.84)	.175
Preorthodontic CBCTPAI			0.262	.631	0.97 (0.46, 2.06)	.946
0	63 (64.9%)	34 (35.1%)				
≥1	44 (61.1%)	28 (38.9%)				

bld, buccal-lingual direction; mdd, mesial-disatal direction; RA, rotation angle; RCT, root canal treatment; TD, traction distance.
*$P < .05$.
†$P < .01$.
‡Numerical variable.
§Median.
‖Interquartile range.

The results of the present study showed that orthodontic movement of RCT teeth, regardless of AP, had no effect on the prognosis. However, relatively few studies have investigated the impact of orthodontic treatment on the prognosis of RCT teeth without AP. Some previous reports speculated that the force applied to RCT teeth during orthodontic treatment has no effect on the pathogenicity and virulence of relevant microbial populations and does not interfere with the abilities of microbes to form biofilms[15]. Therefore, treatment failure during orthodontic movement of RCT teeth is likely not due to the force applied during orthodontic treatment. Of course, in rare cases, the force applied to RCT teeth during orthodontic treatment can lead to apical resorption, which may "open" the small canals and paracanals of the root apex delta, which contain microbes, leading to the activation of AP. However, this rare situation is more likely attributable to the inherent limitations of RCT techniques than orthodontic movement[15].

In regard to orthodontic movement of RCT teeth with AP, the results of a histological study to evaluate the relationship between periapical lesion size and orthodontic tooth movement found no significant difference in the extent of periapical pathology of RCT teeth regardless of orthodontic movement[3]. A histomorphological study of dogs conducted by de Souza et al[4] showed that orthodontic movement of teeth with chronic AP delayed, but did not prevent, the healing process. Moreover, a retrospective study of 128 RCT teeth conducted by Alqerban et al[5] found that the changes to pantographic reproducibility index of RCT teeth before and after orthodontic treatment were not related to orthodontic treatment. A cross-sectional study conducted by Vengerfeldt et al[16] reported that the presence of fixed orthodontic appliances did not influence AP of RCT teeth. These results are consistent with the findings of the present study that orthodontic treatment did not influence AP. This also echoes the views of Consolaro et al[15] that the force applied during orthodontic treatment will not change or enhance the activities of settled microbial populations or compress the blood vessels in areas of AP during the tissue repair process. Therefore, failed RCT teeth with AP after months or years is most likely due to inadequate RCT or technical limitations, rather than orthodontic movement. Other than traumatized teeth, orthodontic movement can

TABLE 2 - Influencing Factors on RCT Outcome in Teeth With Preorthodontic CBCTPAI = 0

	RCT outcome		Univariate analysis		Multivariate analysis	
Variables	**Success**	**Failure**	χ^2/z	***P* value**	**Odds ratios (95% CI)**	***P* value**
Gender			NA	.369		
Male	7 (53.8%)	6 (46.2%)				
Female	56 (66.7%)	28 (33.3%)				
Age group, y			1.25	.923		
< 20	2 (66.7%)	1 (33.3%)				
20–29	39 (65.0%)	21 (35.0%)				
30–39	11 (61.1%)	7 (38.9%)				
40–49	5 (83.3%)	1 (16.7%)				
50–59	6 (60.0%)	4 (40.0%)				
Tooth position			3.976	.055	1.59 (0.53, 4.80)	.414
Mandibular tooth	41 (73.2%)	15 (26.8%)				
Maxillary tooth	22 (53.7%)	19 (46.3%)				
Tooth type			6.938	.037*		
Anterior	14 (70.0%)	6 (30.0%)			Ref.	
Premolar	27 (79.4%)	7 (20.6%)			0.37 (0.10, 1.45)	.155
Molar	22 (51.2%)	21 (48.8%)			0.80 (0.20, 3.18)	.755
Orthodontic Movement						
TD-mdd†	1.4‡ (0.7∼2.3)§	2.2‡ (1.1∼3.2)§	−2.086	.037*	1.23 (0.87, 1.72)	.242
RA-mdd†	3.8‡ (0.8∼7.1)§	3.1‡ (2.3∼7.0)§	−0.246	.806		
TD-bld†	1.9‡ (0.9∼2.8)§	2.1‡ (1.2∼2.9)§	−0.69	.49		
RA-bld†	4.6‡ (3.0∼7.7)§	4.2‡ (2.2∼8.6)§	−0.427	.669		
RCT quality			6.593	.014*	3.55 (1.05, 11.99)	.041*
Adequate	56 (70.9%)	23 (29.1%)				
Inadequate	7 (38.9%)	11 (61.1%)				
Coronal restoration quality			NA	.015*	3.56 (0.78, 16.23)	.101
Adequate	60 (69.8%)	26 (30.2%)				
Inadequate	3 (27.3%)	8 (72.7%)				
Periodontal bone loss			2.105	.366		
Normal	42 (66.7%)	21 (33.3%)				
Mild	16 (69.6%)	7 (30.4%)				
Moderate/Severe	5 (45.5%)	6 (54.5%)				

