INTRODUCTION

Introduction

Endodontic access cavity preparation is one of the most important phases of nonsurgical root canal treatment that facilitates all subsequent phases making it the key to successful treatment [(1)]. The principles of endodontic access cavity preparation were outlined by Ingle, based on the principles of cavity preparation established by G.V. Black [(2)]. Inadvertently, endodontic access cavity preparation may results in weakening of the remaining tooth structure as a result of loss of strategic internal architecture of the tooth at the marginal ridges and the center of teeth due to de-roofing of the pulp chamber. Also, may results in cuspal deflection at the tooth cervix during occlusal function [(3 - 5)].

The choice of an optimal restorative method for endodontically treated teeth is still a major challenge. Different treatment modalities for such teeth ranges from a relatively direct restoration with or without intraradicular post to more complex indirect restorations, including inlay and onlay up to full coverage crowns [(6)].

With the advancement of new technology such as dental operating microscope (DOM), Cone beam computed tomography (CBCT) and ultrasonics in endodontics, several trials have been done to achieve smaller and more conservative access cavities [(7 - 9)].

With regard to conservation of tooth structure, different conservative endodontic access cavity designs such as contracted, truss and ninja access cavity preparation were described. These cavity designs aimed to minimize tooth structure removal and to improve fracture resistance of endodontically treated teeth by preservation of the pulp chamber roof and pericervical dentin [(10,11)].

Moreover, an artificial truss restoration was described as an alternative treatment modalities by pinning a horizontal glass fiber post within the coronal tooth structure in bucco-lingual direction [12].

Till now, very little research have been done to evaluate the fracture resistance of restored endodontically treated teeth with either truss access or artificial truss restorations.

Review of literature

Section outline:

2.1 Fracture of the endodontically treated teeth.

2.2 Prevalence and predisposing factors of fracture of the endodontically treated teeth.

- **2.2.1 Effect of loss of tooth structure by traditional access cavity preparation.**
- **2.2.2 Effect of age changes in dentin.**
- **2.2.3 Effect of endodontic irrigants and medicaments.**
- **2.2.4 Effect of bacteria-dentin interaction.**
- **2.2.5 Effect of post and core restorations.**

2.3 Advanced tooth reinforcement using different access cavity designs.

2.4 Methods of evaluation of the coronal fracture.

Review of literature

2.1 Fracture of the endodontically treated teeth:

Tooth fracture has been described as a major problem in dentistry, as it considered one of the main causes of tooth loss especially in endodontically treated teeth [13,14]. Several studies were proposed to clarify the increased susceptibility of fracture in the endodontically treated teeth.

Historically, **Helfer et al.** [15] argued that, the endodontically treated teeth were more brittle than the sound teeth due to loss of about 9 % of the moisture content of dentin. One dog was anesthetized followed by pulp extirpation for the anterior, premolar, and molar teeth located in the right side of the dog mouth in each arch. Teeth in the left side was left intact acted as a control. Access cavities were then sealed with Cavit and zinc oxyphosphate cement. Teeth were extracted after pre-determined time intervals and placed immediately into small plastic vials containing dog's saliva. Readings were taken from zero time to 24 weeks by weight of teeth specimens before placing into a Fisher Thelco oven. After cooling, teeth were weighed again to determine any changes in the moisture content of the calcified tissues of teeth as a consequence of extirpation. It was found at each recorded interval that the loss of moisture was greater in the endodontically treated teeth more than in the sound teeth.

Furthermore study by **Rivera** & **Yamauchi** [16] evaluated the collagen cross-linking in the dentin matrix that provide dentin with stability and tensile strength. Twenty three incisor, premolar and molar extracted human teeth were included in study. Dentin specimens were obtain and pulverized to a fine powder using a Spex Freezer Mill. Dentin powder were analyzed using a chromatographic elution analyzer to determine the content and types of cross-linking in dentin collagen of the specimens. They observed that cross-linking varies depending on the types and amounts of stress in the respective sites. They concluded that decrease collagen cross-linking in dentin affect the mechanical properties of dentin.

Adversely, **Fusayama et al.** [17] evaluated microhardness of the endodontically treated teeth and sound teeth. Forty canines of ten adult dogs were used in the study. Pulp extirpation were done followed by root canal instrumentation and obturation for 20 teeth located in the right side while 20 teeth in the left side were left intact as controls. Then, access cavities were sealed with amalgam restorations. The dogs were scarified after period of four, six, or nine months follow up and jawbones were immediately cut off, while the canines were removed with surgical burs. Microhardness was determined with knoop indenter loading. The results showed that no significant difference was observed between the endodontically treated teeth and sound teeth. They suggested that endodontic treatment has so few effect on the fracture resistance of the endodontically treated teeth.

Furthermore, **Lewinstein I.** [18] compared changes in the mechanical properties of dentin as the result of root canal treatment. Sixteen extracted human sound teeth and thirty two endodontically treated teeth were used in study. Longitudinal sections were obtained from the cervical portion of the roots using disks. Dentin hardness was measured by the Vickers's test therefore, six readings were taken from each specimen. The results showed that root canal therapy does not significantly affect the hardness of dentin. They support the concept of minimum removal of tooth structure during root canal therapy.

Huang et al. [19] compared the physical and mechanical properties of dentin specimens of endodontically treated teeth and sound teeth at different levels of hydration. Two groups of freshly extracted human anterior and posterior permanent teeth were used. G1; consisted of 54 sound teeth with minimal caries and G2; consisted of 24 endodontically treated teeth at least 1 year before extraction. Specimens of dentin were cut out of the coronal and radicular portion of teeth from both groups, these specimens were subjected to different experimental conditions (wet, air, dried, desiccated, and rehydrated). Compression, indirect tensile and impact tests were conducted to measure the mechanical properties of those specimens. The results reveled that no significant difference in ultimate tensile strength of dentin specimens was observed between the endodontically treated teeth and sound teeth. The results indicated that dehydration does not appear to weaken dentin structure in terms of strength and toughness.

