Prevalence of and Factors Associated With Vertical Root Fracture in a Japanese Population: An Observational Study on Teeth With Isolated Periodontal Probing Depth

Kwangsoon Lee, DDS, MSc, PhD,* Manjeet Ahlowalia, BDS, MSc,† Ruth Perez Alfayate, BDS, MSc, PhD,‡ Shanon Patel, BDS, MSc, PhD,† and Federico Foschi, BDS, MSc, PhD†§

ABSTRACT

Introduction: Previous studies on the prevalence of vertical root fractures (VRFs) were based on extracted teeth, or teeth referred for apical surgery. This study examined teeth with an isolated periodontal probing depth (PD) as an indicator of VRF. The primary aim of this study was to investigate the prevalence of vertical root fracture (VRF) and non-VRF among teeth with an isolated probing depth (PD) 5 mm. The secondary aim was to assess factors associated with VRF by comparing the teeth with and without VRF in the Japanese population. Methods: A total of 288 teeth with an isolated PD 5 mm were grouped pathologically into 8 groups comprising VRF and non-VRF conditions. A descriptive analysis for age, sex, tooth type, endodontically treated teeth (ETT) versus non-ETT, proximal contacts, PD (depth), PD (broadness and location), restoration type, and presence of a post was performed. Moreover, the associations between these factors and VRFs were investigated using the Chi-square test. Results: The prevalence of VRF was 32%. Lower first molars were the most common tooth type in both VRF (31.5%) and non-VRF groups (29.7%), while premolars were exclusively frequent in VRF (30.2%) and not frequent in non-VRF (7.8%). Narrow buccolingual PD was common in VRF (78.1%) whereas wide PD was frequent in non-VRF (67.1%). ETT, narrow buccolingual PD, tooth type (premolars), restoration type (crown), and the presence of a post showed significant associations with VRF (P .001). Conclusions: VRFs may be more prevalent in ETT among the Japanese. Careful assessment is necessary to differentiate VRFs from other conditions when the lower first molars show an isolated PD 5 mm. When an endodontically treated premolar with a post shows a narrow buccolingual PD, the probability of a VRF may be greater than in other tooth types. (J Endod 2023;49:1617–1624.)

KEY WORDS

Vertical root fracture; prevalence; diagnosis; periodontal probing depth

SIGNIFICANCE

An isolated periodontal probing depth (PD) is thought to be an indicator of VRF, however other pathological conditions may present similarly, causing diagnostic challenges. This crosssectional study assessed teeth with the isolated PD in a Japanese population and compared teeth with and without VRF. Five factors were shown to have a significant association with VRF. Also, the result showed a higher prevalence of VRF in Japanese than reports from other countries.

From the *Practice limited to Endodontics, Tokyo, Japan; †Department of Endodontology, King's College London Dental Institute, London, United Kingdom; ‡Department of Endodontics, Universidad Europea de Madrid, Madrid, Spain; and §Peninsula Dental School, University of Plymouth, United Kingdom

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The authors deny any conflicts of interest related to this study.

Data availability statement: The data that support the findings of this study are openly available upon request.

Address requests for reprints to Dr Kwangsoon Lee, Lee's Dental Clinic, 3-810-2F, Nihonbashi, Chuo-ku, Tokyo 1030027, Japan.
E-mail address: klee@leesdentalclinic.com

0099-2399/$ - see front matter

https://doi.org/10.1016/ j.joen.2023.08.018

Vertical root fracture (VRF) is a major cause of tooth loss, especially in endodontically treated teeth (ETT)[1,2]. Previous studies have reported a prevalence rate of VRF between 2.3 and 31.7%[3-8]. However, the study designs, samples, definitions, and methods of identifying VRF vary across these studies. Some studies were retrospective cross-sectional analyses based on extracted teeth[3-6], teeth that failed endodontic treatment[7], or teeth referred for apical surgery[8]. These studies, except that by Yoshino et al[6], included only ETT. The present study investigated the prevalence of VRF among teeth with an isolated periodontal probing depth (PD) 5 mm including non-ETT. [9-11]

A narrow, isolated periodontal pocket is an indicator of VRF . When a fracture line in a root reaches the cementum and the periodontal ligament, the area becomes infected, causing an isolated periodontal pocket[10]. However, other pathological conditions, such as perforation, root resorption, apical periodontitis (AP) draining via the periodontium, subgingival caries, horizontal or oblique fractures, and localized periodontal disease may present similarly, causing diagnostic difficulties[9]. Given that assessing the characteristics of teeth with an isolated PD 5 mm and comparing teeth in VRF and non-VRF conditions may aid in the differential diagnosis. This study aimed to investigate the prevalence of VRF and non-VRF pathological conditions among teeth with an isolated PD 5 mm, and the factors associated with VRF by comparing the teeth with and without VRF.

MATERIALS AND METHODS

Ethical approval for this study was granted by the BDM Research Ethics Office of King's College London (LRU-20/21-21498A). Verbal and written informed consents were obtained from all the patients included in the study. The study was conducted in accordance with the Helsinki Declaration of 1975.