bld, buccal-lingual direction; mdd, mesial-disatal direction; RA, rotation angle; RCT, root canal treatment; TD, traction distance.
*$P < .05$.
†Numerical variable.
‡Median.
§Interquartile range.

be attempted within 15–30 days after RCT regardless of AP, as exudate absorption and inflammation should be resolved[15].

However, it should be emphasized that this study was based on limited research conditions (ie, angle and distance of orthodontic movement) and CBCT images to assess the effects of orthodontics on the efficacy of RCT. Hence, further studies are needed to determine the effects of force (light or heavy), type (continuous or intermittent), and other factors of orthodontic treatment.

In addition, there is currently no consensus about whether the resorption of RCT teeth will be increased or decreased after orthodontic treatment[15]. Therefore, in clinical practice, before orthodontic treatment of RCT teeth, it is necessary to ensure that patients clearly understand possible outcomes of treatment, such as tooth movement, prognosis of RCT, and adverse changes.

Advantages of CBCT over Radiographs

Bender and Seltzer (1961)[17] found that lesions limited to cancellous bone (the trabeculae close to the cortical bone) could be missed on periapical radiographs. Many studies have since found that for periapical inflammation to be detected, 30%–50% mineral loss should occur[8]. False negatives of up to 40% may occur even though no periapical lesions are detected on radiographic images[18]. Due to the distortion and overlap of tooth structures, the 3D anatomic information of teeth and adjacent structures on oral and panoramic images are inevitably masked[6,7]. In addition, radiographic angles, contrast agents, and surrounding bone density can also affect interpretation of radiographic images[8]. CBCT aims to produce 3D information without overlapping anatomic structures, thereby improving diagnostic accuracy of AP and prognosis of RCT[8]. Therefore, in this study, CBCT scans were used to assess the extent of AP.

RCT Quality Affected the Prognosis of RCT Teeth

The quality of RCT is considered a key factor in the health of periapical tissue of RCT teeth[19]. Analysis of CBCT images found that the failure rate of RCT was significantly higher due to inadequate root canal filling, regardless of AP before orthodontics. The radiographic appearance of the root canal filling is only one parameter to assess the quality of RCT. The evaluation criteria should also include the presence of infection and (re)contamination both during and after treatment, in addition to other biological factors and clinical treatment conditions[20]. However, good quality of radiographic images of the root canal filling is essential to assess adequate closure of the root canal system, but also reflects the extent of cleaning of the root canal to ensure a tight seal to achieve healthy periapical tissues[21]. Therefore, it is reasonable to use the quality of root canal filling as an index to evaluate the quality of RCT. Numerous clinical and cross-

TABLE 3 - Univariate Description and Analysis on RCT Outcome in Teeth With Preorthodontic CBCTPAI ≥1

