Implant-associated Vertical Root Fracture in Adjacent Endodontically Treated Teeth: A Case Series and Systematic Review

Eyal Rosen, DMD, Ilan Beitlitum, DMD,† Aviad Tamse, DMD,* Silvio Taschieri, MD, DDS,‡§ and Igor Tsesis, DMD**

Abstract

Introduction: This study aimed to report a possible effect of the presence of an adjacent implant on the development of a vertical root fracture (VRF) in endodontically treated teeth. **Methods:** A series of 8 cases in 7 patients with teeth diagnosed with VRF after the placement of implants in the adjacent area is described and analyzed. In addition, a comprehensive literature search with strict inclusion and exclusion criteria was undertaken to identify additional clinical studies that assessed this clinical scenario. **Results:** The case series analysis revealed that the time from implant placement to the diagnosis of VRF was between 5 and 28 months (average = 11 months). The majority of cases occurred in female patients who received 2 or more implants. Six of the 7 patients were older than 40 years, with an average age of 54 years. The majority of teeth with VRF were premolar or mandibular molar teeth (6/8 teeth). All fractured teeth had been restored with a crown and had a post present, and the quality of the root canal filling was determined to be adequate. The systematic review revealed that implant-associated VRF has not been investigated or reported in the literature yet. **Conclusions:** Based on a systematic review of the literature, this case series, although limited in its extent, is the first clinical report of a possible serious adverse event of implant-associated VRF in adjacent endodontically treated teeth. Additional clinical studies are indicated to shed light on this potential phenomenon. *(J Endod 2016;42:948–952)*

Key Words

Endodontically treated teeth, implant, vertical root fracture

From the Departments of *Endodontology and †Periodontology and Dental Implantology, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel; ‡Department of Biomedical, Surgical and Dental Sciences, Research Centre in Oral Health, Università degli Studi di Milano, Milan, Italy; §IRCCS Istituto Ortopedico Galeazzi, Milan, Italy.

Address requests for reprints to Dr Eyal Rosen, Department of Endodontology, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel. E-mail address: dr.eyalrosen@gmail.com

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2016.03.021

Tooth replacement with an oral implant may be indicated because of tooth loss as a result of trauma, dental caries, periodontal disease, and in case of a congenitally missing tooth. The missing tooth space may be restored with an implant when it is surrounded with healthy teeth or with intact prosthetic reconstruction of the neighboring teeth (1).

The retention of implants is directly related to their osseointegration (2), which is defined as close contact between the bone and implant (3). The most significant difference between natural teeth and implants is the periodontal ligament (PDL), which surrounds only natural teeth, and the unique characteristics of this ligament (4). The PDL enables stress distribution, mobility, occlusal trauma tolerance, and proprioception, thus acting as a modulator of excessive occlusal forces. This modulation mechanism is missing in osseointegrated implants, potentially exposing them to occlusal overload (4).

Although the exact effects of occlusal overload on implants are not fully clarified (5, 6), it has been suggested that implant occlusion should be designed not only according to conventional occlusal schemes but also from the standpoint of reducing overloading factors (7). However, when the occlusion of an implant is altered in order to prevent occlusal overload to the implant, it may change the force distributed to the adjacent natural teeth (8, 9).

Vertical root fractures (VRFs) may initiate from the root at any level (10–12). Under occlusal loads, endodontically treated teeth showed reduced resistance to fracture. However, the exact occlusal relationship between implants and adjacent endodontically treated teeth is not fully elucidated (13–15), and the ensuing possible risk of VRF of the natural teeth is unknown.

Evidence-based dentistry is an approach to oral health care that integrates the best available clinical evidence to support a practitioner's clinical expertise for each patient's treatment needs and preferences (16–18). It is based on the process of systematically finding, appraising, and using research findings as the basis for clinical decision making. Systematic reviews constitute the basis for practicing evidence-based dentistry (15, 17, 18). The application of evidence-based principles in dentistry should result in a reduction of errors in the clinical decision-making process (16–19). Thus, an evidence-based review of the available literature regarding the possible phenomenon of implant-associated VRF is important.

It may be hypothesized that the incidence of VRFs is higher in endodontically treated teeth adjacent to implants ("implant-associated VRF"), especially if the occlusal loads were intentionally decreased from that implant while an ensuing increase of occlusal load was distributed to the adjacent natural teeth.