In addition, **Sedgley & Messer** [20] planned a study to answer the question of whether endodontic treatments results in weakening in tooth structure. Twenty three endodontically treated human teeth and their contralateral sound teeth pairs were used in study. Teeth were prepared and tested immediately, 3 days, 2 months and 3 months after extraction. Two slices 0.3 to 0.4 mm in thickness were cut from the cervical root dentin perpendicular to the long axis using a disk. Dentin specimens were mounted on Shimadzu universal testing machine and punch shear strength, toughness, hardness, and load to fracture test were done. The result reveled that no significant differences between the two groups in punch shear strength, toughness, and load to fracture were observed. They concluded that the endodontically treated teeth are not more brittle and they emphasized the importance of conserving the bulk of dentin to maintain the structural integrity of the endodontically treated teeth.

Moreover, **Papa et al.** [21] compared the moisture content of twenty three matched pairs of endodontically treated human teeth and the contralateral sound teeth. Immediately upon extraction, the teeth were tightly wrapped in aluminum foil and placed into a sealed plastic tube to minimize moisture loss. Three specimens of coronal third of root dentin of each tooth was taken and distributed into three microfuge tubes. Specimens were then weighed on analytical balance and placed in 105 C oven. After cooling, specimens re-weighted again at room temperature. The difference between these two readings would be the amount of the lost moisture. The results revealed that there was no significant difference in the moisture content between the endodontically treated teeth and sound teeth.

Several studies [22 - 25] have also emphasized that the strength of a tooth is directly related to the amount of remaining tooth structure and its loss is the key reason for the increase in fracture predilection of the endodontically treated teeth .

2.2 Prevalence and predisposing factors of fracture of the endodontically treated teeth:

Regarding prevalence of fracture of EET, **Zadik et al**. [26] observed 547 human permanent endodontically treated teeth that were extracted in a multidisciplinary clinic in the period between 2006 and 2007. The reasons for extraction were non-restorable caries (61.4%), endodontic failure (12.1%), vertical root fracture (8.8%), iatrogenic perforation (8.8%), periodontal disease (4.6%), un-restorable cusp fracture (2.4%) and dental trauma (0.5%). They found that the endodontically treated teeth were prone to extraction mainly due to non-restorable carious destruction and to a lesser extent to endodontic related reasons such as endodontic failure, vertical root fracture or iatrogenic perforation.

Several predisposing factors may contribute in incidence of crown/root fracture such as loss of tooth structure, age changes in dentin nature, endodontic irrigants and medicaments, bacteria-dentin interaction, in addition to post and core restoration.

2.2.1 Effect of loss of tooth structure by Traditional access cavity preparation:

The outline form of traditional access cavity preparation dictates further occlusal preparation beyond gaining access to canal orifices to provide maximum accessibly and visibility, and also to facilitate subsequent root canals cleaning and shaping. These principles compromises the mechanical integrity of the endodontically treated teeth provided by the roof of the pulp chamber that allows greater flexure of the tooth during function [(27)].

Larson T. & Douglas W. [(28)] compared effects of the occlusal cavities as well as MOD cavities on the strength of teeth. Sixty human premolar sound teeth were collected and divided according to cavity preparation into 5 group; G1: MOD preparations with extended occlusal cavity preparation, G2: MOD preparations with narrow occlusal cavity preparation, G3: extended occlusal cavity preparations, G4: narrow occlusal cavity preparation and G5: teeth without cavity preparation as controls. Teeth were subjected to a compressive load in universal testing machine until fracture occurred. The result showed that even with conservative preparation with narrow occlusal cavity preparation weakened the tooth by 40% and with extended occlusal cavity preparation weakened the tooth by 60% compared to controls. They concluded that increasing the width of the cavity preparation weaken the tooth significantly.

Reeh E. & Messer H. [(29)] compared the effect of endodontic procedures on strength of the tooth structure. Forty two extracted, non-carious, human, maxillary second permanent premolars were used in the study. Teeth were embedded in nylon rings filled with an acrylic resin to a level of 2 mm below CEJ. The teeth were subjected to an occlusal loading at 37 N per s for 3 s and unloaded at the same rate in loop servo-hydraulic testing machine to measure stiffness. After that, the teeth were divided randomly into two groups according to performed procedures; G1: access preparation was done followed by root canal instrumentation, obturation, and MOD cavity preparation. G2: MOD cavity preparation followed by endodontic access cavity, root canal instrumentation, and obturation. Teeth were loaded and unloaded five times after each step of preparation. The results showed that endodontic procedures have reduced stiffness by 5% followed by access cavity preparation (20%). The largest loss in stiffness were related to the loss of marginal ridge which resulted in an average of a 63%. They concluded that endodontic procedures do not weaken teeth by itself and the loss of marginal ridge integrity was the greatest contribution to loss of tooth strength.

Panitvisai & Messer [30] compared cuspal deflection in molars as result of endodontic and restorative procedures. Overall thirteen non-carious human mandibular permanent molars were collected immediately after extraction. Teeth were placed in a nylon rings filled with dental stone to a level of 2 mm below CEJ. Teeth were subjected to an occlusal loading at 20 N/s for 5 s and unload at the same rate using a closed loop servo-hydraulic testing machine. Teeth were divided into two groups according to cavity preparations; G1: MO cavity preparations followed by endodontic access cavities. G2: MOD cavity preparations followed by endodontic access cavities. Teeth were subjected to occlusal loading four times at each step and cuspal deflection was recorded by linear measuring devices. The result showed the endodontic access in the MOD group weakened the tooth significantly more than in the MO group. They concluded that cuspal deflection in molars increases with increasing cavity size following endodontic access.

