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Dental Vertical Root Fractures: Value of CT in Detection¹

PURPOSE: To determine the value of computed tomography (CT) in the diagnosis of dental vertical root fractures relative to the value of conventional dental radiography.

MATERIALS AND METHODS: Thirty-seven patients with 42 teeth in which vertical root fracture was clinically suspected underwent dental radiography and axial CT. Two radiologists evaluated the images independently and by consensus for a fracture line. The results were compared with intraoperative findings.

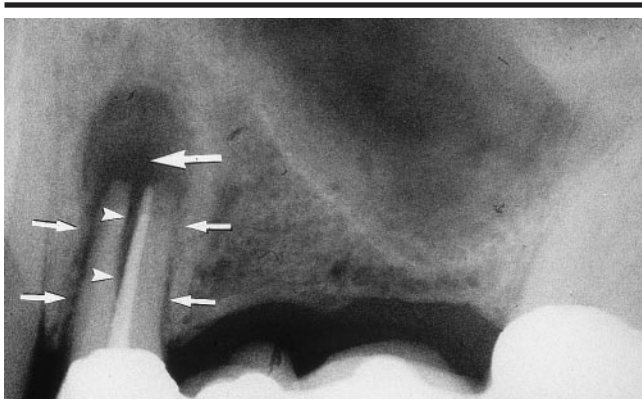
RESULTS: Twenty-eight of the 42 teeth were proved intraoperatively to be fractured. The sensitivity and specificity averaged for the two reviewers in the assessment of vertical fractures were 23% and 70%, respectively, with dental radiography and 100% and 100%, respectively, with CT. Consensus reading showed sensitivities of 25% for dental radiography and 75% for CT. Eight (reviewer A) or nine (reviewer B) false-negative CT findings were encountered in cases in which metallic artifacts obscured parts of the root and in cases in which the root was very small in diameter. Interobserver agreement was 95% for dental radiography and 93% for CT.

CONCLUSION: CT is superior to dental radiography in the detection of dental vertical root fractures.

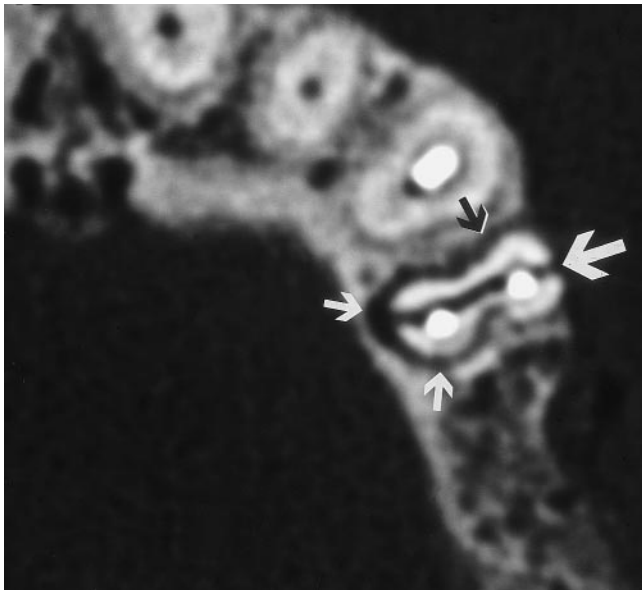
Vertical root fractures occur in at least 3.69% (17 of 460 teeth) of endodontically treated teeth (pulp-extracted teeth with root fillings) and are difficult to diagnose on the basis of clinical findings (1,2). A fracture line is observed on dental radiographs in only 35.7% (134 of 375) of cases (3). Because a vertical root fracture necessitates extraction of the tooth, it would be advantageous to find a more efficient and reliable means of establishing the diagnosis preoperatively so that prosthetic rehabilitation may be initiated and the costs and effort of an ineffective apical root resection may be avoided (4). The goal of this study was to investigate the use of computed tomography (CT) in the diagnosis of vertical root fractures and to compare these findings with those obtained clinically and by means of dental radiography.

