ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at:www.ijdsir.com

Volume – 7, Issue – 5, September – 2024, Page No. : 382 - 396

Factors Affecting Fracture of Endodontically Treated Teeth: A Systematic Review

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Citation of this Article: Mavishna MV, Raja Keerthi R, S. Arun Kumar, K. Savitha, "Factors Affecting Fracture of Endodontically Treated Teeth: A Systematic Review", IJDSIR- September – 2024, Volume –7, Issue - 5, P. No. 382 – 396.

Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

Tooth fracture is a major concern in the field of restorative and endodontic dentistry. Endodontic treatment is a common dental procedure used for treating teeth which the pulp tissue has become irreversibly inflamed or necrotic as a result of the carious process or dental trauma. This procedure which involves mechanical and chemical preparation of root canal may affect several mechanical and physical properties of the tooth structure. The endodontic treatment can also influence the longevity of the rehabilitation of endodontically treated teeth and biomechanics during the oral function. For restoring endodontically treated teeth several factor and clinical decisions should be observed. In this review, the authors will address an overview of risk factors for potential tooth fractures in endodontically treated teeth and to provide awareness during practice of endodontic treatments on controllable and uncontrollable risk.

Keywords: risk factors affecting Fracture of endodontically treated teeth, preventive measures

Introduction

The basic function of a tooth is mastication, as we all know. In endodontically treated teeth, however, tooth breakage remains a serious problem. Endodontically treated teeth (ETT) are more brittle and susceptible to fracture than non-ETT teeth. The inherent difficulties, it has been said, are mostly caused by ETT drying up over time and changes in their collagen cross-linking (1, 2). Although a large epidemiologic survey (3) found that the long-term functional survival of initial endodontically treated permanent teeth was 97.1 percent after 8 years, coronal and/or radicular tooth fractures continue to be common reasons for post endodontic tooth restorations and extractions (4,5). A 5-year follow-up assessment of 857 randomly selected teeth having nonsurgical root canal therapy indicated that nonspecific tooth fractures were responsible for 18 (28.1%) of the total 64 tooth extractions performed by dentists (6). Normal functional stresses, as well as elevated functional and parafunctional pressures, may cause fatigue failures of tooth structure and restorative materials in endodontically repaired teeth. Endodontic instrumentation and post-endodontic repair that removes a lot of dentin might cause tooth deterioration (7). Root canal wear can range from 14 to 45 percent of the dental structure during instrumentation (8), resulting in the removal of a mean dentin volume of 2 to 3 mm3 (9,10). Fractures in endodontically treated teeth are thought to have a complex cause (1). One thing is nearly assured in "dental life": endodontically treated teeth will continue to fracture. When treating a tooth with an endodontic aetiology, there are a few things to keep in mind. Many of these fractures are probably the result of poor treatment planning and endodontic and restorative operations performed by dentists. The goal of this review is to identify and reduce the risk of fractures in endodontically treated teeth. Thus, evidence-based systematic review of the available literature regarding the potential factors affecting fracture of endodontically treated teeth is of utmost importance.

The aim of this study was to systematically search and evaluate the literature regarding the risk factors affecting fracture of endodontically treated teeth by means of a systematic review.

Materials and methods

Study design

A systematic review of all studies that assessed the influence of risk factors affecting fracture of endodontically treated teeth was taken. This systematic review was registered in the PROSPERO database (PROSPERO registry number CRD 42017071644) and followed the recommendations of the PRISMA statement for the report of this systematic review (11).

Criteria for considering studies for this review: This systematic review included clinical studies, case reports, review, invitro studies that assessed the risk factors of fracture of endodontically treated teeth. Table.1 summarizes the criteria for inclusion of studies in the systematic review.

Exclusion Criteria

- Primary teeth
- Avulsed/replanted/transplanted teeth
- Teeth with root resorption

Eligibility Criteria

The focused PICO question for this review was to know "What are the factors which influence the fracture of endodontically treated teeth?"

Although the PICO strategy is generally used for clinical trials, all of the included in vitro studies presented an intervention. Thus, PICO strategy was adapted for this purpose (11). No language or time restrictions were applied.

Information Sources

A comprehensive electronic literature search was conducted in the following databases: Medline accessed via PubMed (National Center for Biotechnology Information, U.S. National Library of Medicine), Scopus (Elsevier, Relx Group plc), and The Cochrane Library

(John Wiley & Sons, Ltd). Search to identify relevant studies was performed without any language restriction. In addition, grey literature was also searched, and the reference lists of selected articles were screened to identify potential studies. Moreover, authors were contacted for any unpublished data.