Sample Selection

This cross-sectional study included 228 teeth confirmed with an isolated periodontal pocket 5 mm from 221 patients who visited a specialist endodontic clinic in Tokyo between 2012 and 2020 for a diagnosis or treatment. The samples included ETT and non-ETT. A posthoc estimation was performed for the power analysis.

A sample size of 228 teeth provided a maximum error of 6.49% to estimate the true prevalence of VRFs in the target population, assuming p 5 q 5 50% and a confidence interval (CI) of 95%.

Patients' Data

The anonymized patient data included age, sex, medical history, dental history, signs, and symptoms recorded at the first visit including spontaneous pain, painful response to percussion and palpation, pulp sensibility tests (for non-ETT), the presence of periodontal pockets (the depth, broadness, and location), and sinus tracts or swelling. Clinical photographs or videos were taken during treatment. Preoperative periapical (PA) radiographs were taken using MAX-DC70 (70 kV, 4 mA. J. Morita MFG Corp, Kyoto, Japan) with photostimulable phosphor plates and a positioning device (CID-4, Hanshin Technical Laboratory, Ltd., Japan). An i-VIEW scanning system (J. Morita MFG Corp, Kyoto, Japan) was used for cases between 2012 and August 2015 and a VistaScan Mini View scanner (Durr Dental SE, Beitigheim, Germany)€ was used for cases after August 2015. Preoperative cone-beam computed tomography (CBCT) scans (114 out of the 228 teeth) were taken using the CS81003D (Carestream Dental, Atlanta, GA, USA), with the following protocol: voxel size 75 mm, field of view (FOV) 5 ! 5 cm, 5 mA, and 60 kV.

Probing Depth Assessment and Definition of "Narrow" versus "Wide" Periodontal Pockets

Broadness of PD was categorized into "narrow" versus "wide" based on the previous studies[9,12]. PD was measured using a metal periodontal probe #5 (1.9% taper with a 0.45 mm diameter of rounded tip, YDM corporation, Tokyo, Japan) at the initial examination and/or during treatment. It was inserted and walked around the entire circumference of the tooth with the probing force of approximately 20 to 25 g. The probing force has been described as the pressure required to depress the skin on the pad of thumb by about 1 mm[13] searching for the deepest point[14] while working along the gingival sulcus. When the insertion of the probe was difficult because of probe inflexibility, the measurement was performed following crown removal. When PD 5 mm was confirmed, its depth, location, and broadness (narrow versus wide, molar furcation versus no molar furcation) were recorded. When width of the deep probing site was approximately within 2 mm (the periodontal probe was tight and could not be translated or could be translated 2 mm horizontally, including the probe diameter), it was defined as a 'narrow' probing site[9,12]. If the probe could be moved more than 2 mm horizontally, but still the defect is isolated with normal sulcus depth on either side, the periodontal probing was defined as "wide"[9,12].

Procedures and the Outcome Assessment

All patients had a consultation regarding their tooth condition, treatment options, and prognosis before treatment initiation. All procedures were performed by the author (KL) under magnification using a dental microscope (OPMI® PROergo, Carl Zeiss Meditec AG, Japan) which had a digital camera (Sony a7s, Tokyo, Japan) attached to it. All root canal retreatment (RCT) were carried out under the rubber dam isolation. Clinical photographs were taken during the course of treatment to illustrate clearly to the patients the condition

of their teeth. The treatment outcome was assessed initially at the follow-up based on the absence of symptoms, and absence (complete healing) or diminished size of apical radiolucency (healing). A blinded examiner (KU) with 15 years of experience as a general dental practitioner (GDP) and 3 years of experience as an endodontist, confirmed the outcome radiographically.

Sample Allocation according to Pathological Conditions

All teeth were allocated to the following 8 groups based on the most possible causes of the PD measuring 5 mm: 1) VRF; 2) subgingival caries (Caries); 3) horizontal or oblique fracture (HF); 4) localized periodontal disease, cemental tear (Perio); 5) perforation (PF); 6) root resorption (RR); 7) pulp necrosis, including 6 cracked teeth (PN); and 8) unclear origin that could not be ascribed to groups 1–7, with AP due to endodontic failure (AP).

Definition of VRF

This study adopted the American Association of Endodontists' definition of VRF: "a complete or incomplete fracture initiated from the root at any level, usually directed buccolingually"[15].

Identification and Allocation into Eight Pathological Groups

Vertical Root Fracture (VRF)

Patients suspected of having a VRF were informed of this possibility and asked to select one of three treatment options: 1) tooth extraction, 2) exploratory surgery to confirm VRF, or 3) exploratory root canal retreatment (reRCT) to remove root canal filling material and to confirm VRF using a methylene blue solution (Sigma-Aldrich, Japan) under magnification. Teeth in which VRFs were confirmed visually by any one of the methods described above, were allocated in the VRF group.

