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ORIGINAL ARTICLE

Dentin thickness as a risk factor for vertical root fracture in endodontically treated teeth: a case-control study

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Abstract

Objectives This study evaluated factors associated with vertical root fracture in endodontically treated teeth, using a cone-beam computed tomography (CBCT) image database.

Materials and methods The sample for this case-control study consisted of 81 CBCT scans of teeth with vertical root fracture (VRF) and 81 CBCT scans of non-fractured teeth, matched by age, sex, and tooth position. The analyzed variables included dentin thickness, an intraradicular post, an adjacent implant, and a missing adjacent tooth. Student's t test test was used to compare the quantitative variables. The chi-square test was used to compare the categorical variables. Logistic regression was performed to evaluate the association between the presence of VRF and the independent factors assessed.

Results The mean dentin thickness of fractured teeth was 1.3 mm, whereas that of non-fractured ones was 1.5 mm ($p < 0.001$). There was no difference between the fractured and non-fractured groups, regarding implant frequency or missing adjacent tooth ($p > 0.05$). There were a significantly larger number of teeth with posts in the fractured versus non-fractured group ($p = 0.007$). However, dentin thickness ≤ 1.3 mm was the only factor associated with VRF in the multiple regression model (OR = 3.60, 95%CI = 1.76–7.37).

Conclusions Dentin thickness may influence the development of VRF. Dentin thickness ≤ 1.3 mm is associated with a greater likelihood of fracture than ≥ 1.4 mm.

Clinical relevance This study suggests there may be a minimum amount of safe dentin thickness that should be preserved after endodontic instrumentation.

Keywords Vertical root fracture · Dentin thickness · Endodontically treated teeth · Cone-beam computed tomography · Case-control · Risk factor

Introduction

Vertical root fracture (VRF) is defined as a complete or incomplete fracture that extends longitudinally along the root [1]. The prevalence of VRF ranges from 3.69 to 31.5% [2–4]. It is more frequent in women aged older than 40 years, and the most affected teeth are mandibular molars and maxillary premolars [5, 6].

The etiology of VRF is multifactorial, and its occurrence is more common in endodontically treated teeth [7]. The microstructural changes in dentin over the years, excessive instrumentation, excessive irrigation with highly concentrated chemical solutions, and excessive compaction force during lateral condensation may increase susceptibility to VRF [8–10]. Other potential risk factors for VRF are endodontic retreatment [11] and overfilled roots [12].

Extensive dentin removal in endodontic instrumentation may result in tooth weakening [13]. Root canal wear during instrumentation can range from 14 to 45% of the dental structure [14], resulting in the removal of a mean dentin volume of approximately 2 to 3 mm^3 [15, 16].

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Knowing how much dentin can be removed without causing considerable weakening is a real challenge.

In addition to the weakening caused by endodontic treatment, other factors can put teeth at risk for VRF. A case series reported the presence of implants adjacent to endodontically treated teeth as a possible VRF-related factor [17]. According to this report, close placement of implants could cause an imbalance in the dissipation of occlusal forces [17, 18]. Based on this principle, one of our hypotheses was that a missing adjacent tooth would also cause a disparity in the dissipation of forces, making the remaining teeth of the dental arch more susceptible to root fractures.

VRF diagnosis poses a great challenge to the clinician, because VRFs have non-specific signs and symptoms, thus mimicking other dental conditions [6]. In addition, radiographic diagnosis of VRFs can be difficult due to limitations inherent to two-dimensional exams, such as the overlap of dental and bone structures [19]. Cone-beam computed tomography (CBCT) allows a three-dimensional evaluation of these structures and has been found to be more accurate than periapical radiography in detecting VRFs [20, 21]. However, CBCT could present a low sensibility in relation to VRF detection [22], influenced by the presence of artifacts [23, 24] and technical exposure parameters [25].