In this study, a series of 8 cases of implant-associated VRFs is described and analyzed. In addition, a systematic review of the literature was performed, aiming to identify and analyze the currently available evidence regarding implant-associated VRFs.

Materials and Methods

The inclusion criteria for the selected cases and studies in the systematic review were as follows:

1. The implants were placed adjacent to endodontically treated teeth with no periradicular pathology.

2. There were occlusal contacts between the endodontically treated teeth and the opposing teeth.
3. The VRF was diagnosed after implant loading based on a clinical and radiographic evaluation.
4. The VRF was confirmed by microscopic evaluation of the extracted tooth (10).

Reviews, expert opinions, and studies not relevant to the topic of this study were excluded from the systematic literature search.

Search Methods for the Identification of Studies for the Systematic Review

The following electronic databases were searched: MEDLINE using the PubMed search engine (http://www.ncbi.nlm.nih.gov/sites/pubmed) and Scopus (http://www.scopus.com).

The following key words were used for an initial search through MEDLINE: ((vertical root fracture) OR cracked tooth) AND implant. The Medical Subject Heading (MeSH) received was as follows: ((vertical[All Fields] AND ("plant roots"[MeSH Terms] OR ("plant"[All Fields] AND "roots"[All Fields]) OR "plant roots"[All Fields] OR "root"[All Fields]) AND ("fractures, bone"[MeSH Terms] OR ("fractures"[All Fields] AND "bone"[All Fields]) OR "bone fractures"[All Fields] OR "fracture"[All Fields])) OR ("cracked tooth syndrome"[MeSH Terms] OR ("cracked"[All Fields] AND "tooth"[All Fields] AND "syndrome"[All Fields]) OR "cracked tooth syndrome"[All Fields] OR ("cracked"[All Fields] AND "tooth"[All Fields]) OR "cracked tooth"[All Fields])) AND implant[All Fields].

An additional search was then performed through the Scopus database using the same key words. The MeSH received for Scopus was as follows: ("vertical root fracture" OR "cracked tooth") AND (implant) AND NOT INDEX(medline) AND (LIMIT-TO(DOCTYPE,"ar")) AND (LIMIT-TO(SUBJAREA,"DENT")).

Related literature reviews that appeared in the MEDLINE search engine were manually evaluated, and their reference lists were searched for possible eligible articles that were not yet identified by the electronic search.

Data Collection and Analysis for the Systematic Review

The identified articles in the literature search were initially evaluated for relevance on the basis of their titles and abstracts by 2 observers independently (I.T. and E.R.). Possibly relevant studies were planned to be submitted to a full-text evaluation based on the inclusion criteria for selected cases and studies in the systematic review. Eventually, the identified eligible articles were planned to be subjected to data extraction and analysis.

The identified relevant cases were planned to be analyzed for the patients' demographics and parameters of the implants and of the associated teeth with VRFs. The studies were also planned to be evaluated regarding their methodologic quality and their heterogeneity for the possibility of a meta-analysis of their results.

Data Collection and Analysis for the Case Series

Data from a series of 7 patients referred for implant treatment in a private practice limited to periodontics between 2010 and 2014 with 8 cases of confirmed VRFs in adjacent endodontically treated teeth that were diagnosed after implant loading were retrospectively collected and analyzed. The following factors were recorded for each patient based on the patients' medical records and clinical and radiographic examinations: age and sex, the number and location of the dental implants, the VRF tooth type (divided into maxillary and mandibular anterior \ premolar \ molar teeth), the presence of a crown, the presence of a post, the radiographic quality of the root canal filling ("adequate" was defined as cases in which all visible canals were obturated, no voids were present, and the root canal filling terminated between 0 and 2 mm short of the radiographic apex; root fillings that did not fulfill these criteria were defined as "inadequate" [20, 21]), the time from implant placement, and the time from implant loading to the diagnosis of VRF.

Results

Results of the Systematic Review

The MEDLINE search identified 16 studies published between 1983 and July 2014. The Scopus database search identified an additional 25 articles. The manual search did not identify additional relevant articles.

The identified articles ($N = 41$) were assessed based on their titles and abstracts. However, based on the prespecified inclusion and exclusion criteria, all articles were excluded because they were not relevant to the topic of this study. Therefore, the systematic literature search revealed that currently there are no available relevant studies assessing implant-associated VRFs. Figure 1 presents the search results (22).