Variables	RCT outcome		Univariate analysis	
	Success	Failure	χ^2/z	*P* value
Gender			1.493	.346
Male	6 (46.2%)	7 (53.8%)		
Female	38 (64.4%)	21 (35.6%)		
Age group, y			3.894	.457
<20	4 (100.0%)	0 (0.0%)		
20–29	26 (59.1%)	18 (40.9%)		
30–39	11 (55.0%)	9 (45.0%)		
40–49	2 (100.0%)	0 (0.0%)		
50–59	1 (50.0%)	1 (50.0%)		
Tooth position			0.35	.632
Mandibular tooth	22 (57.9%)	16 (42.1%)		
Maxillary tooth	22 (64.7%)	12 (35.3%)		
Tooth type			0.164	.906
Anterior	13 (59.1%)	9 (40.9%)		
Premolar	10 (58.8%)	7 (41.2%)		
Molar	21 (63.6%)	12 (36.4%)		
Orthodontic Movement				
TD-mdd†	1.5‡ (1.0∼2.8)§	1.6‡ (0.7∼2.5)§		.795
RA-mdd†	4.0‡ (1.7∼7.0)§	3.5‡ (1.4∼5.4)§		.715
TD-bld†	1.8‡ (0.2∼2.7)§	2.0‡ (0.9∼3.2)§		.526
RA-bld†	4.0‡ (1.0∼7.8)§	4.6‡ (2.6∼9.2)§		.425
RCT quality				.042*
Adequate	34 (69.4%)	15 (30.6%)		
Inadequate	10 (43.5%)	13 (56.5%)		
Coronal restoration quality			NA	.292
Adequate	43 (63.2%)	25 (36.8%)		
Inadequate	1 (25.0%)	3 (75.0%)		
Periodontal bone loss				
Normal	25 (62.5%)	15 (37.5%)	0.69	.794
Mild	14 (63.6%)	8 (36.4%)		
Moderate/Severe	5 (50.0%)	5 (50.0%)		

bld, buccal-lingual direction; mdd, mesial-disatal direction; RA, rotation angle; RCT, root canal treatment; TD, traction distance.
*$P < .05$.
†Numerical variable.
‡Median.
§Interquartile range.

sectional studies have confirmed that the introduction or persistence of microorganisms and related metabolites in the root canal system due to imperfect therapy is a key risk factor for the occurrence of AP and sufficient maintenance of the affected teeth[12,22].

Therefore, before orthodontic movement of RCT teeth, the endodontist must carefully evaluate whether RCT is adequate. Inadequate or inappropriate RCT is more likely to be retreated. However, in realistic clinical scenes, inadequate RCT does not always present as functional or symptomatic failure. Patients often avoid further endodontic treatment for many reasons, especially economic factors. Therefore, postponement of root canal retreatment intervention after orthodontic treatment may be an option for functional teeth with inadequate RCT and periapical lesions to allow for a longer follow-up in order to take into consideration the possibility of late healing of apical lesions[4]. However, rigorous evaluation of the quality of RCT and continuous monitoring and care should be emphasized.

TABLE 4 - Calibration of Observers

Variables	Cohen's kappa/Intraclass correlation
CBCT-PAI (0-5)	0.77
CBCT-PAI (D/E)	0.88
TD-mdd*	0.82
RA-mdd*	0.79
TD-bld*	0.81
RA-bld*	0.82
RCT quality	0.76
Coronal restoration quality	0.73
Periodontal bone loss	0.77

bld, buccal-lingual direction; mdd, mesial-disatal direction; RA, rotation angle; RCT, root canal treatment; TD, traction distance.
*Numerical variable.