Root Resorption (RR)

Root resorption and the associated bone destruction were initially confirmed based on PAs and CBCT images. The match of the disease sites and PD was confirmed during the treatment.

Pulp Necrosis (PN)

Teeth were allocated to this group when the pulp was diagnosed with pulp necrosis based on pulp sensibility tests and the presence of AP confirmed by PAs, and CBCT images.

Apical Periodontitis due to Endodontic Failure (AP)

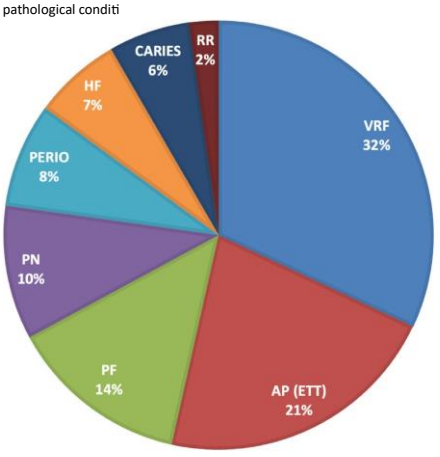
Teeth were allocated to this group when AP was confirmed in ETT. The diagnosis was based on clinical findings, PAs, and CBCT images.

Variables

Nine factors were assessed in this study. Age, sex, tooth type, PD (depth), and PD (broadness and location) for each patient were recorded in the clinical notes. Additionally, ETT versus nonETT, the proximal contacts (missing or nonmissing), types of restoration, and the presence of a post were assessed based on radiographs and clinical photographs.

Statistical Analysis

Statistical analysis was performed using SPSS 15.0 software (IBM Corp.; Chicago, IL, USA). The 95% CI of the prevalence of VRF and the other pathological conditi ons was estimated (Fig. 1). Descriptive analyses of the samples were carried out for the 9 factors differentiated by VRF versus non-VRF (Fig. 2) and by the eight pathological conditions (Supplementary Tables T1–T9), and the prevalence of VRF for each factor was calculated (Table 1). The association between VRF and the 9 independent variables was assessed using the Chi-square test (Table 2). Statistical significance was set at 5% (a5 0.05).



	95%CI
VRF	26.0 – 38.1
AP	16.2 – 26.8
PF	9.2 – 18.1
PN	6.2 – 14.0
Perio	4.4 – 11.4
HF	3.4 – 9.8
Caries	3.0 – 9.3
RR	0.7 – 5.0

FIGURE 1 – Prevalence of 8 pathological conditions and 95% CI among 228 teeth with PD 5 mm. VRF, vertical root fracture; AP, apical periodontitis due to endodontic failure; PF, perforation; Perio, localized periodontal disease; HF, horizontal or oblique fracture; Caries, subgingival caries, or defect; RR, root resorption

healing was confirmed for 93 teeth (the mean follow-up period was 18.6 months, range 6– 72 months) and the remaining 19 teeth lacked follow-up examination (4 in Perio, 3 in PF, 3 in PN, and 9 in AP). Pre- and postoperative CBCT images were used to confirm the healing of 46 out of 93 teeth.

RESULTS

Demographic Characteristics of the 228 Teeth

The sample consisted of 228 teeth from 221 patients (68 males and 153 females; mean age 46.2 6 10.3 years, range 21–73 years). The most affected teeth were the lower first molars (n 5 69, 30.3%) followed by the lower second molars (n 5 44, 19.3%).

Distribution of 8 Pathological Conditions

VRF was the most prevalent pathological condition (32.0%, 73/228) (Fig. 1). Among 73 patients in VRF group, VRF was confirmed by tooth extraction (3/73), the surgical approach (5/73), and reRCT (65/73). Among 228 teeth, tooth extraction was suggested for 116 teeth with a poor prognosis (73 in VRF, 10 in PF, 14 in Caries, 15 in HF, and 4 in Perio). The remaining 112 teeth were treated (14 in Perio, 21 in PF, 5 in RR, 23 in PN, 49 in AP) and the (4 in RR, 8 in PF, 15 in PN, and 19 in AP). The preoperative CBCT images of teeth in PN and AP group showed vertical bone destruction that matched the site and depths of PD 5 mm.

Subgingival Caries (Caries)

Teeth with visually confirmed subgingival caries that matched the sites and depths of PD, were allocated to the caries group.

Horizontal or Oblique Fracture (HF)

Teeth with visually confirmed HF that matched the sites and depths of PD, were allocated to this group.

Localized Periodontal Disease (Perio)

Teeth in which subgingival calculus and the associated periodontal destruction were identified after the removal of restoration, with their sites matching the depths of PD, were allocated to this group.

Perforation (PF)

Teeth with visually confirmed PF that matched the sites and depths of PD, were allocated to this group.