MATERIALS AND METHODS

Within 14 months, 37 consecutive patients (15 female, 22 male; age range, 17-67 years; mean age, 39.8 years) with 42 symptomatic, endodontically treated teeth that had shown clinical indications of dental vertical root fracture were referred to our institution for surgical exploration. Informed consent was obtained from all patients. The study was approved by the institutional review board. Clinical inspection did not reveal a fracture line in any of these cases. In all patients, indirect clinical signs were seen more than 1 year after endodontic treatment and comprised pain, periodontal pockets, sinus tracts, local swelling, and sensitivity to palpation. With regard to location, there were eight central incisors, five lateral incisors, two canines, 10 first premolars, 16 second premolars, and one second molar. First and third molars were not affected. Dental radiographs were obtained (60 kV, 0.3-0.5 second, 7 mA) with a commercially available unit (Heliodent MD; Siemens, Erlangen, Germany). All patients underwent examination with a commercially available CT unit (Tomoscan SR 6000 V; Philips, Eindhoven, Netherlands) at our institution. Axial CT scans with a section thickness of 1.5 mm and a 1-mm table feed were obtained parallel



a.



b.

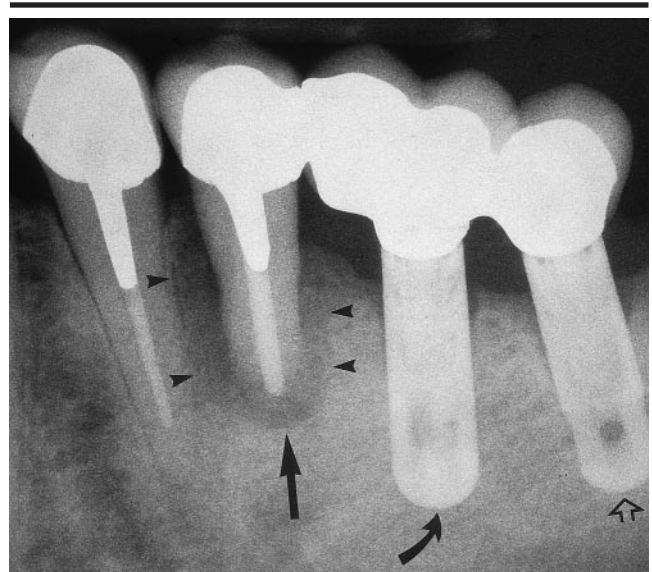
Figure 1. Fracture line of the first premolar confirmed surgically in a 61-year-old man. **(a)** Dental radiograph of the left upper jaw reveals vertical root fracture of the first premolar as a radiolucent line (arrowheads) that approximates the root filling. The apex of the root had been resected (large arrow). The periodontal ligament is enlarged (small arrows). **(b)** Magnified axial CT scan of the left upper jaw (original magnification, $\times 4$) reveals a buccolingually oriented root fracture of the first premolar (large arrow) that extends from the outer surface of the tooth to the surface facing the oral cavity. The adjacent segments are separated widely. The periodontal ligament is enlarged (small arrows).

to the occlusion plane by using fast scanning and thin sections and were evaluated with window and center settings of 2,000 HU and 400 HU, respectively (120 kV, 250 mAs). The area of concern was magnified fourfold.