Results of the Case Series

Data from 7 patients with 8 cases of confirmed VRFs in adjacent endodontically treated teeth were collected and analyzed. There were 5 women and 2 men between the ages of 34 and 65 years (average age = 54 years). In 2 patients, 1 implant was placed, in 4 patients 2 implants were placed, and in 1 patient 3 implants were placed. In 5 patients, the implants were located adjacent to the VRF teeth, and in 2 patients the implants were located opposing ($n = 1$) or contralateral ($n = 1$) to the VRF teeth.

One of the fractured teeth was a maxillary anterior tooth, 5 were premolars (4 maxillary and 1 mandibular premolar), and 2 were molar teeth (1 maxillary and 1 mandibular molar). All 8 fractured teeth had been restored with a post-retained crown, and the radiographic quality of the root canal filling was deemed adequate.

The time from implant placement to the diagnosis of VRF was between 5 and 28 months (average = 11 months). The time from implant loading to the diagnosis of VRF was between 0 and 22 months (average = 6 months).

Figure 2 shows a case of an endodontically treated maxillary premolar that was diagnosed with VRF after the placement of implants in the adjacent space.

Discussion

This study reports and evaluates a series of 8 cases in 7 patients in whom VRF was diagnosed in endodontically treated teeth after tooth loss and implant placement in the adjacent area. In addition, a systematic review of the literature was performed to assess whether this possible adverse event was previously reported (16–19).

Systematic reviews use a systematic approach and explicit methodology to review and synthesize research evidence aimed to minimize bias and explicitly address the issues of the completeness of the identified evidence and assess the quality of the included studies and the combinability of the studies (10). This systematic process requires a comprehensive literature search to identify as much of the relevant literature as possible (17, 18, 21, 23).

In the present study, a combined comprehensive literature search of 2 electronic databases and a hand search of related articles and literature reviews resulted in the identification of 41 potential articles. To overcome heterogeneity of information, strict inclusion and exclusion criteria were applied to assess studies for the systematic review. These