Search Strategy

Different search strategies were used to identify publications. This was achieved by using a combination of key search relevant terms with no limits applied for the year of publication. The search strategy followed the following structure displayed in Table 2. systematic Search without restrictions was performed by two independent reviewers in the electronic databases PubMed, Science Direct, Scopus, Web of Science, and Open Grey from their inception through November 30, 2020.

Study Selection and Data Collection Process

Two independent reviewers (G. R. and F. G. B.) selected all references in two stages. In stage 1, both reviewers evaluated the titles and abstracts of the published studies and then applied the eligibility criteria. Full articles were retrieved and examined when their title and abstract did not provide enough information for a final decision. In stage 2, the selected full articles were independently reviewed and screened by the same two reviewers (G. R. and F. G. B.). Disagreements on eligibility criteria of a study were discussed between the reviewers until a decision was obtained by consensus. If there was no consensus, a third reviewer (E. J. S.) resolved any discrepancies. After the full-text analyses of the potentially relevant studies, the selected studies were included in this systematic review. Articles appearing in more than one database search were considered only once.

Study quality assessment

The quality of the selected studies was evaluated using an adaptation of the methods used in previous systematic reviews performed with in vitro studies [12,13]. Two reviewers (G. R. and F. G. B.) independently assessed the methodological quality of each included study using the following parameters: Significant number of Sample size, Control group (intact teeth), satisfactory methodological quality on root canal procedures or other procedures, Performance of fracture test, Statistical analysis carried out and Risk of Bias. The parameters reported in original studies were assigned as "yes'' and missing information was assigned as "No". The articles were classified as having a low risk of bias if five or six items were reported, a moderate risk of bias if three or four items were reported, and a high risk of bias if one or two parameters were reported. The third reviewer (E. J. S.), when needed, resolved any disagreement into the reviewers. The power analysis is able to measure the effect size that can be detected using a given sample size. For this purpose, a confidence interval of 95% and a two-tailed test using OpenEpi 3.04.04 software were adopted.

Results

Study selection

The identification process and the eligibility criteria of the studies are shown in Fig. 1. A total of 968 articles were obtained in the electronic search: 104 from Science Direct, 210 from PubMed, 503 from Scopus, 151 from Web of Science, and 0 from Open Grey. After the application of the eligibility criteria, the discarding of duplicates, and the inclusion of one study identified from reference lists, 25 articles were selected for full-text assessment. After reading the complete articles, 17 of them were excluded the reasons are explained in Table 2. As a result, eight studies fulfilled the eligibility criteria and were included in this systematic review [14-19].

Study characteristics

All included studies evaluated the potential risk factors affecting fracture of endodontically treated teeth. The studies analyzed different teeth: maxillary incisors [16], premolars [14] and molars [21]. Sample sizes also presented discrepancies ranging from 45 [21] to 160 [14]. The risk factors for fracture of endodontically treated teeth depends on case selection criteria's on endodontic treatment, Complete removal of caries before commencement of endodontic treatment, minimally invasive access cavity preparation, Cleaning and shaping, effect of irrigation, effect of intracanal medicament, obturation forces, effect of post space preparation, Forces acting on tooth and restoration and type of coronal restorations. All included studies analyzed were longitudinal studies where retrospective data were used from patients who were recalled to reevaluate. All studies included were published from 2004–2020. It was observed that there are differences in the methodology in fracture resistance tests. All the included studies evaluated survival, and for those that evaluated success, results were based on radiographic and clinical examination. The evaluation period for outcome assessment ranged from 1–5 years. The studies also demonstrated large variability among the fracture resistance values and standard deviations. Characteristic details of all selected studies [14-21] are summarized in Table 2