Ibrahim et al. [31] evaluated the effect of remaining tooth structure on the fracture resistance of the endodontically treated teeth. Fifty five freshly extracted sound maxillary premolars were collected. Endodontic treatment was performed for the teeth, followed by coronal preparation with 1 mm deep chamfer finish line at 1 mm above the CEJ. Then, teeth were assigned into 11 groups according to the number and the location of missing axial walls; G1: occlusal (O), G2: MO, G3: MOD, G4: occluso-buccal (OB), G5: occluso-palatal (OP), G6: OBP, G7: MOB, G8: MOP, G9: MODP, G10: MODB and G11: MOBP groups. The teeth were restored with bonded composite and casted crowns were fabricated and cemented with self-adhesive resin cement. Teeth were subjected to 500 cycles for 20 seconds and unloaded for 3 s. Then, the teeth were subjected to a compressive load with a maximum load 2000 N within a universal testing machine until fracture occurred. The result showed that teeth occlusal preparation had the highest mean fracture strength among groups, furthermore, mesio-occluso-palatal (MOP) and mesio-occluso-disto-palatal (MODP) groups showed the lowest mean failure loads. They concluded there was a positive correlation between amount and location of remaining dentin surface area and the fracture strength.

Finally, there is agreement that the strength of a tooth decreases in proportion to the amount of tooth tissue removed.

2.2.2 Effect of age changes in dentin:

The main age related changes in older teeth includes a gradual enlargement of the peritubular dentin and intratubular mineral deposits, which result in narrowed or completely occluded dentinal tubules **(32)**. Also, dentin sclerosis increases in teeth that have been subjected to attrition, caries or dental restorative procedures. Moreover, alterations in the organic fractions of dentin such as acid mucopolysaccharides, which are more predominant in mature teeth, may be found in certain instances with increased mineralization **(21)**.

Mireku et al. **(33)** published a study to determine whether patient age contributed to the fracture resistance of the endodontically treated teeth and post placement. Forty five single rooted human teeth were divided into two groups according to age ranges; G1: Young patients group (between 18 and 35 years) and G2: Old patients group (60 years ≤ age). Root canal instrumentations and obturation were done followed by posts placement. After that, teeth were subjected to a cyclic loading at 2000 cycles. Teeth that did not fracture were subjected to static occlusal loading in universal testing machine until fracture occurred. The results showed that the susceptibility to dentin fracture increases significantly with increasing patient age. They concluded that fracture of the endodontically treated teeth is more likely to occur in the teeth of older patients.

Fernando de Noronha et al. **(34)** compared the compressive strength of young and elderly premolars. Thirty human maxillary premolars were extracted from patient between 18 and 60 years. Teeth were divided according to age ranges and number of roots into four groups as follows: G1: teeth of elderly patients with fused roots, G2: teeth of elderly patients with separated roots. G3: teeth of young patients with fused roots and G4: teeth of young patients with separated roots. Each teeth was subjected to compressive loading in a universal testing machine until fracture occurred. The result showed that there was a significant difference between groups and concluded that teeth of the elderly were more susceptible to fracture when compared to young.

2.2.3 Effect of endodontic irrigants and medicament:

Sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA) are common endodontic irrigants. However, their prolonged use at high concentrations has adverse effects on the physical properties of root canal dentin, such as significantly reduced flexural strength, elastic modulus, and micro-hardness, which might increase the risk for root fractures.

Grigoratos et al. [35] compared the effect of NaOCl solutions at 3%, 5% on the flexural strength of dentin. Dentin bars were prepared and exposed to the following solutions; G1: NaOCl 3% for 2 Hours, G2: NaOCl 5% for 2 H and G3: normal saline (control group). After that, dentin bars were subjected to a compressive load in the universal testing machine until fracture occurred. The data revealed a significant decrease in the flexural strength of dentin bars that treated with 3% and 5% NaOCl compared with control group.

Sayin et al. [36] compared the effect of single and combined use of (EDTA) and NaOCl on the microhardness of root canal dentin. Thirty single rooted human teeth were used in the study. Microhardness values of specimens were recorded as a reference using a Vicker's microhardness tester at the apical, mid-root, and cervical levels of root canal. The specimens were randomly distributed and immersed for 5 minutes in a magnetic stirrer bath contained 10 ml of the following test solution: G1: 2.5% NaOCl, G2: 17% EDTA, G3: 17% EDTA, followed by NaOCl for 5 mints, and 10 ml distilled water as final flush, and G4:

distilled water as controls. After that, microhardness values were obtained as with the previous technique. The result reveled that all treatment regimens significantly decreased the microhardness of the root canal dentin. However, the use of EDTA alone or prior to NaOCl resulted in the maximum decrease in dentin microhardness.

Ghisi et al. [(37)] compared the effect of super oxidized Water, NaOCl and EDTA on dentin microhardness. Eighty bovine incisors were used in study. Access cavity preparation was done followed by root canal instrumentation to a file 80 #. Then, teeth were divided into eight group according to the used irrigant solution during root canal instrumentation (30 min per specimen); G1: 5% NaOCl, G2: Sterilox 400 ppm, G3: 17% EDTA, G4: 5% NaOCl followed by 17% EDTA, G5: Sterilox 400 ppm followed by 17% EDTA and G6: distilled water as a negative control. Microhardness of root dentin were measured in Vickers hardness units. The result of showed that no significant difference was detected among groups. Moreover, EDTA showed the lowest microhardness values. They concluded that EDTA promoted lower microhardness values.