VRF is one of the main causes of extraction of endodontically treated teeth [3, 26]. Moreover, late diagnosis leads to damage to periodontal tissues, such as significant alveolar bone loss, which directly impacts a patient's rehabilitation treatment [27]. Knowledge of the factors related to the development of a VRF may help prevent it, and also contribute to establishing procedures for early VRF diagnosis. Some of these factors have not yet been completely elucidated, such as the minimum amount of remaining dentin thickness and the presence of adjacent implants. Thus, this study aimed to evaluate the factors associated with VRF in endodontically treated teeth, using a CBCT image database.

Materials and methods

Study design

A case-control study was designed and conducted following the guidelines set by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) to describe case-control studies [28]. The present research protocol was approved by the ethics committee of the university (CAAE 80421917.0.0000.5083).

Sample selection

Eighty-one CBCT scans of endodontically treated teeth with VRF (cases) were selected and compared with CBCT scans of endodontically treated teeth without VRF (controls). The case and control groups were matched by a ratio of 1:1 for age (± 5 years), sex, and tooth. The CBCTs were provided from the image database of a private oral radiologic clinic, so they were not performed with research purposes. The VRF group was selected from radiological reports with suspicion of VRF and the record of a positive confirmation of VRF obtained by exploratory surgery. The controls were selected from CBCT scans, with no evidence of VRF, requested for the planning of third molar extraction or endodontic evaluation. The scans were acquired by i-CAT Next Generation (Imaging Sciences International, Hatfield, PA, USA), under the following exposure protocol: voxel 0.125–0.2, FOV 16 × 4 cm, mA 5, and kVp 120.

A pilot study was performed to calculate the sample size, using a convenience sample of 20 CBCT images of teeth with VRF and 20 matched control teeth (without VRF). Considering root dentin thickness as the main tested risk factor for VRF (exposure variable)—$\leq$ 1.3 mm (exposed) and $\geq$ 1.4 mm (unexposed)—the proportion of exposed teeth was 54.2% ($n = 11$) for the cases and 35.0% ($n = 7$) for the controls. Other parameters included a 5% level of significance (type I error rate) and 80% power (20% type II error rate). Based on this information, the minimum odds ratio (OR) to detect was 2.2, and the estimated sample size was 81 cases and 81 controls for this matched case-control study (one-sided test).

The variables analyzed included dentin thickness, an intraradicular post, an adjacent implant, and missing adjacent teeth. Adjacent implants and adjacent teeth were considered as such when they were next to the analyzed tooth.

Radiological reports of endodontically treated teeth, which included descriptive images of VRFs and information on the clinical confirmation of VRF, were previously selected. Then, the entire volume was evaluated following multiplanar reformatting to confirm the presence of a clear fracture line. A fracture line was so considered when a radiolucent/hypodense linear image was observed simultaneously and continuously in the axial, coronal, and sagittal planes.

To permit the use of digital applications and to aid in dental measurement procedures, all the CBCT scans obtained from the oral radiologic clinic database that aimed the investigation of dental fractures, or the planning of third molar extraction or endodontic evaluation, were obtained in disclusion. This procedure is helpful if the CBCT scan is captured for dental measurements, and in cases that having accurate occlusal details is currently indispensable.

After defining the case group, the patient profile (sex, age, and tooth) of these scans was recorded. The control group was selected according to similar characteristics specified in the case group. For this purpose, an initial selection was made based on the radiological reports, gender, age, and tooth. After this preselection, a simple, random draw was performed to choose 1 control from the eligible scans. All CBCT scans were acquired with a FOV of 16 × 4 cm, following the As Low As Reasonably

Achievable (ALARA) principle. The CBCT scans, performed between 2014 and 2018, from patients with single-rooted and/or multirooted endodontically treated teeth were included in the study. CBCT scans with artifacts that hindered their evaluation were excluded, as well as teeth with internal root resorption and extensive periapical lesions.