Strength to fracture results of individual studies

Table 3 summarizes the characteristics of the included studies and the main statistical findings. Plotino et al. [14] evaluated maxillary and mandibular molars and premolars. No difference was observed between CECs, ninja endodontic cavities (NECs), and intact teeth in all types of teeth. TEC showed lower strength than other groups. Tavanafar et al. [15] evaluated fracture resistance of mandibular premolars upon cleaning and shaping with different instruments. All experimental groups showed statistically significant reductions in fracture resistance as compared with the control group. Uzunoglu et al. [16] evaluated fracture resistance of incisors after using different irrigation protocol. The negative control group showed the highest FRV. There were statistically significant differences between the negative and positive control groups ($P < .05$). Specimens irrigated with REDTA and QMix showed a higher FRV compared with the positive control group ($P < .05$). Specimens exposed to chlorhexidine and Bio Pure MTAD showed a lower FRV compared with the negative control group. Doyon et al. [17] evaluated fracture resistance of single rooted human teeth upon application of different intra canal medicament. After 30 days exposure to the test solution, there was no difference in the peak load at fracture for the three groups of teeth. However, after 180 days, the roots of the teeth exposed to USP $Ca(OH)2$ showed a significant decrease in peak load at fracture when compared to the 30-day groups and the 180-day groups exposed to saline or Metapaste. Ersoy et al. [18] demonstrated different obturation techniqueson mandibular premolars and found out the fracture resistance upon application of lateral forces. Thermafil group showed higher fracture resistance than single cone technique, cold lateral condensation technique, and system B. Fadag et al.[19] evaluated fracture resistance of central incisors upon the use of different post and core systems. Endodontically treated teeth restored with zirconia post, glass fiber post, titanium post, or mixed post were more resistant to fracture loads compared with those that were not restored (control group) or restored with either carbon fiber post or cast post and core. Pereira et al. [20] demonstrated the effect of ferrule on canine on its fracture resistance. The results of this study showed that an increased amount of coronal dentin significantly increases the fracture resistance of endodontically treated teeth. Plotino et al. [21] evaluated the effect of extensive coronal restoration on mandibular molars on its fracture resistance. No significant difference was observed in the fracture resistance of endodontically treated molars restored to original contours with an extensive cusp-replacing direct or indirect composite resin restoration.

Study quality assessment

On the basis of the study methodological parameters, an assessment of the methodological quality of the included studies was planned to be undertaken following the recommendations of the guest editorial on evidence-based dentistry published by the Journal of Endodontics in 2009 [22]. The study accuracy was planned to be calculated by comparing the results of the index tests with the outcomes of the reference standards (23,24). Of the eight studies included, all of them presented low risk of bias. The results are described in Table 3 according to the parameters considered in the analysis. The power analysis demonstrated, all the included studies obtained 100% power. The power analysis of all selected studies [19-21] was showed in Table 4.

Discussion

A total of 968 studies were obtained from the electronic search. However, after the eligibility criteria and the discard of duplicates, only seven of them [14-21] were included. It is important to emphasize that the seven studies included were classified as low/moderate risk of bias. Even though it was not comparable due to the important discrepancies in the methodology of the included studies, in these cases, the meta-analysis is not recommended.

For decades, the typical endodontic cavity (TEC) design for various tooth types has remained identical, with only minimal changes made (24). The reduction of tooth structure required for access cavity preparation, on the other hand, may weaken the tooth's ability to withstand functional loads (1,25). The second most common cause of tooth structural loss was revealed to be the preparation of the endodontic access cavity according to TEC principals (26). As a result, a well-designed and minimised endodontic access could improve the prognosis of an endodontically treated tooth (27). When compared to TEC, conservative endodontic access canals such as CEC and NEC increased the fracture strength of teeth. For TEC, the proportion of coronal dentin removed during access cavity preparation is greater than 15%, CEC is 15%, and NEC is up to 6% (21)

The contact between instruments and root dentin walls during instrumentation with NiTi files cuts and enlarges a root canal. Instrumentation may contribute to VRF by inducing stress or through excessive dentinal removal. Tavanafar et al. [15] used NiTi K-file, BioRaCe, and Wave One for instrumentation. Because each represents different instrumentation techniques featuring different cross-sectional geometry, taper, flute form, type of manufactured alloy, number of instruments used, and rotational motion that can influence tooth resistance to VRF. In his study, no difference in fracture resistance was evident between roots prepared with single-file Wave One when compared with either hand NiTi K-files or the rotary NiTi BioRaCe instrument ($p > 0.05$). The control group was more resistant to fracture than all other groups ($p < 0.05$), suggestive of roots becoming more susceptible to fracture regardless of instrumentation technique; which was consistent with the findings of previous studies. [28,29] Root canal treatment weakens roots, and in this study, instrumentation with the single-file reciprocating technique was associated with resistance to fracture comparable with the roots prepared with NiTi hand or rotary instruments.

Uzunoglu et al. [16] demonstrated whether the root canal preparation and final irrigation influenced the vertical root fracture resistance. In this study, vertical root fracture resistance of MTAD treated dentin was lower compared with EDTA-treated dentin. However, the vertical root fracture resistance of MTAD-treated dentin was also lower compared with detergent containing REDTA and QMix. One possible explanation for this result can be the difference in irrigation duration. Irrigation duration was 1 minute in all groups except MTAD, which was used for 5 minutes according to manufacturer instructions. Here the specimens irrigated with QMix showed higher resistance to vertical root fracture compared with specimens irrigated with EDTA. The study results have shown that the root canal preparation and final irrigation influenced the vertical root fracture resistance.