2.2.4 Effect of bacteria-dentin interaction:

Microbe induced degradation of collagen resulted in deterioration of the mechanical properties such as strength toughness of dentin. Bacteria induced collagenolytic activity can break chemical bonds and aid in crack propagation through the dentin substrate.

Ferrari et al. [(38)] observed the collagen degradation in the endodontically treated teeth after clinical function. Forty two previously endodontically treated single rooted teeth from 5 - 12 years ago, and restored using intra-radicular posts and composite restorations. Teeth were divided according to their clinical years into five groups; G1: five teeth endodontically treated 12 years before, G2: 7 teeth endodontically treated 10 years before, G3: 14 teeth endodontically treated 8 years before, G4: 13 teeth endodontically treated 5 years before, and G5: 3 teeth endodontically treated 2 years before. The roots were processed for scanning electron microscopic (SEM) examination. The results revealed a progressive degradation of the demineralized collagen matrices (DCMs) related to G1 and G2. They suggested that bacterial colonization and the release of the bacterial enzymes may contribute to the degradation of the collagen fibrils in the root dentin after clinical function.

2.2.5 Effect of post and core restoration:

Loss of considerable amount of tooth structure makes retention of subsequent restorations more problematic and increases the fracture during functional loading. Different clinical techniques have been proposed to solve these problems, and one such technique is the post and core. [39]

Prefabricated metal posts are widely used as a restorative option [6]. These posts are typically made of stainless steel, nickel chromium alloy or titanium alloy. They are very rigid and very stiff that resisted lateral forces without distortion and this resulted in stress transfer to the less rigid dentin causing potential root cracking and fracture [40].

Duret et al. [41] described a non-metallic material for the fabrication of posts based on the carbon fiber reinforcement principle. Their main proposed advantage that they were more flexible than metal posts and had approximately the same modulus of elasticity (stiffness) as dentin. Moreover, when bonded in place with resin cement, it was thought that forces would be distributed more evenly in the root, resulting in fewer root fractures. Because of black color of the carbon fiber posts, it do not lend themselves to aesthetic restorations with all-ceramic units. This led to the introduction of the silica-fiber posts also called glass-fiber or quartz-fiber posts which are translucent and more tooth colored.

Omiri M. & Wahadni A. [42] investigated the fracture resistance and fracture patterns of the endodontically treated teeth restored with composite cores supported by different prefabricated post systems and different heights of remaining coronal dentin. The result reveled that teeth with retained dentin were more resistant to fracture. Moreover, teeth that restored with titanium posts were associated with higher fracture resistance than those restored with carbon fiber posts or glass fiber posts.

In an article published by **Lili Zhou et al.** [43] compared the fracture resistance of the endodontically treated teeth restored with cast posts versus fiber posts by means of Meta-Analysis. The result of thirteen studies indicated that cast post groups were significantly had higher fracture resistance than fiber post groups. Therefore, they suggested that the fiber posts can be used when ample coronal dentin remains and the crown is well supported by remaining tooth structure, otherwise, cast posts may be used when there is moderate to severe loss of the tooth structure.

Adversely, several studies have affirmed that intraradicular post and core do not reinforce remaining tooth structure and it can even weaken the tooth due to the necessity for preparation and additional dentin removal for its placement, leading to higher root fracture susceptibility [44 - 47]

One of the interesting article published by **karzoum et al.** [12] described more conservative approach for restoring the endodontically treated teeth using a horizontal glass fiber post. Sixty recently extracted upper premolars were used. Access cavity preparations were performed as small as possible, followed by root canal instrumentation and obturation using gutta-percha and resin sealer. After that, the teeth were embedded into molds filled with an acrylic resin to a level 2 mm below CEJ. MOD cavity preparations were done using a custom made parallelometer for all teeth except control teeth. Teeth were assigned into 5 groups as follows, G1: intact teeth as controls, G2: MOD preparation without restoration, G3: MOD preparation restored with bonded composite restoration, G4: MOD preparation restored with a horizontal placed glass fiber post cemented within holes created in both buccal and palatal walls and filled with bonded composite restoration and G5: MOD preparation restored with horizontal glass fiber post without restoration. All specimens were subjected to compressive loads within a universal testing machine until fracture occurred. The results revealed that no significant difference between G4 and the controls, while there were a significant difference between G4 and other groups. They concluded that usage of horizontal glass fiber post increase significantly the fracture resistance of the endodontically treated teeth.

In addition, **Bromberg C et al.** [48] described a restorative alternative by using horizontally transfixed glass fiber posts to restore the endodontically treated teeth. Fifty extracted human third molars were used in study, then MOD cavity preparation was done followed by access cavity preparation, root canal instrumentation and obturation. Teeth were randomly divided into 5 groups according to treatment options as follows; G1: Control group, G2: onlay, G3: inlay, G4: composite restoration and G5: horizontally transfixed fiber post groups. In G2 and G3, the prepared cavities were scanned using a CAD/CAM and molded to a restoration. In G4, the prepared cavities were etched and bonded then filled with an increments of composite restoration. In G5, the buccal and lingual walls were prepared to support fiber posts by drilling 2 holes in each wall using rounded bur under coolant. The posts were fitted into the holes and cemented with flowable composite then the rest of the cavity were restored with bonded composite. Teeth were submitted to fatigue cycling with a vertical load of 200 N applied to the occlusal surface. Then, a static compressive load parallel to the long axis of the tooth were applied in universal testing machine until fracture occurred. The result revealed that onlay group had the highest percentage of fracture strength compared with the control group, followed by the horizontally transfixed fiber post group and then followed by inlay group. They concluded that the endodontically treated teeth have higher fracture resistance values when restored with horizontally transfixed glass fiber posts and composite restoration.