Distribution of Teeth With VRF and Non-VRF According to the Nine Variables

In the VRF (n 5 73) group, patients were mostly between 40 and 49 years old and females were more frequent than males (Fig. 2A, B). The lower first molars were the most affected teeth (31.5%, 23/73) followed by the upper premolars (19.2%, 14/73) (Fig. 2C). The majority (87.7%, 64/73) had neighboring teeth (Fig. 2E), 50.7% (37/73) had a PD 8 mm (Fig. 2F). For PD broadness and location, the narrow buccolingual group was the most common (57/73, 78.1%) (Fig. 2G). Most teeth were crowned (60/73, 82.2%) (Fig. 2H), and teeth with a post (31/73, 42.5%) were less common than those without a post (42/73, 57.5%) (Fig. 2I).

The frequency of non-ETT was 14.0% (32/228) and those were in the group of PN (23/32 23), HF (7/32), and RR (2/32) (T3 in Supplementary tables). Non-ETT was absent in the VRF group. Six out of 23 teeth in PN group were cracked teeth.

Prevalence of VRF and Its Association with the Nine Variables

The prevalence of VRFs according to each variable is summarized in Table 1, and their association with VRF is presented in Table 2. Six out of the nine variables including ETT, PD (depth), PD (broadness and location), tooth type, restoration, and presence of a post were significantly associated with VRF (P .001) (Table 2).

DISCUSSION

Prevalence of VRFs

The prevalence of VRF in this study was 32% (73/228). The result is similar to a previous study in Japan which reporting a prevalence of 31.7% from 736 extracted teeth (including non-ETT) over a 6-month period[6]. Studies from different countries (including ETT only) reported lower prevalence of VRF; 7.2% from Italy[8], 13.4% from Senegal[4], 10.9% from Israel[3], and 8.8% from USA[5]. A higher prevalence of VRF can be conjectured when samples are limited to ETT because VRF is