Quality of Coronal Restoration Affected the Prognosis of RCT Teeth

The results of this study found that besides the quality of RCT, the quality of coronal restoration is crucial to the success of RCT. These findings are supported by some cross-sectional studies[23,24]. Ray et al[25] and Kirkevang et al[26] found that the quality of coronal restoration is even more important than the quality of RCT for periapical health. In contrast, other studies have reported that the quality of coronal restoration is less important than the quality of RCT[27,28]. However, clinical examination and intraoral radiographs may be more reliable methods of evaluating the quality of coronal restorations than CBCT imaging[29]. The actual quality of coronal restoration cannot be accurately assessed based solely on radiographic images, especially CBCT scans due to beam hardening artifacts[7], imaging distortion of adjacent objects[8], and patient movements during the scan[29], which affect assessment of the quality of coronal restoration. Therefore, the results of imaging studies should be carefully interpreted. At the same time, in this study, inadequate coronal restoration was rare (15 teeth, 8.9%), which may be due to the fact that most orthodontic patients had adequate fillings or crowns before orthodontic treatment. Therefore, further studies with larger sample sizes and more comprehensive clinical examinations are needed to evaluate the impact of the quality of coronal restoration on the prognosis of RCT teeth.

Currently, the most consistent conclusion is that the highest success rate was always observed when teeth were treated adequately as a whole (both root canal treatment and coronal restoration follow acceptable quality standards). High-quality coronal restoration and RCT have a synergistic effect in preventing bacterial invasion, protecting tooth function, and maintaining long-term outcomes. Therefore, for the benefit of the patient, the provision of the adequate coronal restoration should be considered the final part of the RCT procedure to prevent postoperative re-infection before orthodontic movement.

Standards for Evaluation of AP

Clinical and radiographic criteria are used in the diagnosis of AP lesions[8]. Clinical symptoms such as pain, swelling, sinus tract formation, and tenderness are only moderately specific and occur to varying degrees. Therefore, oral radiography is still the basis of AP diagnosis.

Many standards are used to evaluate AP, including the 5-level PAI proposed by Orstavik et al[18] (1986) to assess radiographic manifestations of periapical lesions at different histological stages. However, the cut-off scores vary among studies. For example, in the Toronto study series, a PAI of 1 and 2 indicates the absence of periapical lesions[30,31], while a PAI of 2 indicates mild inflammation of the periapical tissue and small periapical lesions[32].

In the present study, AP was evaluated using a new CBCT-based PAI system proposed by Estrela et al[8], which classifies AP on a 5-point scale, where a score of 1-5 indicates periapical radiopacity >0.5 mm. As compared to the loose standards of the Toronto study, the criteria for evaluation of AP in this study were more stringent. The CBCT-PAI evaluation system also includes cortical bone expansion and destruction, as these 2 variables may be missed on radiographs, thereby further improving the accuracy of AP assessment.

Evaluation Standards for RCT Outcome

Clinical examination combined with radiography are commonly used to evaluate RCT outcome. However, the incidence of clinical symptoms/signs after RCT is often less than 5%[33]. In this study, all patients had at least 1 RCT tooth, and all RCT teeth were asymptomatic with normal function; otherwise, orthodontic treatment should not be performed. Therefore, oral radiography was applied to evaluate the RCT outcome.

In the present study, the criteria to evaluate RCT outcome of periapical inflammation included shrinkage of the periapical lesion. Currently, there are 2 observation endpoints to assess the efficacy of RCT: the presence or absence of periapical lesions and shrinkage of the lesions[12,30,31]. The main aim of RCT is to maintain or restore a healthy lesion-free periapical state[34,35]. As the understanding of the anatomic complexity of the root canal system and limitations to existing technology for cleaning have gradually improved[21], some researchers have suggested that the goal of RCT for chronic periapical inflammation is to reduce infection in the root canal as much as possible to promote healing of the lesion, with the corresponding endpoint of the reduction of periapical lesions. Shrinkage of the lesion indicates that the host immune system has an advantage over residual microbes and will not cause adverse effects on systemic health[36]. Therefore, a more lenient criterion (reduction in the size of periapical radiopacity) was adopted in this study as an imaging standard for successful RCT treatment of teeth with periapical inflammation.