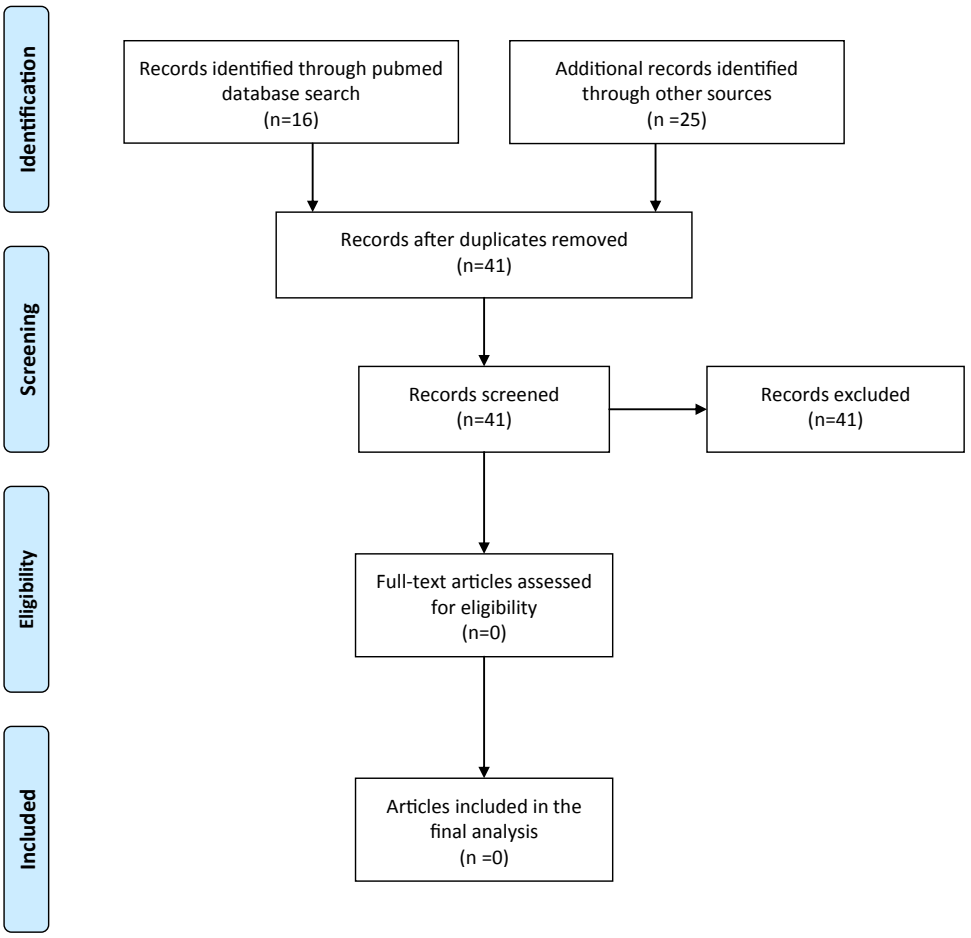

Figure 1. A flow chart of the systematic search process.

same criteria were used to include cases in the case series (10). At the time of implant placement, the associated endodontically treated teeth had no periradicular pathology, the presence of opposing teeth and occlusal contacts was confirmed, and the VRF was diagnosed after implant loading. In addition, detection of the etiology of VRFs requires a valid gold standard to ensure the presence of a VRF in the evaluated tooth (10, 11, 17). In the present study, the gold standard selected as acceptable for verification of the VRF (the target condition) was a confirmation after tooth extraction (10). However, after the initial screening of the 41 possibly relevant articles, all articles were excluded because they were not relevant to the topic of this study. Therefore, the current systematic review of the literature revealed that the possible

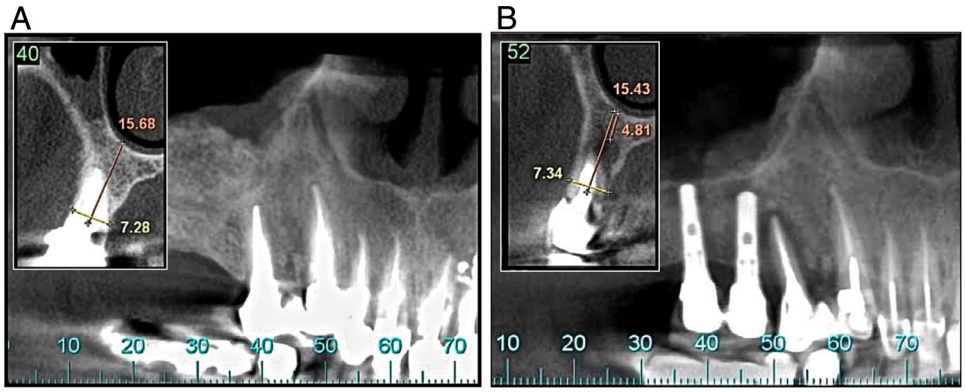

Figure 2. An endodontically treated maxillary premolar diagnosed with VRF after the placement of implants in the adjacent space. (*A*) An endodontically treated maxillary right second premolar tooth at the time of placement of 2 distal implants. There were no clinical or radiographic signs of pathology in the endodontically treated premolar tooth. (*B*) After 10 months, the patient presented with pain and a deep periodontal pocket in the premolar tooth. The tooth was extracted, and the VRF was confirmed.

phenomenon of implant-associated VRF has not yet been investigated or reported. Thus, although limited in its extent, this case series is the first clinical report of this possible serious adverse event.

In the current study, the majority of cases occurred in female patients (5/7 patients). A female predominance is usually reported in studies assessing the sex effect on the risk for VRF development (24) and the risk of VRF-related litigation after dental procedures (25–28). One of the reasons for this sex discrepancy may be that relatively more female patients are seeking dental treatment (26, 29).

Patient age may be associated with an increased risk of VRFs, and it has been reported that most VRFs occur in patients between 40 and 60 years old (30–32). Although this effect of age on the risk of VRFs is not fully elucidated, several *ex vivo* studies show that dentin strength and fracture toughness under mechanical loading decrease significantly with increasing patient age (30, 33–36). In the present study, 6 of 7 patients were older than 40 years, with an average age of 54 years, which is in accordance with previous reports of VRFs.