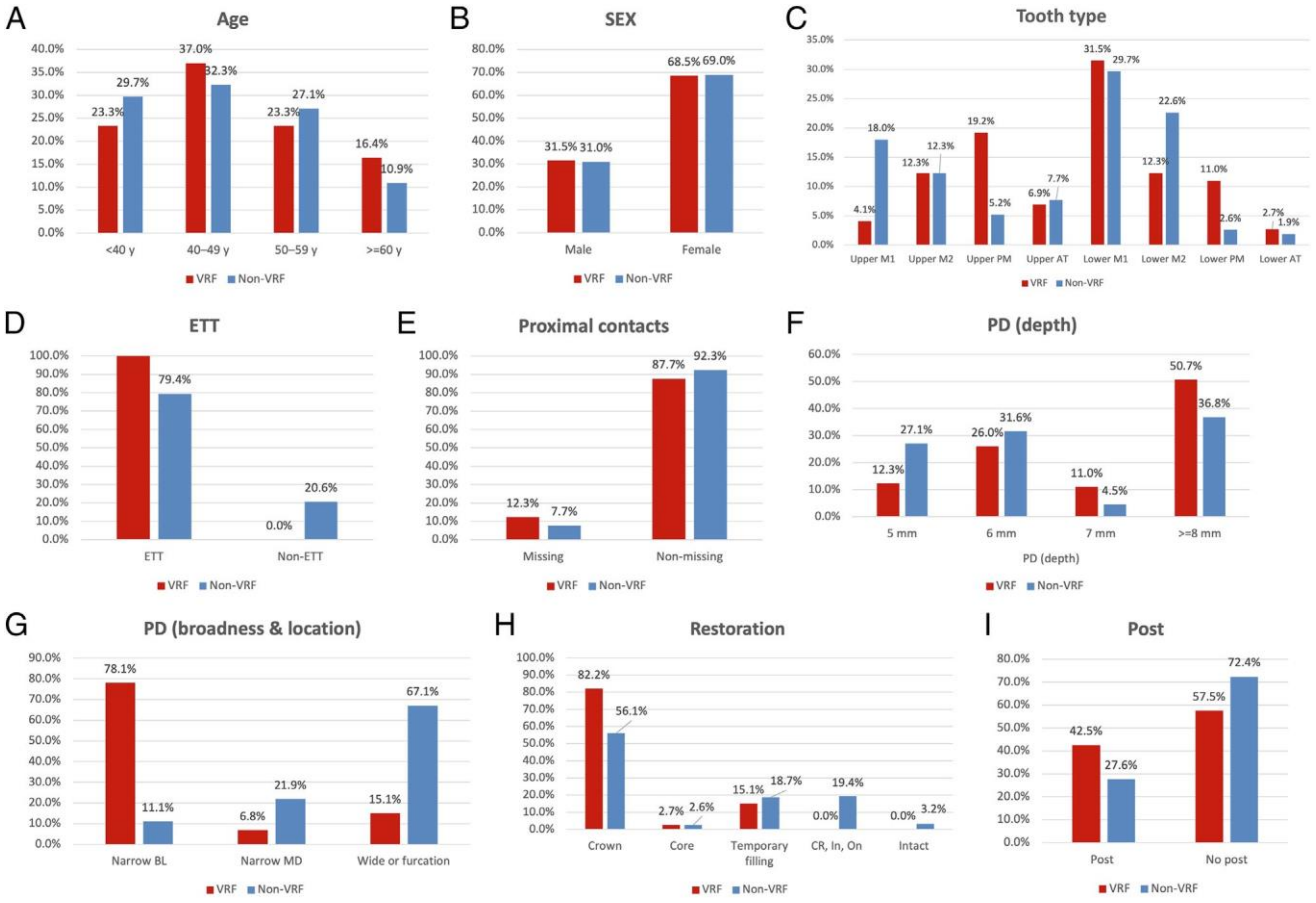


FIGURE 2 – (A–I): Distribution of teeth with VRF and non-VRF according to the nine variables. ETT, endodontically treated teeth; M1, first molar; M2, second molar; PM, premolar; AT, anterior teeth; BL, buccolingual; MD, mesiodistal; CR, composite resin; In, inlay; On, onlay

uncommon in non-ETT; nevertheless, the prevalence in this study was higher. Samples in this study consisted of teeth with an isolated PD 5 mm, which is a strong indicator of VRF, whereas previous studies were based on extracted teeth[3], teeth referred for apical surgery[8], patients' data,[5] or the questionnaires stating extraction reasons fulfilled by the dentists who carried out the tooth extraction[4,6]. Confirmation of VRF during apical surgery could miss (underestimate) VRF on the palatal/lingual aspect of midroot. Furthermore, the present study might have detected early VRF more than other previous reports. The PD measurement was carried out thoroughly by the author (endodontist). Pitts and Natkin reported that periodontal pocket related to VRF are generally narrow (1 to 2 mm wide) with normal sulcus depth on either side, sometimes the pockets are wider'[9]. Such narrow periodontal pockets could be easily missed without careful standardized assessment. In this study, however, VRF limited to apical part and not progressing coronally might have been missed; therefore, true prevalence of VRF might be higher.

A selection bias might be present in this study since the majority of patients visited the author's clinic (a practice limited to endodontics) as self-referred following online search and thus may have been more proactive and concerned about keeping their teeth than the average population. The prevalence of VRFs might thus be underestimated because patients who do not have a special regard for their teeth might have opted directly for tooth extraction for different reasons, such as periodontal disease or persistent AP, without confirming VRF.

The above reasons cannot explain the similar (and higher than other countries) prevalence of VRF among a Japanese population despite the different methodologies in this study and in the study by Yoshino et al[6]. It could be attributed to endodontic treatment approaches in Japan[6,16]. Further standardized study may be required.

Characteristics of the 73 Teeth with VRFs and the Associated Factors

Patients Related Factors

Aging can predispose individuals to VRF.

However, VRFs were most prevalent in the 40–49 age group (27/73, 37.0%) and least prevalent in the oldest age group (60 years) (12/73, 16.4%) (Fig. 2A). This might be attributed to the smallest number of samples in this age group (60 years) (29/228, 12.7%). Teeth that are prone to dental disease might have already been lost in the older patients. According to a survey of dental disease among a Japanese population[17], the number of teeth started to decrease from the 45-54 age group with an average of 20.8 teeth to be remained in the 65-74 age group, while an average of 15.7 teeth remained in the 75 . age group. Chan et al. compared VRF in ETT and non-ETT, and they revealed that the 40–49 age group was the most frequent age group in ETT; however, in non-ETT, frequent representation shifted to 50–59 age group[18].

TABLE 1 - Prevalence of VRFs and 95% CI by Independent Factors

Variables	%	95% CI
Age		
,40 y	27.0	16.0 – 37.9
40–49 y	35.1	24.4 – 45.7
50–59 y	28.8	17.3 – 40.4
60 y	41.4	
Sex		
Male	32.4	
Female	31.8	
ETT		
Non-ETT	0.0	

ETT	37.2	30.5–44.0
Tooth type		
Upper M1	9.7	2.0–25.8
Upper M2	32.1	15.9–52.4
Upper PM	63.6	40.7–82.8
Upper AT	29.4	10.3–56.0
Lower M1	33.3	22.2–44.5
Lower M2	20.5	8.5–32.4
Lower PM	66.7	34.9–90.1
Lower AT	40.0	5.3–85.3
PD (depth)		
5 mm	17.6	7.2–28.1
6 mm	27.9	17.3–38.6
7 mm	53.3	26.6–78.7
8 mm	39.4	29.5–49.2
PD (broadness & location)		
Narrow BL	77.0	67.4–86.6
Narrow MD	12.8	4.3–27.4
Wide or furcation	9.6	4.2–14.9
Proximal contacts		
Missing	42.9	21.8–66.0
Non-missing	30.9	24.6–37.2
Restoration		
Crown	40.8	32.9–48.8
Core	33.3	4.3–77.7
Temporary filling	27.5	13.7–41.3
CR, In, On	0.0	0.0–11.6
Intact	0.0	0.0–52.2
Post		
No post	32.1	24.1–40.1
Post	47.7	35.6–59.8

ETT, endodontically treated teeth; PD, periodontal probing depth.
*P, .05 **P, .01 ***P, .001.