Long-term calcium hydroxide therapy weakens dental structures and can diminish tooth strength dramatically, increasing the risk of fracture. The findings of Doyon et al. [17] in his study appear to support the contention that long term exposure to Ca(OH2) alters the physical properties of dentin. This may be a result of a change in the organic matrix (30). It has been shown that Ca(OH2) dissolves pulp tissue (31,32), a process that may occur by denaturation and hydrolysis. In addition, the pH increase observed after exposure to Ca(OH2) may also reduce the organic support of the dentin matrix (33,34). These processes may disrupt the interaction of the collagen fibrils and hydroxyapatite crystals that could negatively influence the mechanical properties of dentin. It is noteworthy that the dentin disks exposed to Metapaste for 180 days did not demonstrate the same reduction in peak load at fracture as did the disks exposed to USP Ca(OH)2. The results showed that, statistically significant difference in the peak load at fracture between human dentin disks exposed to USP Ca(OH2) for 180 days when compared to teeth exposed to USP Ca(OH2), Metapaste, and saline for 30 days and to teeth exposed to Metapaste and saline for 180 days. The difference in peak load at fracture between the 180 day USP Ca(OH2) group and the other experimental groups ranged from 9.9 to 19.0%. It may be that a 10 to 20% decrease in strength is sufficient to significantly increase the likelihood of fracture to already structurally compromised teeth. The authors are unaware of any studies on the use or effectiveness of this material as a long-term intracanal medicament. Additional research is necessary to verify the results of this study and to examine the clinical value of this material.

When the root canal diameters were increased to 40%–50% of the whole root widths using a fine finger spreader and standard loads during lateral compaction, all 34 maxillary incisor tooth specimens developed craze lines and root fractures (35). To avoid potential fractures of thin-walled roots, care should be taken during cold lateral compaction of root filling materials. Ersoy et al. [18] demonstrated different techniques for determining fracture resistance. It includes cold lateral condensation techniques, Obtura technique with continuous heat, System B, Single cone technique and Thermafill system. Of these, thermafill increased the fracture resistance of the roots and other groups showed least fracture resistance. This was due to the force which was created by the plugger used and the heat applied caused thermal expansion in the root dentin and this affected the fracture resistance adversely. Here the author suggesting to develop techniques and materials that increase the fracture resistance of the roots in terms of the prognosis of the teeth and to conduct further researches.

Posts do not often strengthen roots, and the post space preparations required for their placement may potentially damage the remaining tooth structure and cause apical microleakage if the root canal obturation seal is insufficient (65). Fadag et al. [19] demonstrated different post systems on enhancing fracture resistance of ETT. This study showed that, the use of RelyX glass fiber posts exhibited the highest fracture resistance., casted metal posts recorded the lowest fracture resistance values and Carbon fiber posts showed lower fracture resistance than those restored with glass fiber posts. It is due to glass fiber posts generate the least amount of stress concentration at the middle and apical parts of posts and the elasticity modulus of glass fiber posts is similar to that of dentin, which can better absorb forces concentrated along the root and can decrease the probability of fracture and the Carbon fiber posts are quite stiff and strong, to a degree that is comparable to that of several posts made of metal, and it possess a modulus approximately 10 times higher than dentin. The UHT (control group), CPC, and CFP groups had the lowest fracture resistance values, because in UHT (control group), there was no resin cement, the absence of resin cement means the absence of a monoblock system. The presence of resin cement with fiber posts created a unique system called a monoblock system where the resin cement can bond to the dentin and fiber posts. In the CPC group, because of the high modulus of elasticity in such posts, they can directly transfer the applied forces to the root and cause fracture.

Pereira et al. [20] showed that increasing ferrule length significantly increased the fracture resistance of endodontically treated teeth restored with prefabricated posts and cores. It was observed that the control group presented significantly higher fracture resistance when compared with the 0-mm ferrule group, and the 3-mm ferrule group showed significantly higher fracture resistance when compared with the 0-mm and 1-mm ferrule groups. These findings are believed to be related to the higher strength of the nickel-chromium alloy, the higher modulus of elasticity, and the larger amounts of coronal tooth structure. Furthermore, the size and shape of the composite resin matrix particles account for 66% of its volume. This higher quantity of inorganic particles corresponds to the maximum resistance of compressive load, surface hardness, and wear resistance. The results of this study indicate that the presence of remaining coronal structure did influence the fracture resistance of the teeth.

A normal tooth structure transfers external biting loads via enamel into dentin as compression under specific circumstances where excessive forces are applied, such as parafunctional habits, traumautic injury, and masticatory accidents. Normal cyclic contact loads cause fatigue and promote incomplete fracturing in repaired teeth (36). Plotino et al. [21] demonstrated that there are no differences in the in vitro fracture resistance of extensive direct and indirect composite resin restorations. Both direct and indirect restorations had a decrease in fracture resistance, respectively, of 42% and 44%, compared to intact teeth. The endodontically treated molars prepared with an extensive loss of tooth structure and restored to their original contours with direct composite resin restorations presented a resistance to fracture under simulated occlusal load not significantly different than that of indirect composite resin restorations. Restored teeth had a decrease in fracture resistance compared to intact teeth.