Image analysis

DICOM files were exported to CS 3D Imaging Software version 3.1.9 (Carestream Health, Rochester, NY, USA) and ITK-SNAP version 3.8.0 (www.itksnap.org) and analyzed by a single radiologist with 10 years of experience, in a dark environment, on a Dell XPS X8700 computer with a 28-in. color monitor, an Intel 3.4-GHz processor, 12-GB memory, and 2-TB HD (Dell, Austin, TX, USA).

Dentin thickness was evaluated using the CS 3D Imaging Software, with the linear measurement tool. Oblique slicing was used to adjust the planes on the long axis of the tooth. The evaluations were performed on oblique coronal and oblique sagittal slices. The roots were divided proportionally into three parts, and measured at three points (cervical, middle, and apical thirds—1 mm from the apex), in each dental aspect (buccal, lingual, mesial, and distal) (Fig. 1). The final measurement was the simple arithmetic mean of the measurements of each aspect. The measurements of multirooted teeth were performed on the fractured root. In regard to the teeth that had two root canals in a root and significant presence of dentin between them, the dentin thickness between the canals was included in the evaluation. The same points were evaluated in the mesial and distal aspects.

Statistical analysis

Statistical analysis was performed using the SPSS 24 software (Statistical Package for Social Sciences, IBM Corp, NY, USA). Fifteen percent of the sample was reevaluated and the intraclass correlation coefficient (ICC) was calculated to evaluate the intraexaminer agreement of the measurements for dentin thickness. The Kolmogorov-Smirnov test was used to evaluate normality of the sample. Student's t test was used to compare the dentin thickness between the fractured and non-fractured groups. The categorical variables were compared using the chi-square test. Statistical significance was set at $p < 0.05$. Logistic regression was performed to evaluate the association between the presence of VRF and the independent factors assessed.

Results

The intraexaminer agreement (intraclass correlation coefficient) was excellent for dentin thickness (0.8). Of the 81 teeth selected with root fractures, 58% ($n = 47$) were single-rooted and 42% ($n = 34$) were multirooted. For case-control study purposes, the non-fractured group had the same proportions. The sample consisted mostly of women (63%), with a mean age of 51 years, and the most frequently assessed teeth were mandibular molars (21%) and maxillary premolars (21%).

The mean dentin thickness for teeth with VRF was 1.54 (± 0.28), 1.45 (± 0.24), and 0.96 (± 0.15) mm for the cervical, middle, and apical thirds, respectively. These measurements in the control group were 1.85 (± 0.30), 1.62 (± 0.23), and 1.03 (± 0.14) mm for the cervical, middle, and apical thirds, respectively. Figure 2 shows that dentin thickness was significantly lower for teeth with VRF in all regions of the root—cervical ($p < 0.001$), middle ($p < 0.001$), and apical ($p = 0.002$).

The measurements of the dentin thickness are described in Table 1. A thinner dentin wall was found for teeth with VRFs ($p < 0.001$). The dentin thickness of the fractured tooth with an intraradicular post was 1.25 mm (± 0.21), whereas the mean value of the fractured tooth without an intraradicular post was 1.38 mm (± 0.15; $p = 0.004$). The presence of an intraradicular post was significantly higher in the fractured group ($p = 0.007$). The presence of implants adjacent to fractured teeth was 8.6%, and missing adjacent teeth represented 19.8%. Similar percentages were found for the control group (Table 1).