AT, anterior teeth; BL, buccolingual; CR, composite resin; In, inlay; M1, first molar; M2, second molar; MD, mesiodistal; On, onlay; PM, premolar; TT, endodontically treated teeth.

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TABLE 2 - Association Between VRF and 9 Independent Variables

Variables	P Value
Age	.474
Sex	.935
ETT	, .001***
Tooth type	, .001***
PD (depth)	.013*
PD (broadness & location)	, .001***
Proximal contacts	.264
Restoration	, .001***
Post	.001**

Therefore, endodontic procedures could fasten the occurrence of VRF.

No association was observed between sex and VRFs (P 5 .935). More females (50/73, 68.5%) than males (23/73, 31.5%) were in the VRF and non-VRF groups (female: 107/155, 69.0%; male: 48/155, 31.0%) (Fig. 2B).

Teeth Related Factors

VRFs in non-ETT in Chinese[18-20] and Japanese[6] patients have been reported; however, in this study, all teeth in the VRF group were ETT. The frequency of VRF in non-ETT in constitute the reason for this difference, since Japanese population does not have the habit of chewing hard food[19]. Iatrogenic effects from restorative[21] and endodontic procedures (eg, dentin loss[22,23], stress concentration[24-26], micro-crack formation[27], or the effect of the chemical agent[28] and their cumulative effects[29,30] might be the major cause for VRF in a Japanese population.

Japan has a compulsory insurance system by the government, offering inexpensive endodontic treatment, and all residents are covered by this insurance[6,16]. It is reported that the prevalence of root filled teeth is higher in Japan than those in western countries[16]. Pan et al. also indicated the significance of endodontic treatment on VRF occurrence. In their study, the number of VRF occurred in ETT increased significantly from 2015 to 2019 as more patients had endodontic treatment[20].

PD 6 mm as "probing positive"[8,19] however, the author adopted a PD 5 mm as the cut-off because it was the minimum PD related to VRF in this study.

In the VRF group, about 62 % teeth showed a PD 7 mm (Fig. 2F) and an association between PD (depth) and VRFs was indicated (P 5 .013). The result is consistent with the previous study by Tamse et al.[10] where 67.4% of teeth with a VRF showed deep isolated periodontal pockets that often reached the root apex. However, VRF should not be diagnosed based solely on the depth of the periodontal pocket, since the same tendency was observed in the AP (22/49, 44.9%) and PN (14/23, 60.9%) groups, in which a PD 8 mm was the most common (T5 in Supplementary tables). Other groups, (PF, HF, caries, perio, and RR), frequently had relatively shallow PDs (6 mm) (T5 in Supplementary tables) and developed an infection site at the coronal third of the roots. For instance, perforation is likely to occur at the furcation of a tooth or the coronal third of the root.

Narrow buccolingual PD was the most common in the VRF group (57/73, 78.1%) whereas wide PD was frequent in the nonVRF group (104/155, 67.1%) (Fig. 2G). A significant association occurred between VRFs and PD broadness and location categories (P , .001), with the highest prevalence to be detected in the narrow buccolingual group (77%) (Tables 1 and 2). This finding may be helpful in diagnosing VRF. However, PD and its broadness might vary depending on the degree of periodontal involvement. Lustig reported that "narrow" type bony defect initially develops along the fracture and it becomes wider extending to interproximal area or furcation at a later stage. This "wide" type bone resorption was seen in the 72 of the 100 roots in their study[12]. Historical VRFs can develop wider periodontal pockets, whereas more recent VRFs can present with a limited or absent periodontal pocket[32]. Similarly, some ETT can develop fracture at the apical or mid root creating "fenestration type" of bone resorption[12] and in such cases, the isolated periodontal pocket will not appear until the fracture progresses to the coronal direction and the associated periodontal destruction occurs. In this study, 114 out of the 228 teeth had preoperative CBCT images, and bone resorption that matched the site of PD 5 mm was observed. Some similarities were seen between vertical bone destruction pattern and PD (broadness). The vertical bone destruction observed in molars in AP tended to be wider and involved furcation and root apex. On the other hand, narrow bone destruction with slight or no apical radiolucency was seen in molars in VRF. However, some teeth in VRF showed wider bone destruction involving the entire root. Therefore, the bone resorption pattern of VRF can vary depending on the time point of the pathology.

Five teeth in the VRF group had periodontal pockets in a mesiodistal direction, and fractures were confirmed in the same area. One of these teeth was a right upper incisor that had a ceramic crown and a fiber post. The VRF was confirmed surgically. The remaining 4 teeth were molars, and the fracture might have originated from cracks extending below the cemento-enamel junction of their roots, although it was impossible to confirm because the coronal tooth structure of these teeth was already lost.