Furthermore, no differences were found in the mode of failure of the restored and intact teeth.

Conclusion

Although in vitro studies present limitations, the included studies have a satisfactory methodological quality contributing with a preliminary important information regarding this subject. In this systematic review, an overview of risk factors for potential tooth fractures on endodontically treated teeth and what has to be done to provide awareness during practice of endodontic and post endodontic treatments on controllable and uncontrollable risk is given.

References

1. Kishen A. Mechanisms and risk factors for fracture predilection in endodontically treated teeth. Endodontic topics. 2006;13(1):57–83.
2. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002;87(3):256–63.
3. Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30:846–50.
4. Hansen EK, Asmussen E, Christiansen NC. In vivo fractures of endodontically treated posterior teeth restored with amalgam. Endod Dent Traumatol 1990;6:49–55.
5. Zadik Y, Sandler V, Bechor R, Salehrabi R. Analysis of factors related to extraction of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e31–5.
6. Chen S-C, Chueh L-H, Hsiao CK, Wu H-P, Chiang C-P. First untoward events and reasons for tooth extraction after nonsurgical endodontic treatment in Taiwan. J Endod 2008;34:671–4.
7. Tavanafar S, Karimpour A, Karimpour H, Saleh AM, Saeed MH. Effect of different instrumentation techniques on vertical root fracture resistance of endodontically treated teeth. J Dent. 2015; 16:50–55
8. Sousa K, Andrade-Junior CV, Silva JM, Duarte MAH, De-Deus G, Silva EJNL. Comparison of the effects of TripleGates and Gates-Glidden burs on cervical dentin thickness and root canal area by using cone beam computed tomography. J Appl Oral Sci. 2015; 23: 164–168.
9. Moura-Netto C, Palo RM, Camargo CHR, Pameijer CH, Bardauil MRRS. Micro-CT assessment of two different endodontic preparation systems. 2013; Braz Oral Res 27:26–30.
10. Elnaghy AM, Elsaka SE. Evaluation of root canal transportation, centering ratio, and remaining dentin thickness associated with ProTaper Next instruments with and without glide path. J Endod. 2014; 40:2053–2056.
11. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group (2010) Preferred reporting items for systematic reviews and meta analyses: the PRISMA statement. Int J Surg 8:336–341.
12. Onofre R et al. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of in vitro studies. Oper Dent. 2014; 39:31–44.
13. WL et al. Bond strength of universal adhesives: a systematic review and meta-analysis. J Dent. 2015; 43:765– 776.
14. Plotino et al. Fracture strength of endodontically treated teeth with different access cavity designs. J Endod. 2017; 43(6): 995-1000.
15. Tavanafar S et al. Effect of different instrumentation techniques on vertical root fracture resistance of endodontically treated teeth. J Dent Shiraz Univ Med Sci.2015; 16: 50-55.

16. Uzunoglu et al. Final irrigation regimen affect fracture resistance values of root filled teeth. J endod.2016; 12: 1-3.
17. Doyon et al. Fracture resistance of human root dentin exposed to intra canal calcium hydroxide. J Endod. 2005; 31(12):895-897.
18. Ersoy et al. Evaluation of the effect of different root canal obturation techniques using two root canal sealers on the fracture resistance of endodontically treated teeth. Micro Res Tech. 2015; 10: 1-4.
19. Fadag et al. Fracture resistance of endodontically treated anterior teeth restored with different post systems: an invitro study. Eur Endod J. 2018; 3: 147-8
20. Pereira et al. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J prostdent. 2005; 95: 50-4.
21. Plotino et al. Fracture resistance of endodontically treated molars restored with extensive composite resin restorations. 2008; 99: 225-232.
22. Gutmann JL. Evidence-based/guest editorial. J Endod 2009;35:1093
23. ssuyt PM, Leeflang MM. Chapter 6: developing criteria for including studies. Cochrane handbook for systematic reviews of diagnostic test accuracy: the Cochrane Collaboration; 2008.
24. Whiting P, Westwood M, Burke M, Sterne J, Glanville J. Systematic reviews of test accuracy should search a range of databases to identify primary studies. J Clin Epidemiol 2008;61:357–64.
25. Zhi-Yue L, Yu-Xing Z. Effect of post-core design and ferrule on fracture resistance of endodontically-treated maxillary central incisors. J Prosthet Dent 2003;89: 368–73.
26. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609–17.
27. Rezaei Dastjerdi M, Amirian Chaijan K, Tavanafar S. Fracture resistance of upper central incisors restored with different posts and cores. Restor Dent Endod 2015; 40:229–35.
28. Andbiglari T, Davids H, Schäfer E. Influence of instrument taper on the resistance to fracture of endodontically treated roots. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006; 101: 126-131.
29. Adorno CG, Yoshioka T, Jindan P, Kobayashi C, Suda H. The effect of endodontic procedures on apical crack initiation and propagation ex vivo. Int Endod J 2013; 46: 763- 768.
30. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol 2002;18:134 –7.
31. Anderson M, Lund A, Andreasen JO, Andreasen FM. In vitro solubility of human pulp tissue in calcium hydroxide and sodium hypochlorite. Endod Dent Traumatol 1992; 8:104 – 8.
32. Hasselgren G, Olsson B, Cvek M. Effects of calcium hydroxide and sodium hypochlorite on the dissolution of necrotic porcine muscle tissue. J Endod. 1988;7:17–21.
33. Tronstad L, Andreasen JO, Hasselgren G, Kristerson L, Riiss I. pH changes in dental tissues after root canal filling with calcium hydroxide. J Endod 1980;7:17–21.
34. Nerwich A, Figdor D, Messer HH. pH changes in root dentin over a 4-week period following root canal dressing with calcium hydroxide. J Endod 1993;19:302– 6.