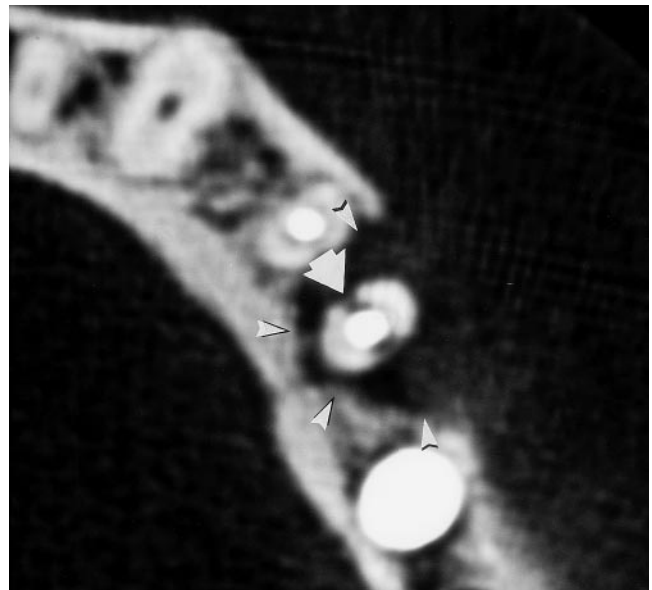
Two experienced radiologists (S.Y., A.G.) evaluated the images independently—with no clinical information except the site of the concerned tooth—for the direct visualization of a fracture line. The diagnosis of a fracture detected on dental radiographs was based on direct visualization of a radiolu-

cent line that traversed the root only, without propagation into the surrounding alveolus (Fig 1a). CT findings of a root fracture were characterized by a separation of the adjacent root segments visualized on at least two contiguous sections without continua-

tion of the hypoattenuated line into the adjacent tissue (Figs 1b, 2b). The sensitivity and specificity of dental radiography and CT were determined separately for each reviewer. After independent review, the two reviewers compared their findings and dis-



a.



b.

Figure 2. Fracture of the second premolar confirmed surgically in a 42-year-old man. **(a)** Dental radiograph of the upper jaw shows a root filling and post in the second premolar; no fracture line is visible. The periodontal ligament is enlarged (arrowheads), and there is a periapical area of radiolucency (solid straight arrow). Dental implants are seen in the first molar (curved arrow) and the second molar (open arrow). **(b)** Magnified axial CT scan of the left upper jaw (original magnification, $\times 4$) shows a mesiodistally oriented root fracture that extends from the surface closest to the midline (referred to as the mesial surface) to the opposite surface (referred to as the distal surface; arrow). The periodontal ligament is enlarged (arrowheads). There are no artifacts from the dental implants made of titanium.

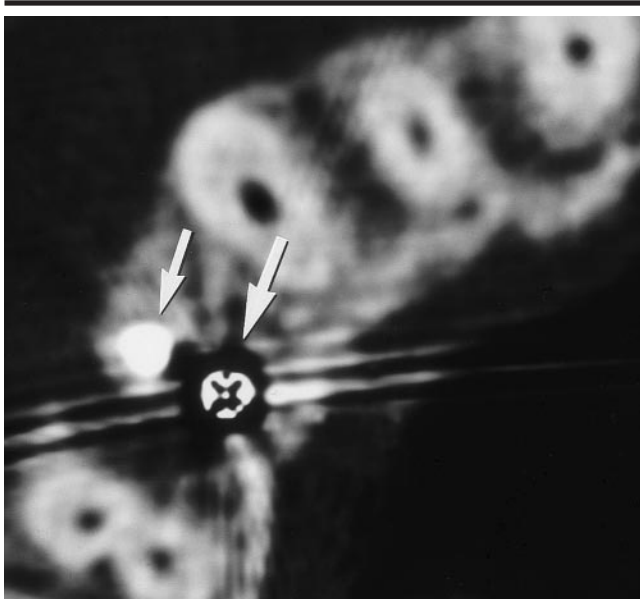


Figure 3. Surgical finding of a fracture line of the buccal root of the first premolar not seen on the CT scans in a 63-year-old woman. Magnified axial CT scan of the right upper jaw (original magnification, $\times 4$) shows the first premolar has two roots: The buccal root (small arrow) is filled, and the palatine root (large arrow) has been replaced by a post. The metallic artifacts of the post overlie the buccal root and deteriorate the image quality. The fracture line cannot be detected.