Previous ex vivo study[21] has suggested that cuspal coverage may have a beneficial effect on ETT resistance, and clinical studies have reported longer survival of teeth restored with cuspal coverage restorations after RCTs[31,33]. However, the effect of crown on VRF development is uncertain. Pan et al[20] suggested crown placement on ETT since 78.3% of teeth with VRF were not crowned in their study. Conversely, 82.2% of teeth in the VRF group were crowned in this study (Fig. 2H) indicating a negative effect of crown on VRF (P , .001) (Tables 1, 2). Similarly, (ie, no positive influence of crown placement on VRFs) a retrospective observational study of 154 extracted teeth with VRFs[34] reported the same findings. This inconsistency might be attributable to differences in the study methodologies, and other factors such as the degree of tooth structure loss, time elapsed since the primary RCT, or the number of reRCTs received confounding the results. These factors were assessed in an ongoing study that we performed.

This study revealed a significant association between VRF and the presence of a post (P 5 .001), which is in accordance with the previous reports[6,8]. Among teeth with the post (31/73), more than half of them were premolars or anterior teeth (13 premolars and 6 anterior teeth). Those teeth often require posts for coronal retention and higher tensile stress was observed in buccopalatal direction of upper premolars with nonbonded posts under loading[35]. Although the stress concentration found in premolars with bonded posts was similar to that in the intact teeth[35], the true effect of the bonded post for VRF is uncertain in a clinical situation. Five of 13 posts in premolars were bonded posts (fiber reinforced posts) in this study. Postplacement in oval and concaved root morphology in combination with radicular dentin loss by post placement or root canal shaping might contribute to VRF.

VRFs were most frequent in the lower first molars (23/73, 31.5%), followed by the upper premolars (14/73, 19.2%) (Fig. 2C), which is consistent with previous studies[6,10]. Among the lower first molars, VRFs were prevalent in the mesial roots (16/23, 69.6%), an insight that is in line with previous reports that concaved, curved, or oval root morphologies are more likely to fracture due to higher stress concentration[23,25]. In addition, these roots may become thinner because of lack of centering ability that endodontic instruments possess.

A strong association was observed between VRFs and the tooth type (P , .001). Although the lower first molars were the most affected tooth type in both VRF and non-VRF group (31.5%, 23/73; 46/155, 29.7%), premolars were exclusively affected in VRF (22/73, 30.2%) and not frequent in non-VRF (12/155, 7.8%) (Fig. 2C). Therefore, the highest prevalence of VRF solely occurred in premolars (Table 1). The result substantiates the study by Pan et al. which reported that endodontically treated premolars are susceptible to VRF[20]. This result might be helpful for the diagnosis of VRFs in premolars with a PD 5 mm.

A tooth with a missing neighboring tooth possibly undergoes greater occlusal forces. The presence of both mesial and distal proximal contacts is a favorable prognostic factor for tooth survival following nonsurgical root canal treatment[31], albeit this study found no association between VRF and the proximal contacts (P 5 .264). For that contradiction, a longer observational follow-up may be required.

The PD reflects the degree of periodontal destruction in the vertical direction[9,10] and can vary depending on the infection site. Previous reports have used

CONCLUSION

Within the limitation of this study, prevalence of VRF was higher than that in previous reports but consistent with a report from Japan[6]. VRFs may occur more frequently in ETT among the Japanese population.

While, lower first molars were the most common tooth type in both VRF (31.5%) and non-VRF (29.7%), premolars were exclusively frequent in VRF (30.2%) and not frequent in non-VRF (7.8%). Narrow buccolingual PD was common in VRF (78.1%), whereas wide PD was frequent in non-VRF (67.1%). This study revealed a strong association between VRFs and the following: ETT, narrow buccolingual PD, tooth type (premolars), restoration type (crown), and the presence of a post (P .001). When an endodontically treated premolar with a post shows narrow buccolingual PD, the probability of a VRF may be greater than in other tooth types.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Kwangsoon Lee: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing. Manjeet Ahlowalia: Writing – review & editing. Ruth Perez Alfayate: Writing – review & editing. Shanon Patel: Writing – review & editing, Supervision. Federico Foschi: Writing – review & editing, Supervision.

ACKNOWLEDGMENTS

This work was undertaken at a practice limited to endodontics (Lee's Dental Clinic), Tokyo, Japan, as a research project for the postgraduate course of MSc in Endodontics (2020–2021) of King's College London Dental Institute. The authors express their sincere gratitude to staff members (Ayumi Shimada, Rie Sakai) at Lee's Dental Clinic for completing the data collection forms, Kan Ushijima for the blinded outcome evaluation, MG from TOP MBA consultant for English editing support, and Juan Luis Gomez Martinez for the statistical analyses.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com(https://doi.org/10.1016/j.joen.2023.08.018).