35. 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.

36. Kraus BS, Jordan RE, Abrams L: Dental anatomy and occlusion, ed 1, Baltimore, 1969, Williams & Wilkins.

Legend Tables & Chart

Table 1:

Criteria for Inclusion of Studies in the Systematic Review
1. Clinical studies including the patients who are undergoing endodontic and post endodontic treatments
2. Influence of endodontic procedures and post space preparations
3. Effect of post and core design and ferrule
4. Forces acting on tooth and restoration
5. Post endodontic coronal restoration

Table 2: Search Strategy (Example from the PubMed Database)

Factors affecting fracture of endodontically treated teeth: 547
#1 00fracture of endodontically treated teeth "[MeSH Terms] OR (“endodontic teeth fracture"[All Fields] AND “endodontic tooth"[All Fields] AND “fracture"[All Fields]) OR “factors affecting fracture of endodontically treated teeth"[All Fields] OR (“fracture"[All Fields] AND “endodontically treated tooth"[All Fields]) OR “factors affecting endodontically treated tooth"[All Fields]
Effect of Root canal therapy AND fracture of endodontically treated tooth: 91
#2 (“effect of root canal therapy"[MeSH Terms] OR (“effect of root canal therapy"[All Fields] AND “"[All Fields] AND “fracture of endodontically treated tooth "[All Fields]) OR “effect of root canal therapy"[All Fields]) AND (“fracture of endodontically treated tooth "[MeSH Terms] OR (“Effect of Root canal therapy "[All Fields] AND “tooth"[All Fields] AND “fracture of endodontically treated tooth "[All Fields]) OR “Effect of Root canal therapy "[All Fields] OR (“fracture of endodontically treated tooth "[All Fields] AND “tooth"[All Fields]) OR “Effect of Root canal therapy "[All Fields])
Effect of post endodontic restoration on endodontically treated tooth AND fracture: 94
#3 (“effect of post endodontic restorations on tooth fracture"[MeSH Terms] OR (“tooth fractures"[All Fields] AND “ferrule design"[All Fields] AND “post endodontic restorations"[All Fields]) OR “"[All Fields] OR (“root"[All Fields] AND “effect of post endodontic restorations on tooth fracture "[All Fields]) OR “tooth fracture "[All Fields]) AND (“ferrule designs"[Subheading] OR “post designs"[All Fields] OR “tooth fracture "[All Fields] OR “therapeutics"[MeSH Terms] OR “therapeutics"[All Fields]) AND (“tooth fracture cocaine"[MeSH Terms] OR (“endodontically treated tooth fracture "[All Fields] AND “cocaine"[All Fields]) OR “ fracture of endodontically treated tooth cocaine"[All Fields] OR “crack"[All Fields])

Flow Chart 1: Flow diagram outlining the study identification and screening process adapted from PRISMA recommendation.