Because of their surrounding PDL, natural teeth exhibit proprioception signaling, which is considered to be a protective mechanism (4). However, unlike natural teeth, implants have no PDL, no periodontal receptors, and no proprioception mechanism to signal excessive force (4). As a result, the load sharing ability, adaptation to occlusal force, and the proprioception are all significantly reduced compared with natural teeth (4, 37). Therefore, implants may be more susceptible to occlusal overloading. Yet, the clinical significance of the occlusal forces on the prognosis of implants is controversial (4–6, 38, 39).

To reduce the risk of implant occlusal overload, a preventive mechanism ("implant-protective occlusion" [IPO]) has been suggested. According to this proposed mechanism, the overload on the implant-supported prosthesis is decreased, minimizing the risk for the implant osseointegration (38). The primary principles of IPO are to direct the occlusal loads to the implant bodies, decrease the forces of occlusal contacts, and increase the number of implants and their diameters, thus allowing successful withstanding of the occlusal loads (4). It has been claimed that a wide occlusal table may cause offset contacts during mastication and parafunction. Therefore, IPO may be achieved by reducing the implant occlusal table buccal-lingual dimensions in order to reduce the force required to penetrate a bolus of food (4). Because the implant occlusion is part of the entire occlusal system of the patient, when the occlusion is designed to minimize the occlusal force to the implant, it maximizes the force distributed to the adjacent natural teeth (8, 9, 37, 40, 41).

In addition, it has been suggested that endodontically treated teeth may have reduced levels of proprioception (42, 43), which may lead to a possible reduction in their fracture resistance compared with vital teeth (42, 43). The combination of excessive occlusal overload on the teeth adjacent to implants and the reduced levels of proprioception and fracture resistance of these teeth may potentially contribute to the development of implant-associated VRFs.

In the current case series, the majority of patients (5/7 patients) received 2 or more implants, potentially increasing the load on the VRF teeth (8, 9, 37, 40, 41). Additionally, in 5 patients, the implants were located adjacent to the VRF teeth, and in 2 patients the implants were located opposing or contralateral to the VRF teeth. It seems conceivable to assume that the occlusal alterations caused by the tooth loss and implant placement were a significant contributor to the development of the VRF. However, additional large-scale clinical studies are warranted to elucidate the exact occlusal interrelationship between the inserted implants and the affected VRF teeth.

In this study, the majority of VRFs were identified in premolar or in mandibular molar teeth (6/8 VRF teeth). The other 2 cases were identified in an anterior tooth (n = 1) and a maxillary posterior tooth (n = 1). This is consistent with the known classification of matched tooth locations as the more susceptible locations for VRF development after root canal treatment (10, 23, 31, 44–49).

In the present study, all VRF teeth (n = 8) were previously restored by a crown and had a post present. Restorative procedures after root canal treatment such as post space preparation, traumatic fitting of the post, and expansion of posts because of corrosion may contribute to the susceptibility to VRF (44, 47). In the present study, posts were observed in all 8 cases, which is a higher proportion than was previously reported by Fuss et al (ie, 62%) (44).

In all VRF teeth (n = 8), the quality of the root canal filling was judged as adequate. Previous reports revealed that a VRF is more prone to occur in cases in which a good quality root filling is performed compared with cases with poor root filling quality (10, 23, 31, 44–49), which is compatible with the results of this study.

The time from implant placement to the diagnosis of VRF was between 5 and 28 months (average = 11 months). The time from implant loading to the diagnosis of VRF was between 0 and 22 months (average = 6 months). VRF is usually diagnosed years after all endodontic and prosthetic procedures have been completed (8). The final diagnosis of VRF may be complicated because of the lack of specific clinical and/or radiographic features and because a number of etiologic factors may be implicated. Thus, the differential diagnosis from other possible pathologic conditions may be complicated (23, 31, 44, 48, 50–53).

This study presents a possibility of association between the presence of an adjacent implant and the development of VRFs in endodontically treated teeth. However, several independent variables that were not available in this study, such as the post type, when the endodontically treated teeth were initially restored, and how long they were in occlusion, need to be controlled for in future studies before one can assume a direct cause relationship.

Conclusions

Based on a systematic review of the literature, this case series, although limited in its extent, is the first clinical report of a possible serious adverse effect of implant placement—an ensuing VRF of adjacent endodontically treated teeth. Additional clinical studies are warranted in order to shed light on this potential complication.