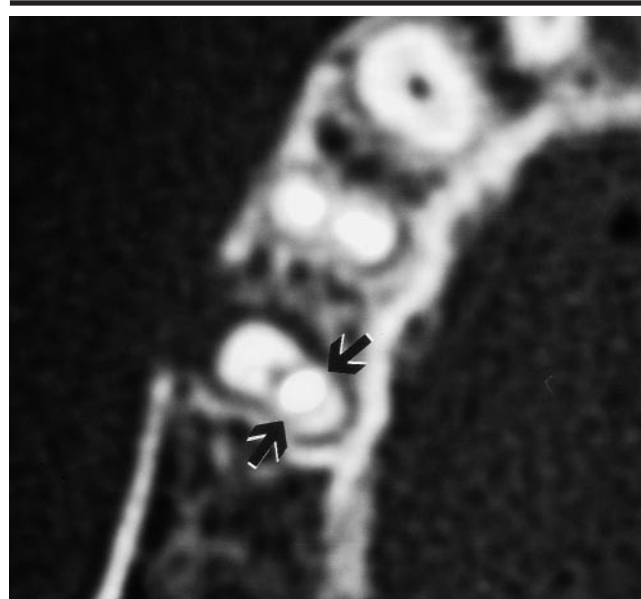


Figure 4. Surgical finding of a fracture line of the second molar not seen on the CT scans in a 48-year-old woman. Magnified axial CT scan of the right upper jaw (original magnification, $\times 4$) shows a very narrow diameter of the second molar root (arrows), which had been filled. No fracture line is detectable.

TABLE 1
Statistical Analysis of Dental Radiographic Findings

Interpretation	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Efficacy (%)
Reviewer A	25 (7/28)	100 (14/14)	100 (7/7)	40 (14/35)	50 (21/42)
Reviewer B	21 (6/28)	100 (14/14)	100 (6/6)	39 (14/36)	48 (20/42)
Average value	23	100	100	40	49
Consensus reading	25 (7/28)	100 (14/14)	100 (7/7)	40 (14/35)	50 (21/42)

Note.—Intraobserver agreement was 95% (40 of 42) for reviewer A and 95% (40 of 42) for reviewer B. Interobserver agreement was 95% (40 of 42).

TABLE 2
Statistical Analysis of CT Findings

Interpretation	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Efficacy (%)
Reviewer A	71 (20/28)	100 (14/14)	100 (20/20)	64 (14/22)	81 (34/42)
Reviewer B	68 (19/28)	100 (14/14)	100 (19/19)	61 (14/23)	79 (33/42)
Average value	70	100	100	63	80
Consensus reading	75 (21/28)	100 (14/14)	100 (20/20)	67 (14/21)	83 (35/42)

Note.—Intraobserver agreement was 93% (39 of 42) for reviewer A and 93% (39 of 42) for reviewer B. Interobserver agreement was 93% (39 of 42).

cussed the imaging findings to achieve consensus. After 4 weeks, the images were re-scored to determine intraobserver variability.

In all patients, the teeth in which vertical

root fractures were clinically suspected were assessed at surgery. A mucoperiosteal flap was mobilized, and the root surface was inspected with a microscope (Leica;

Wild, Heerbrugg, Switzerland) with a magnification factor of 14. Fractures were diagnosed when separation of fragments was seen or when lines were darker than the surrounding tooth structure. In questionable cases, the root surface was dyed with methylene blue stain. The solution was applied to the tooth with a cotton pellet, and then the tooth was rinsed with water. At visual examination, a darkly stained line indicated a fracture.

The results of image evaluation were compared with intraoperative findings to assess sensitivity and specificity of dental radiography and CT in the detection of vertical root fractures.

RESULTS

Of the 42 teeth, 28 were proved at surgery to be fractured. The following teeth were affected: four central incisors, three lateral incisors, two canines, seven first premolars, and 12 second premolars.