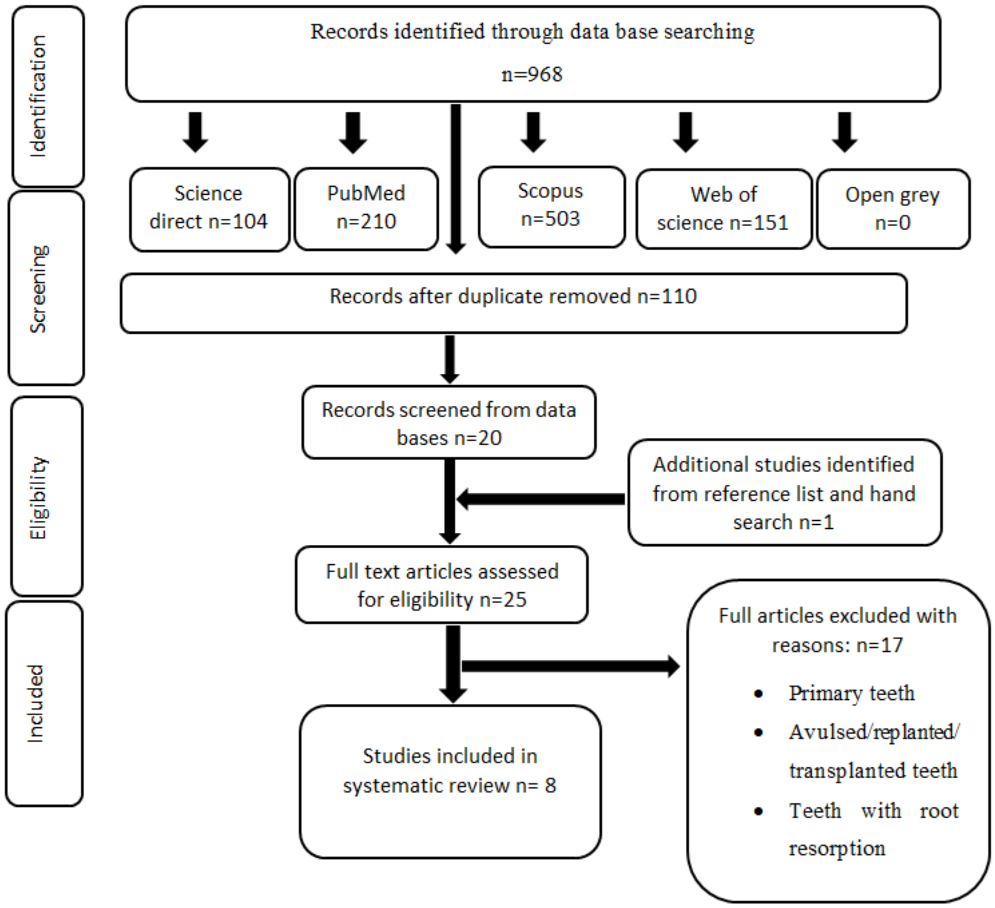

Table 3: Summary of included studies

Study	Study design	Sample size	Teeth	Tooth status/ Load at fracture test	Fracture resistance/ Load at fracture	Analysis of resistance test results
Plotino et al.	invitro	160	Maxillary molars and premolars Mandibular molars and premolars	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a 6-mm spherical crosshead at 0.5 mm/min until failure occurred	Maxillary molars: NEC (1170 ± 432 N) CEC (1143 ± 506 N) TEC (810 ± 425 N) Control (1172 ± 598 N) Maxillary premolars: NEC (805 ± 204 N) CEC (821 ± 324 N) TEC (498 ± 250 N) Control (913 ± 188 N) Mandibular molars: NEC (1459 ± 278 N) CEC (1401 ± 495 N) TEC (923 ± 393 N) Control (1572 ± 639 N) Mandibular premolars:	No difference was observed between CEC, NEC (ninja), access cavity designs, and intact teeth. Teeth with TEC showed lower strength than other groups

					NEC (945 ± 267 N) CEC (929 ± 384 N) TEC (704 ± 310 N)	
Tavanafar et al	Invitro	120	Mandibular premolars	After cleaning and shaping the root canals, the root canals were embedded vertically in standardised autopolymerising acrylic resin blocks, and subjected to a vertical load to cause vertical root fracture. The forces required to induce fractures were measured using a universal testing machine	Control (rootcanals without instrumented) : 303 ± 60a NiTi hand K-file : 264 ± 54b BioRaCe : 198 ± 43c WaveOne : 234 ± 57b,c	All experimental groups showed statistically significant reductions in fracture resistance as compared with the control group.
Uzunoglu et al	invitro	80	incisors	After irrigation protocol, the specimens were loaded in a vertical direction at 1 mm/ min speed until they were vertically fractured.	Negative control - 508.29a Positive control - 224.79b Saline - 322.81abc EDTA - 356.74abc REDTA 10 398.37ad 355.69 541.98 Chlorhexidine - 302.56bcd QMix - 414.23ac BioPure MTAD - 257.15bc	The negative control group showed the highest FRV. There were statistically significant differences between the negative and positive control groups (P < .05). Specimens irrigated with REDTA and QMix showed a higher FRV compared with the positive control group (P < .05). Specimens exposed to chlorhexidine and BioPure MTAD showed a lower FRV compared with the negative control group (P < .05).
Doyon et al	invitro	102	Single rooted human teeth	the roots of 17 teeth from each group were sectioned horizontally into 1-	Saline-30 d - 61.66 Metapaste-30 d - 59.02 Ca(OH)2-30 d - 61.46 Saline-180 d - 57.81 Metapaste-180 d - 56.02	After 30 days exposure to the test solution, there was no difference in the peak load at fracture for the