Acknowledgments

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

References

1. Mericske-Stern R, Grutter L, Rosch R, Mericske E. Clinical evaluation and prosthetic complications of single tooth replacements by non-submerged implants. Clin Oral Implants Res 2001;12:309–18.
2. Depprich R, Zipprich H, Ommerborn M, et al. Osseointegration of zirconia implants compared with titanium: an *in vivo* study. Head Face Med 2008;4:30.
3. Novaes AB Jr, de Souza SL, de Barros RR, et al. Influence of implant surfaces on osseointegration. Braz Dent J 2010;21:471–81.
4. Jackson BJ. Occlusal principles and clinical applications for endosseous implants. J Oral Implantol 2003;29:230–4.
5. Chambrone L, Chambrone LA, Lima LA. Effects of occlusal overload on peri-implant tissue health: a systematic review of animal-model studies. J Periodontol 2010;81:1367–78.
6. Gotfredsen K, Berglundh T, Lindhe J. Bone reactions adjacent to titanium implants subjected to static load of different duration. A study in the dog (III). Clin Oral Implants Res 2001;12:552–8.
7. Koyano K, Esaki D. Occlusion on oral implants: current clinical guidelines. J Oral Rehabil 2015;42:153–61.
8. Misch CE. Occlusal considerations or implant supported prostheses. In: Misch CE, ed. *Contemporary Implant Dentistry*, 1st ed. St Louis: Mosby; 1993:705–33.