Logistic regression analysis (Table 2) was performed to identify factors associated with the occurrence of VRF. The independent variables were dentin thickness—dichotomized as ≤ 1.3 mm and ≥ 1.4 mm, based on the mean value of dentin

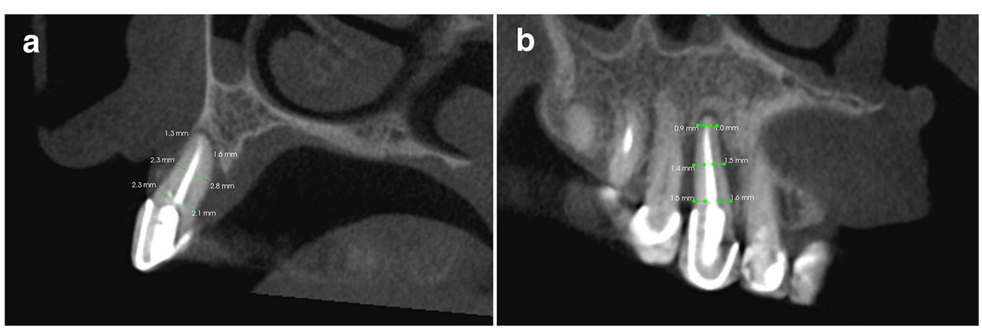

Fig. 1 Measurement points. **a** Oblique sagittal slice of mesial and distal dentin thickness measurement. **b** Oblique coronal slice of vestibular and lingual dentin thickness measurement

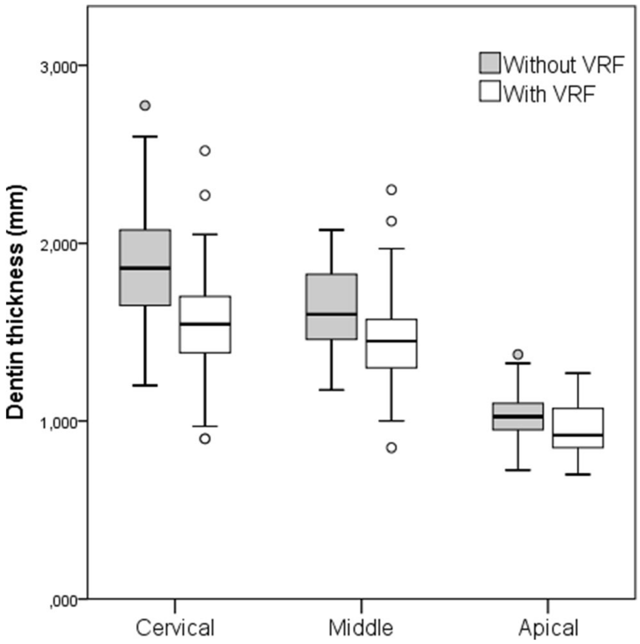

Fig. 2 Distribution of dentin thickness measurements according to the area of the root, for teeth with and without VRF. There were significant differences for the pairwise group comparison in the cervical ($p < 0.001$), middle ($p < 0.001$), and apical ($p = 0.002$) thirds of the root

thickness of the fractured group, the presence of intraradicular post, adjacent implant, and missing adjacent tooth.

The bivariate logistic regression models showed that lower dentin thickness (OR = 4.24; 95% CI = 2.19–8.18) and the presence of an intraradicular post (OR = 2.4; 95% CI = 1.26–4.53) were associated with VRF (Table 2). However, as the presence of an intraradicular post was highly associated with lower dentin thickness, due to root canal preparation, this variable lost statistical significance in the multiple regression model. Hence, the only factor that was considered associated with VRF was the thickness of the root dentin ($p < 0.001$).

Discussion

The multifactorial etiology of VRFs and their non-specific symptoms make diagnosis a challenge in clinical practice [6]. Identification of the factors causing a VRF is crucial for its diagnosis and prevention. The present study evaluated some factors associated with the development of VRFs in endodontically treated teeth, using CBCT images. The results showed that dentin thickness ≤ 1.3 mm was a risk factor, regardless of the presence of an intraradicular post, adjacent implants, or missing adjacent tooth.

In the present investigation, we executed a case-control study to evaluate the association of some factors with VRF. According to the case-study design, the case and the control groups were matched for age, sex, and tooth type to reduce the influence of these variables as confounding factors. We performed tomographic measurements of dentin thickness in the CBCT scans based on the premise that this exam provides an accurate means to measure dentin thickness, even in the presence of metallic artifacts [29]. According to a previous study, there is a very high correlation between CBCT and micro-CT in the measurement of dentin thickness, with the last being considered the reference standard [30], showing that CBCT can be used to accurately assess radicular dentin wall thickness [29].