2.3 advanced tooth reinforcement using different access cavity designs:

Unfortunately, traditional access cavity preparation as discussed before may come on the expense of crucial structural of dentin, which may compromise the biomechanical integrity of tooth [(49)]. With the aids of preoperative 3D radiographic analysis (CBCT) [(50, 51)] in conjunction with magnification [(52, 53)], clinicians are able to achieve smaller and more conservative access cavities with precision especially with advancement of super elastic NiTi instruments, specially designed ultrasonic tips for orifices scouting, advanced irrigating techniques, in addition to canal warmed gutta percha techniques [(54 - 56)].

In 2010**, Clark & Khademi** [(57)] described modern conservative access cavity in molars that was designed to minimize tooth structure removal and to improve the fracture resistance of the endodontically treated teeth. Their access cavity design shifted away from coronally divergent walls, complete de-roofing in addition to straight-line access towards preservation of both pulp chamber roof and pericervical dentin (soffit).

Four years later, **Krishan et al.** (58) studied the impact of conservative endodontic access cavity on fracture resistance of the endodontically treated teeth. Ninety extracted human sound teeth (Maxillary central incisors, mandibular second premolars and mandibular first molars) were used in the study. CBCT scan were done for all teeth followed by grouping according to access cavity design into three groups; G1: Traditional cavity design group, G2: Conservative cavity design group and G3: Control group (unprepared sound teeth). In G1, Traditional access cavity preparations were done following the guidelines of conventional outline form. In G2, Conservative access cavity preparations were done following conservative outline based on the preoperative CBCT imaging. Specimens were subjected to a continuous compressive force in universal testing machine until fracture occurred. The results showed that the mean load for fracture of teeth with Conservative cavity design group was significantly higher than those in Traditional cavity design group, in addition, there were non-significant difference between both conservative cavity design group and control groups. In conclusion, conservative cavity design group afforded conservation of remaining coronal dentin and increased resistance to fracture in molars and premolars.

Adversely, **Moore et al.** (59) assessed the impact of conservative access cavity preparation on the biomechanical responses of the endodontically treated teeth. Fifty nine extracted human non-caries maxillary molars were used in the study. Preoperative CBCT analysis were done for all teeth, followed by grouping according to access cavity design into 3 groups; G1: Traditional cavity design group, G2: Conservative cavity design group and G3: control group (unprepared sound teeth). In G1, Traditional access cavity preparations were done following the guidelines of conventional outline form. In G2, Conservative access cavity preparations were extended only as necessary to access canal orifices while preserving pericervical dentin. Teeth were restored with bonded composite restoration and mounted within universal testing machine followed by subjecting to a continuous compressive force until fracture occurred The results showed that no significant difference between Traditional cavity design group and conservative cavity design group. They concluded that conservative cavity design group in maxillary molar did not appear to impact biomechanical responses.

Concomitantly, **Yuan et al.** **[60]** compared the effect of conservative and traditional access cavity design on the biomechanical properties of the endodontically treated teeth. Six 3D models were constructed based on preoperative CBCT scan for Intact, extracted, non-carious mandibular first molar. Models were divided according to access cavity designs into two groups; G1: Traditional cavity design group and G2: Conservative cavity design group. In G1, Traditional access cavity preparations were done following the guidelines of conventional outline form. In G2, Conservative access cavity preparations were done following four lines that projected from the coronal third of 3D models and extended to the canal orifices to outline the conservative access cavity. The dimensions of the two types of access cavities were measured. With the aid of digital sensor for bite force registrations **[61]**, models were subjected to two different tooth loading patterns were applied to simulate the vertical and lateral masticatory forces. The results showed that the amount of tooth structure that removed during preparation in conservative cavity design group were very little compared to the amount that removed in traditional cavity group. They concluded that conservative cavity design group reduced the stress distribution in crown and cervical regions.

In 2017 **Plotino et al.** **[62]** compared the fracture strength of the endodontically treated teeth with traditional, conservative or ultraconservative "**Ninja**" endodontic access cavity preparations. Forty maxillary first molars and forty mandibular first molars were used in the study. Teeth were assigned into 4 groups according to endodontic access cavity designs; G1: control group (unprepared sound teeth), G2: Traditional cavity design group, G3: conservative cavity design group and G4: ultraconservative cavity design group. The teeth in G2, G3 and G4 were imaged with the aid of preoperative CBCT scan to plan traditional, conservative and ultraconservative "Ninja" access cavity outlines. Then, endodontic access cavity preparations were performed based on these outlines followed by another CBCT scan to calculate the volume of coronal enamel and dentin that removed by preparation. After that, root canal preparation and obturation were done followed by composite restorations. Teeth were mounted in a universal testing machine and subjected to continuous compressive force until fracture occurred. The result showed that mean load at fracture for Traditional cavity design group was significantly lower than for the conservative, ultraconservative cavity design group and control groups, with no significant difference among conservative, ultraconservative cavity design group and control groups. They concluded that Ultraconservative "ninja" endodontic cavity access did not increase the fracture strength of teeth compared with the ones prepared with conservative cavity design preparation.

2.4 Methods of evaluation of coronal fracture:

Various technique modes are used in testing fracture resistance of the endodontically treated teeth. The most widely used type is the linear compressive (static) loading in a common universal material testing machine until fracture occurred. Static loading is a frequently applied method that simulates clinical load conditions in a very simplistic way, in addition to its efficiency and not time consuming for testing [(63)].

Alternatively, different types of dynamic loading have been described with different cycle counts with or without thermocycling and with or without additional static loading until fracture occurs. The most popular dynamic load test is the chewing simulation introduced by **Krejci et al.** [(64)] as the computer controlled mastication simulation which simulate the wear mechanisms and temperature changes that can occur in the mouth by 240,000 load cycles of 50 N combined with 600 thermocycles. The results indicated that the machine fulfilled the parameters concerning chewing motion. Furthermore it was shown that chewing simulator able to evaluate dental restorative systems under clinically relevant conditions.