9. Engelman MJ. *Occlusion. Clinical Decision Making and Treatment Planning in Osseointegration*, 1st ed. Chicago: Quintessence Publishing Co; 1996:169–76.
10. Tsesis I, Rosen E, Tamse A, et al. Diagnosis of vertical root fractures in endodontically treated teeth based on clinical and radiographic indices: a systematic review. J Endod 2010;36:1455–8.
11. Tsesis I, Nemkowsky CE, Tamse E, Rosen E. Preserving the natural tooth versus extraction and implant placement: making a rational clinical decision. Refuat Hapeh Vehashinayim (1993) 2010;27:37–46. 75.
12. Colleagues for Excellence. *Cracking the Cracked Tooth Code: Detection and Treatment of Various Longitudinal Tooth Fractures*. Chicago: American Association of Endodontics; 2008.
13. Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent 1999;82:643–57.
14. Goodacre CJ, Spolnik KJ. The prosthodontic management of endodontically treated teeth: a literature review. Part I. Success and failure data, treatment concepts. J Prosthodont 1994;3:243–50.
15. Robbins JW. Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 1990;120:558. 560, 562 passim.
16. Gutmann JL. Evidence-based/guest editorial. J Endod 2009;35:1093.
17. Mileman PA, van den Hout WB. Evidence-based diagnosis and clinical decision making. Dentomaxillofac Radiol 2009;38:1–10.
18. Rosenberg W, Donald A. Evidence based medicine: an approach to clinical problem-solving. BMJ 1995;310:1122–6.
19. Sutherland SE, Matthews DC. Conducting systematic reviews and creating clinical practice guidelines in dentistry: lessons learned. J Am Dent Assoc 2004;135:747–53.
20. European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. Int Endod J 2006;39:921–30.
21. Tsesis I, Goldberger T, Taschieri S, et al. The dynamics of periapical lesions in endodontically treated teeth that are left without intervention: a longitudinal study. J Endod 2013;39:1510–5.
22. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 2009;339:b2700.
23. Tamse A, Fuss Z, Lustig J, et al. Radiographic features of vertically fractured, endodontically treated maxillary premolars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999;88:348–52.
24. Berman LH, Hartwell GR. Diagnosis. In: Cohen S, Hargreaves KM, eds. *Pathways of the Pulp*, 9th ed. St Louis: Mosby; 2006:2–39.
25. Bjorndal L, Reit C. Endodontic malpractice claims in Denmark 1995-2004. Int Endod J 2008;41:1059–65.
26. Givol N, Rosen E, Taicher S, Tsesis I. Risk management in endodontics. J Endod 2010;36:982–4.
27. Givol N, Taicher S, Halamish-Shani T, Chaushu G. Risk management aspects of implant dentistry. Int J Oral Maxillofac Implants 2002;17:258–62.
28. Rosen E, Tsesis I, Tamse A, et al. Medico-legal aspects of vertical root fractures in root filled teeth. Int Endod J 2012;45:7–11.
29. Manski RJ, Moeller JF, Maas WR. Dental services. An analysis of utilization over 20 years. J Am Dent Assoc 2001;132:655–64.
30. Mireku AS, Romberg E, Fouad AF, Arola D. Vertical fracture of root filled teeth restored with posts: the effects of patient age and dentine thickness. Int Endod J 2010;43:218–25.
31. Tamse A. Iatrogenic vertical root fractures in endodontically treated teeth. Endod Dent Traumatol 1988;4:190–6.
32. Testori T, Badino M, Castagnola M. Vertical root fractures in endodontically treated teeth: a clinical survey of 36 cases. J Endod 1993;19:87–91.
33. Arola D, Reprogel RK. Effects of aging on the mechanical behavior of human dentin. Biomaterials 2005;26:4051–61.
34. Kinney JH, Nalla RK, Pople JA, et al. Age-related transparent root dentin: mineral concentration, crystallite size, and mechanical properties. Biomaterials 2005;26:3363–76.
35. Koester KJ, Ager JW 3rd, Ritchie RO. The effect of aging on crack-growth resistance and toughening mechanisms in human dentin. Biomaterials 2008;29:1318–28.
36. Nazari A, Bajaj D, Zhang D, et al. Aging and the reduction in fracture toughness of human dentin. J Mech Behav Biomed Mater 2009;2:550–9.
37. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. Clin Oral Implants Res 2005;16:26–35.
38. Misch CE, Bidez MW. *Occlusal Considerations for Implant-supported Prosthesis: Implant Protective Occlusion. Dental Implant Prosthetics*. St Louis: Elsevier/Mosby; 2005:472–507.
39. Heitz-Mayfield LJ, Schmid B, Weigel C, et al. Does excessive occlusal load affect osseointegration? An experimental study in the dog. Clin Oral Implants Res 2004;15:259–68.
40. Sekine H, Komiyama Y, Potta H, Yoshida K. Mobility characteristics and tactile sensitivity of osseointegrated fixture-supporting systems. In: van-Steenberghe D, Albrektsson T, Branemark PI, et al., eds. *Tissue Integration in Oral and Maxillofacial Reconstruction*. Amsterdam: Excerpta Medica; 1986:326–32.
41. Schulte W. Implants and the periodontium. Int Dent J 1995;45:16–26.
42. Makam S, Shashikala K. A comparative evaluation of the fracture resistance of endodontically treated teeth using two obturating systems—an *in vitro* study. International Journal of Contemporary Dentistry 2011;2:93–7.
43. Assif D, Nissan J, Gafni Y, Gordon M. Assessment of the resistance to fracture of endodontically treated molars restored with amalgam. J Prosthet Dent 2003;89:462–5.
44. Fuss Z, Lustig J, Katz A, Tamse A. An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod 2001;27:46–8.
45. Fuss Z, Lustig J, Tamse A. Prevalence of vertical root fractures in extracted endodontically treated teeth. Int Endod J 1999;32:283–6.
46. Tamse A. Vertical root fractures in endodontically treated teeth: diagnostic signs and clinical management. Endod Topics 2006;13:84–94.
47. Tamse A. Vertical root fractures of endodontically treated teeth. In: Ingle JI, Bakland LK, Baumgartner JC, eds. *Ingle's Endodontics*, 6th ed. Hamilton: BC Decker Inc; 2008:676–89.
48. Tamse A, Fuss Z, Lustig J, Kaplavi J. An evaluation of endodontically treated vertically fractured teeth. J Endod 1999;25:506–8.
49. Tamse A, Kaffe I, Lustig J, et al. Radiographic features of vertically fractured endodontically treated mesial roots of mandibular molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:797–802.
50. Cohen S, Blanco L, Berman L. Vertical root fractures: clinical and radiographic diagnosis. J Am Dent Assoc 2003;134:434–41.
51. Meister F Jr, Lommel TJ, Gerstein H. Diagnosis and possible causes of vertical root fractures. Oral Surg Oral Med Oral Pathol 1980;49:243–53.
52. Moule AJ, Kahler B. Diagnosis and management of teeth with vertical root fractures. Aust Dent J 1999;44:75–87.
53. Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod 1992;18:332–5.