REFERENCES

1. Axelsson P, Nystro€m B, Lindhe J. The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. J Clin Periodontol 2004;31:749–57.
2. Caplan DJ, Cai J, Yin J, et al. Root canal filled versus non-root canal filled teeth: a retrospective comparison. J Public Health Dent 2005;65:90–6.
3. Fuss Z, Lustig J, Tamse A. Prevalence of vertical root fractures in extracted endodontically treated teeth. Int Endod J 1999;32:283–6.
4. Toure B, Faye B, Kane AW, et al. Analysis of reasons for extraction of endodontically treated teeth : a prospective study. J Endod 2011;37:1512–5.
5. Zadik Y, Sandler V, Bechor R, et al. Analysis of factors related to extraction of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e31–5.
6. Yoshino K, Ito K, Kuroda M, et al. Prevalence of vertical root fracture as the reason for tooth extraction in dental clinics. Clin Oral Investig 2015;19:1405–9.
7. Olcay K, Ataoglu H, Belli S. Evaluation of related factors in the failure of endodontically treated teeth: a cross-sectional study. J Endod 2018;44:38–45.
8. Maddalone M, Gagliani M, Citterio CL, et al. Prevalence of vertical root fractures in teeth planned for apical surgery. A retrospective cohort study. Int Endod J 2018;51:969–74.
9. Pitts DL, Natkin E. Diagnosis and treatment of vertical root fractures. J Endod 1983;9:338–46.
10. Tamse A, Fuss Z, Lustig J, et al. An evaluation of endodontically treated vertically fractured teeth. J Endod 1999;25:506–8.
11. PradeepKumar AR, Shemesh H, Jothilatha S, et al. Diagnosis of vertical root fractures in restored endodontically treated teeth: a time-dependent retrospective cohort study. J Endod 2016;42:1175–80.
12. Lustig JP, Tamse A, Fuss Z. Pattern of bone resorption in vertically fractured, endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;90:224–7.
13. Preshaw PM. Detection and diagnosis of periodontal conditions amenable to prevention. BMC Oral Health 2015;15(Suppl 1):S5.
14. Listgarten MA. Periodontal probing: what does it mean? J Clin Periodontol 1980;7:165–76.
15. Rivera EM, Walton RE. Cracking the Cracked Tooth Code: Detection and Treatment of Various Longitudinal Tooth Fractures. Endodontics: Colleagues for Excellence. American Association of Endodontists; 2008. p. 1–8. Summer).
16. Tsuneishi M, Yamamoto T, Yamanaka R, et al. Radiographic evaluation of periapical status and prevalence of endodontic treatment in an adult Japanese population. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:631–5.
17. Survey of dental disease. Ministry of health, labour and welfare Japan [Internet]. Available at: https://www.mhlw.go.jp/toukei/list/62-28.html; 2016.
18. Chan CP, Lin CP, Tseng SC, et al. Vertical root fracture in endodontically versus nonendodontically treated teeth: a survey of 315 cases in Chinese patients. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999;87:504–7.
19. Chan CP, Tseng SC, Lin CP, et al. Vertical root fracture in nonendodontically treated teeth–a clinical report of 64 cases in Chinese patients. J Endod 1998;24:678–81.
20. Pan X, Tang R, Gao A, et al. Cross-sectional study of posterior tooth root fractures in 2015 and 2019 in a Chinese population. Clin Oral Investig 2022;10:6151–7.
21. Panitvisai P, Messer HH. Cuspal deflection in molars in relation to endodontic and restorative procedures. J Endod 1995;21:57–61.
22. Wilcox LR, Roskelley C, Sutton T. The relationship of root canal enlargement to finger-spreader induced vertical root fracture. J Endod 1997;23:533–4.
23. Sathorn C, Palamara JEA, Palamara D, et al. Effect of root canal size and external root surface morphology on fracture susceptibility and pattern: a finite element analysis. J Endod 2005;31:288–92.
24. Yuan K, Niu C, Xie Q, et al. Apical stress distribution under vertical compaction of gutta-percha and occlusal loads in canals with varying apical sizes: a three-dimensional finite element analysis. Int Endod J 2018;51:233–9.
25. Lertchirakarn V, Palamara JEA, Messer HH. Patterns of vertical root fracture: factors affecting stress distribution in the root canal. J Endod 2003;29:523–8.
26. Jiang W, Bo H, Yongchun G, et al. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. J Prosthet Dent 2010;103:6–12.
27. Kim HC, Lee MH, Yum J, et al. Potential relationship between design of nickel-titanium rotary instruments and vertical root fracture. J Endod 2010;36:1195–9.
28. Grigoratos D, Knowles J, Ng YL, et al. Effect of exposing dentine to sodium hypochlorite and calcium hydroxide on its flexural strength and elastic modulus. Int Endod J 2001;34:113–39.
29. Patel S, Bhuva B, Bose R. Present status and future directions: vertical root fractures in root filled teeth. Int Endod J 2022;55:804–26.
30. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609–17.
31. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 2002;87:256–63.
32. Nicopoulou-Karayianni K, Bragger U, Lang NP. Patterns of periodontal destruction associated with incomplete root fractures. Dentomaxillofac Radiol 1997;26:321–6.
33. Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30:846–50.

34. Fuss Z, Lustig J, Katz A, et al. An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod 2001;27:46–8.

35. Santos AFV, Tanaka CB, Lima RG, et al. Vertical root fracture in upper premolars with endodontic posts: finite element analysis. J Endod 2009;35:117–20.