Furthermore, **Naumann et al.** [(63)] introduced a modified dynamic testing mode with gradual load. They examines whether this could be an alternative to static loading or chewing simulation methods. The results reveled that maximum load capacities obtained from gradual dynamic loading did not differ significantly from that of linear compressive loading or of chewing simulation. In contrast, static loading resulted in significantly different load capacities.

Aim of the study

The aim of the study was to evaluate the fracture resistance of endodontically treated mandibular molars with MOD cavities using different treatment modalities, including Traditional access, Nature truss access cavity preparations in addition to Artificial truss restoration. Also, the patterns of fractures were evaluated for all treatment modalities.

Materials and Methods

4.1 Selection of the teeth.

4.2 Preparation of the specimens.

4.3 MOD cavity preparations for the specimens.

4.4 Grouping of the specimens.

4.5 Root canal treatment of the specimens.

4.4.1 Access cavity preparations phase.

4.4.2 Root canals cleaning and shaping phase.

4.4.3 Obturation phase.

4.6 Restoration of the specimens.

4.7 Loading of the specimens.

4.8 Statistical analysis for the data.

Material and Methods

4.1 Selection of the teeth:

Sixty six recently extracted mandibular first molar teeth were collected from the outpatient clinic of the National institute of Diabetes and Endocrinology. Extractions were due to medical reasons on patient age range between 20 and 45 years old to be used in this study. The selected teeth were cleaned of calculus and soft tissue remnants using a hand curette. A dental operating microscope DOM [*] (8x) were used to examine the selected teeth. The teeth that had caries, deep cracks, attritions, fractures or restorations would be excluded from the study. Measuring the Buccolingual and mesiodistal dimensions were done at the level of cervical margin using a digital caliper[†]. The teeth that had bucco-lingual and mesio-distal widths of 10.73 mm. (± 0.44 mm.) and 10.91 mm (± 0.44 mm.), respectively were include in the study. After that, all teeth were stored in normal saline solution at room temperature until the time of use in the study.

4.2 Preparation of the specimens:

Four circular plastic molds were constructed (9cm in diameter and 1.5 cm in thickness) containing 12 hexagon shape holes (1.4 cm width and length) as a modification of **Alkhawas M.** 2011[(65)] **(figure 1)**. The sides of the mold were marked according to the root surfaces as buccal, lingual, mesial, distal, cervical and apical sides. On the cervical side of the mold, 3 vertical & 4 horizontal grooves that intersected in the center of the previously mentioned holes were done for standardized positioning of the teeth within each hole. Furthermore, a box shape

---

[*] DOM S2350, Zumax Medical Co., Ltd
[†] AIDOUT Digital Caliper

cavity was made on the mesiobuccal corner of the mold and was filled with amalgam for easy identification of the surfaces on the exposed cone-beam computed tomography (CBCT). Then, the mold was placed on a square glass slab (10x10 cm.) and separating medium was brushed inside of each hole. Then, a chemically cured acrylic resin* was mixed and poured into the holes of the mold. After that, the teeth were embedded in the soft acrylic resin to a level 2 mm below the cementoenamel junction (CEJ). The teeth were orientated to the corresponding surfaces on the mold. Care was taken to align the teeth to the intersecting lines previously mentioned. So that, the lines divided the tooth into two equal half buccolingualy and mesiodistally (Teeth blocks).

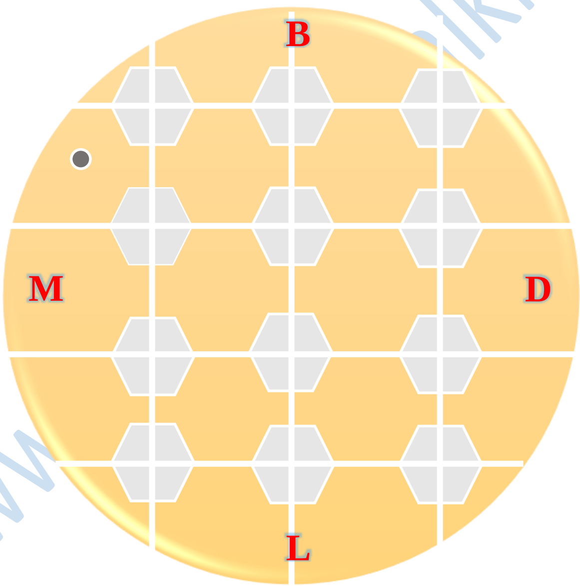


Figure (1): A diagram showing the circular plastic mold.

A CBCT † scan was made of the mold with the embedded teeth. The teeth were evaluated to exclude the aberrant root canal morphology i.e. extra roots, calcified canals and internal resorption. Also measurements of the average mesiodistal dimensions of the pulp chamber and the average distance between the occlusal surface (central

*ACROSTONE, Chemically Cured Acrylic Resin.
† PLANMECA PROMAX ® 3d, Voxel Size 75µm with 90 Kv, 12 mA

fissure) and the roof of the pulp chamber were done. The teeth that had mesiodistal dimensions of the pulp chamber between (3.74 - 4.44 mm.) only were included in this study. Also the teeth that had an average occlusal distance 4.19 mm. (± 0.17) were included **(Figure 2 & 3).** (Refer to the exclusion table (**Table 4, page no. 52**)

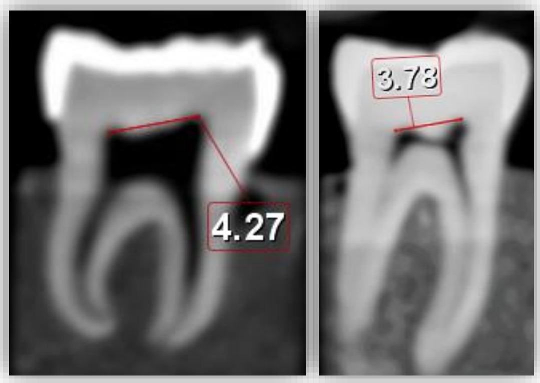


Fig. (2): A CBCT (coronal view) showing mesiodistal measurement of the pulp chamber.