Dental Radiographs

Reviewer A (S.Y.) correctly diagnosed fracture in seven of the 28 teeth at dental radiography (Table 1). Diagnoses were false-negative in 21 cases. All 14 cases without fracture were diagnosed cor-

rectly. There were no false-positive results. The corresponding sensitivity and specificity were 25% and 100%, respectively.

Reviewer B (A.G.) diagnosed six of the 28 fractures correctly. There were false-negative results in 22 cases. There were 14 correct negative diagnoses and no false-positive results. The corresponding sensitivity and specificity were 21% and 100%, respectively.

The average sensitivity and specificity of the two observers was 23% and 100%. Consensus reading showed sensitivity and specificity of 25% and 100%. Intraobserver agreement for both reviewers, as well as interobserver agreement, was 95%.

In 18 (64%) of the 28 cases with fracture a periapical area of radiolucency was seen, and in 20 (71%) of the 28 cases the dental radiographs showed enlargement of the periodontal ligament.

CT Scans

Reviewer A diagnosed 20 of the 28 fractures correctly at CT (Table 2). There were eight false-negative studies. In all cases with false-negative findings, parts of the teeth were either obscured by severe artifacts caused by the root filling (post and gutta-percha) (Fig 3), or the post approximated the periodontal ligament due to a very-small-diameter root (Fig 4). There were 14 correct negative diagnoses and no false-positive results. The corresponding sensitivity and specificity were 71% and 100%, respectively.

Reviewer B diagnosed 19 of the 28 fractures correctly. There were nine false-negative studies. Again, all 14 cases without fracture were diagnosed correctly. Thus, there were no false-positive results. The corresponding sensitivity and specificity were 68% and 100%, respectively.

The average sensitivity and specificity were 70% and 100%. Consensus reading showed a sensitivity of 75% and a specificity of 100%. Intraobserver agreement was 93% for both reviewers. Interobserver agreement was 93%.

DISCUSSION

There are only a limited number of reports in the radiology literature that deal with the problem of dental vertical root fractures, although these fractures represent an unsolved clinical challenge (5,6). Whereas horizontal root fractures are typically of traumatic origin and easy to diagnose, vertical root fractures tend to have an iatrogenic cause (2). They occur in vital teeth with an intact pulp as a

result of conservative restorations (filling restoration such as amalgam filling) or in endodontically treated teeth (pulp-extracted teeth with root fillings that are consequently not vital) as a result of excessive pressure used during endodontic treatment or during the placement of a post. Detection of a vertical fracture is of clinical importance, since infection develops from the marginal periodontium, with subsequent destruction of the adjacent bone. Thus, cases of vertical root fracture necessitate extraction of the tooth. With other causes of periradicular chronic inflammatory processes or periradicular cystic lesions, apical root resection (ie, removal of 1–3 mm of the apex of the root to create a neoapect) suffices. Thus, preoperative detection of a fracture influences therapeutic strategies.

Clinical signs of the fracture develop slowly and are usually not apparent until 1 or 2 years after injury. On occasion, gingival recession or slight retraction of the gingival tissue may reveal the fracture. In the majority of cases, the diagnosis is suspected only when a combination of the following symptoms is observed: pain, local swelling, mobility of the tooth, periodontal pocket, sinus tract, abscess, or sensitivity to palpation or percussion (2). All these signs are highly nonspecific and also may be seen in other entities that necessitate completely different therapeutic management.

Indirect radiologic signs are sequelae of chronic inflammation induced by the fracture and develop late. They cause changes in the periodontium, such as enlargement of the periodontal ligament along the root, and a periapical area of radiolucency (Figs 1, 2, 4). These changes are again highly nonspecific and also very common in cases of poor oral hygiene; they also may be symptoms of endodontic failure. Indirect radiologic signs may increase the index of suspicion in the work-up of vertical root fractures; nevertheless, these findings are of limited value in clinical practice.