The CBCT scans used in this investigation were obtained with a voxel size varying from 0.125–0.2 mm, which according to Ozer et al. [31] and Bragatto et al. [32], allows an accurate analysis for VRF diagnosis. Additionally, the voxel sizes used in the present study (0.125–0.2 mm) show no differences between them in respect to the detection of VRF in teeth with metallic posts [23].

In the intent to prevent measurement bias, all the analyses were performed by a single experienced radiologist, showing an excellent intraexaminer agreement for all the measurements. A single examiner provides more consistency in observations, improves distinction among the groups, and suppresses the interexaminer variation [33].

Table 1 Comparison between case and control groups regarding dentin thickness (mean and standard deviation), and frequency (%) of intraradicular post, adjacent implant, and missing adjacent tooth

		Single-rooted teeth ($n = 94$)			Multirooted teeth ($n = 68$)			All teeth ($n = 162$)		
		With VRF	Without VRF	p value	With VRF	Without VRF	p value	With VRF	Without VRF	p value
Dentin thickness (mm)		1.34 (0.18)	1.52 (0.19)	< 0.001	1.26 (0.20)	1.47 (0.19)	< 0.001	1.30 (0.19)	1.5 (0.19)	< 0.001
Intraradicular post	Yes	32 (68.1)	19 (40.4)	0.007	11 (32.4)	7 (20.6)	0.272	43 (53.1)	26 (32.1)	0.007
	No	15 (31.9)	28 (59.6)		23 (67.6)	27 (79.4)		38 (46.9)	55 (67.9)	
Adjacent implant	Yes	7 (14.9)	7 (14.9)	1	–	3 (8.8)	0.076	7 (8.6)	10 (12.3)	0.442
	No	40 (85.1)	40 (85.1)		34 (100)	31 (91.2)		74 (91.4)	71 (87.7)	
Missing adjacent tooth	Yes	10 (21.3)	10 (21.3)	1	6 (17.6)	7 (20.6)	0.758	16 (19.8)	17 (21)	0.845
	No	37 (78.7)	37 (78.7)		28 (82.4)	27 (79.4)		65 (80.2)	64 (79)	

Table 2 Logistic regression models for the potential risk factors associated with VRF

Risk factor	Bivariate model		Multivariate model	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Dentin thickness (≤ 1.3 mm)	4.2 (2.19–8.18)	< 0.001	3.60 (1.76–7.37)	< 0.001
Intraradicular post (yes)	2.4 (1.26–4.53)	0.007	1.49 (0.72–3.05)	0.280
Adjacent implant (yes)	0.67 (0.24–1.86)	0.444	0.82 (0.27–2.52)	0.732
Missing adjacent tooth (yes)	0.93 (0.43–1.99)	0.845	0.97 (0.42–2.25)	0.945

The minimum amount of remaining dentin not promoting considerable weakening after endodontic treatment has not yet been determined. In this study, the mean thickness of the fractured teeth was 1.3 mm, whereas that of the non-fractured teeth was 1.5 mm. Mireku et al. [8] found similar values in their evaluation of the effects of dentin thickness on extracted single-rooted teeth, treated endodontically with intraradicular post, where the fractured and non-fractured teeth had a mean thickness of 1.24 mm (± 0.35) and 1.52 mm (± 0.27), respectively. Unlike our investigation, which determined dentin thickness at three points, theirs evaluated it along the fracture line, and their approach, sample size, and study design were different from ours. Accordingly, our results suggest that there is a possible minimum amount of safe dentin thickness after root canal treatment.