				mm thick disks and each disk was loaded to fracture at 2.5 mm/min with a SATEC universal-testing machine. After 180 days the same procedure was performed on the remaining 17 teeth in each of the 3 groups. The peak load at fracture was measured for each dentin disk	$Ca(OH)_2$-180 d - 49.99 Total - 57.89	three groups of teeth. However, after 180 days, the roots of the teeth exposed to USP $Ca(OH)_2$ showed a significant decrease in peak load at fracture when compared to the 30-day groups and the 180-day groups exposed to saline or Metapaste.
Ersoy et al	invitro	120	Mandibular premolar	Lateral force was applied to the samples during root canal treatment with 1 mm/min speed in the Universal Tester.	Control Group - 414 ± 104 Shaped but not filled - 241 ± 73 Cold Lateral Condensation + AH Plus - 239 ± 69 Cold Lateral Condensation + MTA Fillapex 238 ± 36 Single Cone + AH Plus 12 245 ± 94 Single Cone + MTA Fillapex 192 ± 41 System B + AH Plus - 174 ± 80 System B + MTA Fillapex - 213 ± 87 Thermafil+ AH Plus - 280 ± 88 Thermafil + MTA Fillapex - 284 ± 124	Thermafil group showed higher fracture resistance than single cone technique, cold lateral condensation technique, and system B
Fadag et al	invitro	56	Maxillary central incisor	The specimens were loaded in a universal testing machine until fracture occurrence.	UHT (control group): healthy root-filled 551.2±69.1A teeth without endodontic posts ZRP: root-filled teeth with prefabricated 704.8±112.8B zirconia post GFP: root-filled	Endodontically treated teeth restored with zirconia post, glass fiber post, titanium post, or mixed post were more resistant to fracture loads compared

					teeth with prefabricated 764.±156B glass fiber post CFP: root-filled teeth with prefabricated 562.8±131A carbon fiber post CPC: root-filled teeth with 524.0±73A custom-made post TIP: root-filled teeth with prefabricated 736.2±83.9B titanium post MIP: root-filled teeth with prefabricated 714.1±65.8B mix post	with those that were not restored (control group) or restored with either carbon fiber post or cast post and core
Pereira et al	invitro	50	canine	The fracture resistance (N) was measured in a universal testing machine at 45 degrees to the long axis of the tooth until failure.	Groups SD At 0 mm: 136.8 At 1 mm : 122.6 At 2 mm : 144.8 Control : 147.9 At 3 mm : 269.9	The results of this study showed that an increased amount of coronal dentin significantly increases the fracture resistance of endodontically treated teeth.
Plotino et al	invitro	45	Mandibular molars	Specimens were loaded to failure and the fracture loads were recorded (N). The mode of fracture was determined using a stereomicroscope and classified as favourable or unfavourable failure	DIR (direct) : 67% (n = 10) Unfavourable, 33% (n = 5) favourable IR (Indirect) : 67% (n = 10) Unfavourable, 33% (n = 5) favourable Intact teeth : 60% (n = 10) Unfavourable, 40% (n = 5) favourable	No significant difference was observed in the fracture resistance of endodontically treated molars restored to original contours with an extensive cusp-replacing direct or indirect composite resin restoration.

Table 4: Quality assessment and risk of bias

Study	Significant number of Sample size	Control group (intact teeth)	satisfactory methodological quality on root canal procedures or other procedures	Performance of fracture test	Statistical analysis carried out	Risk of Bias
Plotino et al.	Yes	Yes	Yes	Yes	Yes	Low
Tavanafar et al	Yes	Yes	Yes	Yes	Yes	Low

Uzunoglu et al	Yes	Yes	Yes	Yes	Yes	Low
Doyon et al	Yes	Yes	Yes	Yes	Yes	Low
Ersoy et al	Yes	Yes	Yes	Yes	Yes	Low
Fadag et al	Yes	Yes	Yes	Yes	Yes	Low
Pereira et al	No	Yes	Yes	Yes	Yes	Low
Plotino et al	No	Yes	Yes	Yes	Yes	Low