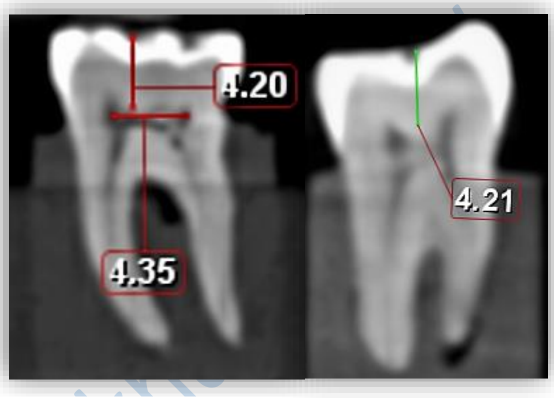


Fig. (3): A CBCT (coronal view) showing the occlusal distance to the roof of pulp chamber .

4.3 MOD cavity preparations for the specimens.

Standard MOD cavity preparations were performed in all specimens using cylindrical carbide burs[*] (4.0 mm in length and 2.5 mm. in diameter) attached to a high speed handpiece (HP)[†] mounted in a custom-made parallelometer device to ensure standard MOD cavities for` all teeth. **(Fig. 4 & 5)**

4.3.1 Parallelometer device description:

The parallelometer device was comprised of a stainless steel base (20 cm. x 17 cm x 1.5 cm – length x width x height) with two metal projections (2.5 cm. x 2 cm. x 1 cm. – length x width x height) having two holes in the center fixed to the stainless steel base by screws and placed opposite to each other 3.5 cm from the short side of the base to which was attached two main parts, A Vice - Table Unit and a Vertical Metal Rod.

[*] **ELA Carbide Ce0197**
[†] **NSK TI-MAX X, High Torque, Push Bottom, Kanuma, Japan**

A. The vice - Table Unit was comprised of a stainless steel vice firmly attached to a stainless steel table. The vice was comprised of two jaws, one fixed and the other mobile with a surveyor table attached to the mobile one. Furthermore, the two jaws were connected together with a vice screw handle, by turning the vice screw handle, the jaws tightened to keep the tooth block fixed in its place. The stainless steel table was formed of one horizontal part (7cm x 7cm. x 1 cm. – length x width x height) and two vertical legs (2.5cm. x 7cm. x 1cm. – length x width x height). All parts of the table were fixed together with screws and the vice was attached firmly in the center of the horizontal part. Furthermore, the vertical legs had two holes in the center opposite to each other. The vice – Table unit was attached passively to the stainless steel base by mean of a horizontal connecting screw passing through the two previously mentioned holes in the two vertical legs of the stainless steel table and through the two holes in the metal projections to allow lateral motion of the vice – table unit in a single plane.

B. A vertical metal rod with an attached micrometer was attached to the stainless steel base and placed at a distance 10 cm. from the short side of the base and also at 10 cm from the long side of the base. A horizontal rigid attachment was fixed to the vertical metal rod via a fixation screw to control the vertical movement. The horizontal rigid attachment was comprised of two holes, one vertical for the vertical metal rod as previously mentioned and the other one horizontal for the HandPiece Attachment Apparatus. The HandPiece Attachment Apparatus was comprised of a hole for the handpiece placement and of a plastic rotating arm to fix the handpiece in a constant position. The Hand Piece was attached to the HP attachment apparatus and adjusted to be 90º perpendicular on the vertical rod (lateral view) and parallel to the vertical rod (frontal view) and fixed in its position by the plastic rotating arm. Then, the HP was connected to the air water module of the dental unit.

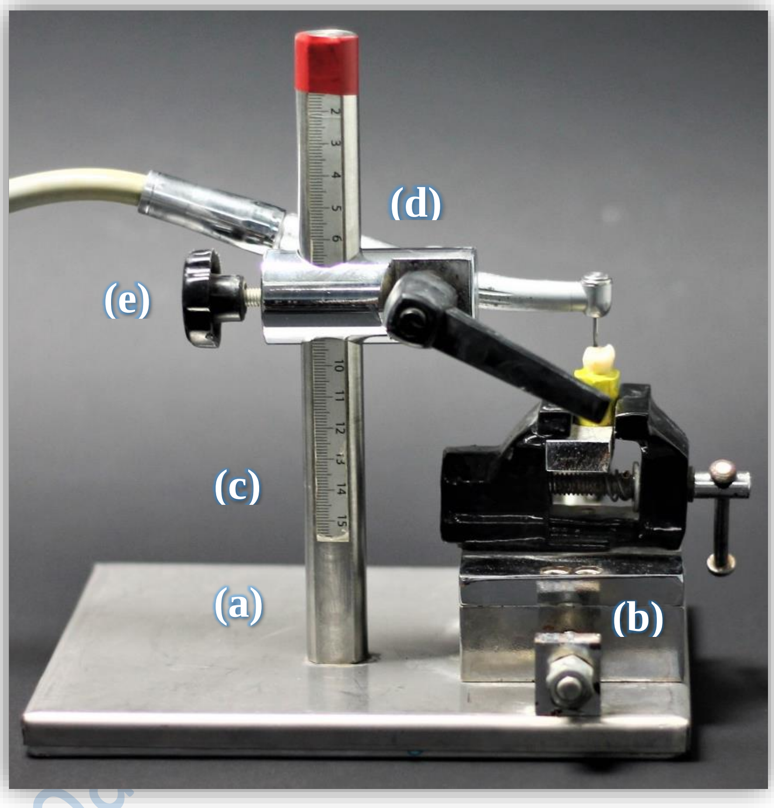


Figure (4): A photograph (lateral view) showing the parallelometer device including,