This limitation is why we focused entirely on the detection of the direct radiologic fracture sign: the fracture line. It is unfortunate that only approximately one-third of fractures may be visualized directly at dental radiography (3) (Fig 1). Our averaged results showed an even lower sensitivity of 23%. This finding is explained by the inclusion of only cases in which the fracture was not diagnosed at physical examination, whereas Rud and Omnell (3) also included cases in which the fracture was visible at clinical inspection owing to separation of the fragments.

Early stages, in which there are subtle fissures with no separation of the adjacent segments, are not detectable at dental radiography before a soft-tissue proliferation between the root segments separates them (7). It has been shown that the fracture line can be visualized directly when it is oriented parallel to the x-ray beam or at an angle of 4° to either side (3). Furthermore, mesiodistally oriented root fractures (extending from the surface closest to the midline, referred to as the mesial surface, to the opposite surface, referred to as the distal surface) are not visualized directly on a typically exposed radiograph unless dislocation of the two components has led to a step phenomenon along the border of the root. For reasons of radiation protection, the angulation of the x-ray beam cannot be rotated to repeat the exposure several times in one patient.

Findings in our study group reconfirm the finding of Tamse (2) that vertical root fractures tend to occur more frequently in posterior teeth. Because posterior teeth have several roots that superimpose on other roots, it is plausible that fractures may be obscured.

All these factors indicate that conventional radiography is not the imaging modality of choice in the detection of vertical root fractures. The next logical step in the radiologic management of these cases is the use of CT, which has the advantage of a modern cross-sectional technique.

CT of the jaw primarily has focused on the temporomandibular joint (8–10), three-dimensional reconstruction of the jaw before major maxillofacial operations (11), or dental reformats for implantation (12). We were not able to find in the literature any reports on the evaluation of root fractures with CT.

From our results, evaluation of dental vertical root fractures with thin-section CT seems promising. We found an average sensitivity of 70% and specificity of 100% for CT in the diagnosis of this fracture. Of course, consensus reading had a higher sensitivity (75%). This method of assessment, however, is not practicable in daily routine practice. Our CT findings demonstrate excellent diagnostic benefit in comparison with the poor results of conventional radiography. It seems noteworthy that the results are reproducible, with inter- and intraobserver agreement both at 93%, which is high. We did not encounter false-positive results; we had, however, a relatively high number of false-negative findings. This result is explained by the requirement

that a fracture line be visualized on at least two contiguous sections and not extend into the adjacent tissue. Thus, only hypoattenuated lines confined to the root were considered to show true fractures. Cases in which questionable fracture lines were associated with multiple hypoattenuated lines that traversed the root and adjacent bone tissue, caused by metallic artifacts from conventional restorations, such as crowns or posts, in neighboring teeth, were considered to be negative (Fig 3). Furthermore, in cases of very small root diameters in which the root filling directly approximated the surrounding periodontal ligament in one direction, the fracture lines with extension into this area could not be detected (Fig 4).

Axial CT sections are ideal for the diagnosis of vertical fractures because the plane is perpendicular to the fracture line. Commercially available dental software packages allow the reconstruction of cross-sectional images that are perpendicular to a line along the midportion of the alveolus on an axial image. These images are helpful for the evaluation of dental implants; vertical fractures, however, may be overlooked. Thus, dental software packages are of limited value in the detection of vertical root fractures.

The radiation dose of dental CT was

reported to be 20-fold higher than that of panoramic radiography; it is strongly dependent, however, on the CT protocol (13). Because the radiation exposure dose of dental CT was found to be comparable to that of skull radiography in two views (14), the radiation risk seems to be acceptable.

In conclusion, our results demonstrate that CT is superior to dental radiography in the assessment of dental vertical root fractures. CT should be performed whenever a fracture is suspected clinically.

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