Limitations

There were some limitations to this study. First, due to the lack of a control group of non-orthodontically treated patients, comparative analysis was not possible. Second, potential confounding factors (eg, duration of AP before orthodontic treatment, severity of orthodontic malocclusion, and force/type of orthodontic treatment) that could influence the outcome of RCT were not addressed due to the limited sample size and lack of clinical data.

Therefore, the generalizability of these results should be interpreted with caution in the context of limited populations and settings, especially the conclusions regarding the relationship between orthodontic treatment and RCT prognosis. Nonetheless, these findings provide useful insights. Future studies with larger sample sizes and control groups are needed to further clarify the relationship between orthodontic treatment and RCT prognosis.

CONCLUSION

Orthodontic movement had no effect on the outcome of RCT teeth regardless of the presence of AP. Further studies are still needed to determine other factors (eg, force or type) of orthodontic treatment on the prognosis and verify the orthodontic treatment protocol for endodontically treated teeth.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Xue Chen: Conceptualization, Resources, Data curation, Formal analysis, Writing – original draft. **Shao-Qing Liu:** Conceptualization, Resources, Data curation, Writing – original draft. **Xiao-Xiao Wang:** Conceptualization, Data curation, Writing – original draft. **Wei Liu:** Data curation, Writing – original draft. **Xin Zhou:** Data curation, Writing – original draft. **Xiao Wang:** Conceptualization, Project administration, Resources, Writing – original draft.

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REFERENCES

1. Spurrier SW, Hall SH, Joondeph DR, et al. A comparison of apical root resorption during orthodontic treatment in endodontically treated and vital teeth. Am J Orthod Dentofacial Orthop 1990;97:130–4.
2. Wickwire NA, Mc Neil MH, Norton LA, et al. The effects of tooth movement upon endodontically treated teeth. Angle Orthod 1974;44:235–42.
3. Mah R, Holland GR, Pehowich E. Periapical changes after orthodontic movement of root-filled ferret canines. J Endod 1996;22:298–303.
4. de Souza RS, Gandini LG Jr, de Souza V, et al. Influence of orthodontic dental movement on the healing process of teeth with periapical lesions. J Endod 2006;32:115–9.