Our findings imply that teeth with less remaining dental tissue are more susceptible to VRF due to the weakening of the dental structure. Marchi et al. [34] evaluated the effect of remnant thickness of bovine dental roots on fracture resistance, with different intraradicular systems, and found that teeth with less root structure are less resistant to fracture, regardless of the type of post used. In addition, our results demonstrated that when an intraradicular post was involved, the dentin thickness was significantly smaller. Accordingly, the clinician should be aware of the greater chances of fracture in post-preparation procedures when the dentin thickness of roots is ≤ 1.3 mm.

In the logistic regression, the odds ratio found for dentin thickness indicates that teeth endodontically treated with a dentin remnant ≤ 1.3 mm are 3.6 times more likely to present a root fracture, in comparison with teeth with a greater thickness. Although the presence of a post may be independently associated with the development of VRF (OR = 2.3; 95% CI = 1.26–4.53), this variable was not a risk factor in the multiple regression model (OR = 1.49; 95% CI = 0.72–3.05). In a retrospective cohort study, Maddalone et al. [35] reported that the presence of a post was a risk factor for VRF (OR = 15; 95%CI = 6.84–33.59). However, the authors of the mentioned study did not evaluate dentin thickness, whereas we tested the effect of both the dentin thickness and the presence of the post, in a bivariate logistic regression model. Our results indicated that dentin thickness was the main factor associated with VRF, regardless of the presence of an intraradicular post.

It was also postulated that the combination of excessive occlusal overload on endodontically treated teeth adjacent to dental implants may potentially contribute to the development of VRF [17]. This assumption was based on the finding that dental implants do not offer the protective action of proprioception, which may result in occlusal overload, and also on the fact that endodontically treated teeth have reduced proprioception and fracture resistance. In this respect, Rosen et al. [17] related a possible association between the presence of implants and the development of VRFs in endodontically treated teeth. The results of the present study did not show a significant difference between the case and the control groups regarding the presence of implants. From a clinical perspective, the interpretation of results was impaired, because it was not known if the implant was placed before or after the occurrence of the VRF, or if the dental implant was really related to occlusal overload in the region of the analyzed teeth. Despite the plausibility of this theory, the only evidence currently available regarding the relation between the presence of dental implants and VRF in endodontically treated teeth comes from only a few reported cases [17].

Likewise, in the present study, we found no significant relation between missing adjacent teeth and VRFs. Our hypothesis was that a missing adjacent tooth would also cause a disparity in the dissipation of forces and occlusal overload in the endodontic tooth region. However, our study design did not allow us to determine whether the patient indeed wore a removable partial prosthesis in the missing tooth region, an important factor that would directly influence the dissipation of occlusal forces.

The limitations of this study are related to the use of an image database that did not contain all the clinical information on the patients analyzed, as well as the lack of information on the type of restoration and post, and on their use with an adhesive or non-adhesive system.

New studies using micro-CT should be carried out to establish and reinforce the concept of an optimal minimal thickness of dentin that should be maintained in endodontic treatments. Further research to understand related, yet unelucidated factors, such as the presence of adjacent implants, is also necessary.

The results of the present study showed the influence of dentin thickness on the development of VRF and emphasize the importance of preserving utmost tooth structure in endodontic procedures, and in preparations for intraradicular post placement. The findings related to dentin thickness can alert professionals to the possibility of root fractures in teeth with smaller thicknesses, and guide them in more conservative protocols.

Conclusion

Based on our results, we concluded that dentin thickness influences the development of VRF. Dentin thickness ≤ 1.3 mm is associated with a greater likelihood of fracture, compared with thicknesses ≥ 1.4 mm, regardless of the presence of intraradicular posts. Missing adjacent teeth and the presence of implants are factors that do not seem significant for the development of VRFs.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the ethics committee of the university (CAAE 80421917.0.0000.5083) and conducted in accordance with the 1964 Helsinki declaration.

Informed consent For this type of study (retrospective study), formal consent is not required.

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