5. Alqerban A, Almanea A, Alkanhal A, et al. Impact of orthodontic treatment on the integrity of endodontically treated teeth. Eur J Orthod 2019;41:238–43.
6. de Paula-Silva FW, Wu MK, Leonardo MR, et al. Accuracy of periapical radiography and cone-beam computed tomography scans in diagnosing apical periodontitis using histopathological findings as a gold standard. J Endod 2009;35:1009–12.
7. Kruse C, Spin-Neto R, Wenzel A, et al. Cone beam computed tomography and periapical lesions: a systematic review analysing studies on diagnostic efficacy by a hierarchical model. Int Endod J 2015;48:815–28.
8. Estrela C, Bueno MR, Leles CR, et al. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J Endod 2008;34:273–9.
9. Peters LB, Lindeboom JA, Elst ME, et al. Prevalence of apical periodontitis relative to endodontic treatment in an adult Dutch population: a repeated cross-sectional study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:523–8.
10. SEDENTEXCT Project. Radiation protection: cone beam CT for dental and maxillofacial radiology. Evidence based guidelines. Geneva: European Commission; 2012. Available at: http://www.sedentexct.eu/files/radiation_protection_172.pdf.
11. Estrela C, Bueno MR, Azevedo BC, et al. A new periapical index based on cone beam computed tomography. J Endod 2008;34:1325–31.
12. Ng Y-L, Mann V, Rahbaran S, et al. Outcome of primary root canal treatment: systematic review of the literature – Part 2. Influence of clinical factors. Int Endod J 2008;41:6–31.
13. Tronstad L, Asbjornsen K, Doving L, et al. Influence of coronal restorations on the periapical health of endodontically treated teeth. Endod Dent Traumatol 2000;16:218–21.
14. Engebretson SP, Lamster IB, Elkind MS, et al. Radiographic measures of chronic periodontitis and carotid artery plaque. Stroke 2005;36:561–6.
15. Consolaro A, Consolaro RB. Orthodontic movement of endodontically treated teeth. Dental Press J Orthod 2013;18:2–7.
16. Vengerfeldt V, Mändar R, Nguyen MS, et al. Apical periodontitis in southern Estonian population: prevalence and associations with quality of root canal fillings and coronal restorations. BMC Oral Health 2017;17:147.
17. Bender IB, Seltzer S. Roentgenographic and direct observation of experimental lesions in bone: I. 1961. J Endod 2003;29:707–12.
18. Ørstavik D, Kerekes K, Eriksen HM. The periapical index: a scoring system for radiographic assessment of apical periodontitis. Endod Dent Traumatol 1986;2:20–34.
19. Sjogren U, Hagglund B, Sundqvist G, et al. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16:498–504.
20. Sundqvist G, Figdor D, Persson S, et al. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative re-treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:86–93.
21. Haapasalo M, Shen Y, Ricucci D. Reasons for persistent and emerging post-treatment endodontic disease. Endod Topics 2008;18(1):31–50.
22. Liu SQ, Chen X, Wang XX, et al. Outcomes and prognostic factors of apical periodontitis by root canal treatment and endodontic microsurgery- a retrospective cohort study. Ann Palliat Med 2021;10:5027–45.
23. Craveiro MA, Fontana CE, de Martin AS, et al. Influence of coronal restoration and root canal filling quality on periapical status: clinical and radiographic evaluation. J Endod 2015;41:836–40.
24. Karteva T, Manchorova-Veleva NA, Karteva E, et al. Quality of endodontic treatment and prevalence of apical radiolucencies in a Bulgarian subpopulation: a CBCT analysis. Folia Med 2021;63:81–7.
25. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995;28:12–8.
26. Kirkevang LL, Hörsted-Bindslev P, Ørstavik D, et al. Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population. Int Endod J 2001;34:198–205.
27. Segura-Egea JJ, Jimenez-Pinzon A, Poyato-Ferrera M, et al. Periapical status and quality of root fillings and coronal restorations in an adult Spanish population. Int Endod J 2004;37:525–30.

28. Tavares PBL, Bonte E, Boukpessi T, et al. Prevalence of apical periodontitis in root canal-treated teeth from an urban French population: influence of the quality of root canal fillings and coronal restorations. J Endod 2009;35:810–3.

29. Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. Dent Clin 2008;52:825–41.

30. Friedman S, Abitbol S, Lawrence HP. Treatment outcome in endodontics: the Toronto study. Phase 1: initial treatment. J Endod 2003;29:787–93.

31. de Chevigny C, Dao TT, Basrani BR, et al. Treatment outcome in endodontics: the Toronto study. Phase 4: initial treatment. J Endod 2008;34:258–63.

32. Wu MK, Shemesh H, Wesselink P. Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment. Int Endod J 2009;42:656–66.

33. Marquis VL, Dao T, Farzaneh M, et al. Treatment outcome in endodontics: the Toronto study-phase: initial treatment. J Endod 2006;32:299–306.

34. Friedman S. Considerations and concepts of case selection in the management of post-treatment endodontic disease (treatment failure). Endod Topics 2002;1:54–78.

35. Trope M. The vital tooth: its importance in the study and practice of endodontics. Endod Topics 2003;5:1–11.

36. Wu MK, Wesselink P, Shemesh H. New terms for categorizing the outcome of root canal treatment. Int Endod J 2011;44:1079–80.