- **(a) Stainless steel base.**
- **(b) Vice table unite.**
- **(c) Vertical metal rod.**
- **(d) Horizontal rigid attachment.**
- **(e) Fixation screw.**

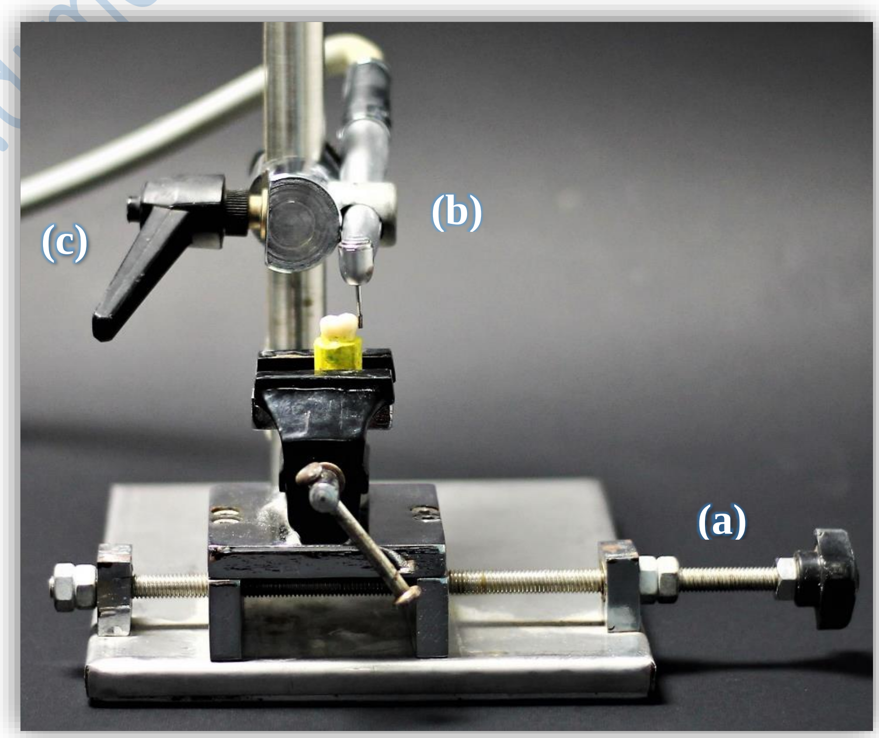


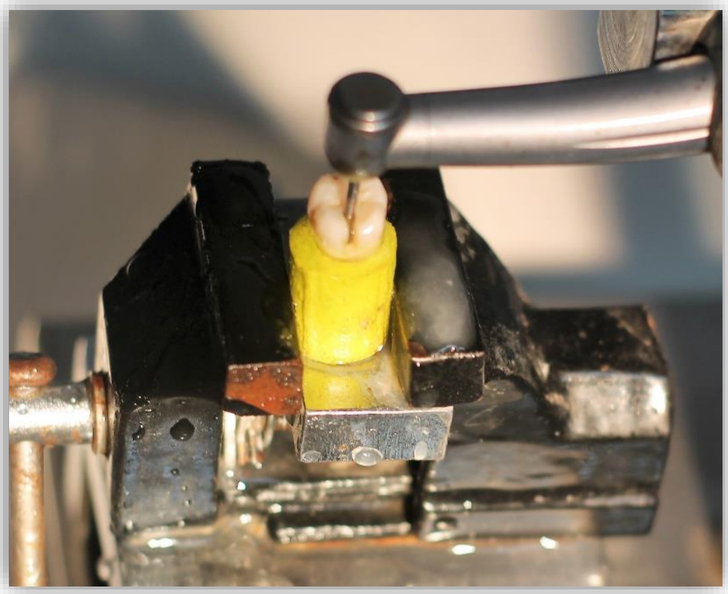
Figure (5): A photograph (frontal view) showing the custom made parallelometer device including,

- **(a) Horizontal connecting screw.**
- **(b) Handpiece attachement apparatus.**
- **(c) Plastic rotating arm.**

4.3.2 MOD Cavity Preparation Technique:

All teeth blocks were placed on the surveyor table of the Vice - Table Unit and fixed in place by tightening of the vice screw handle (the buccal surfaces of the teeth were oriented toward the vertical rod). Prior to preparation, the handpiece with a placed cylindrical bur was calibrated by adjusting the cylindrical bur to be parallel to the vertical rod, so that the tip of the bur was placed at the central groove of the occlusal surface of the teeth.

The cylindrical bur was placed on the mesial surface of the tooth at a distance 4.0 mm. below the lowest point of marginal ridge. Then, the hand piece was activated and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface for a distance of 2 mm. to create the mesial proximal box (2.5 mm. in width × 2.0 mm. in depth × 4.0 mm. height). After that, the hand piece was stopped and the cylindrical bur was placed on the distal surface of the tooth at distance 4.0 mm. below the lowest point of the marginal ridge. Then, the hand piece was activated and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface also for a distance of 2 mm. to create the distal proximal box (2.5 mm. in width × 2.0 mm. in depth × 4.0 mm. height). Moreover, the hand piece was stopped and the cylindrical bur was placed on the mesial surface of the distal proximal box to be 2 mm. below the central groove of the occlusal surface. Then, the hand piece was activated again and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface to create complete MOD cavity. The burs were replaced after each 6 preparation to ensure the cutting efficiency. **(Fig 6 & 7)**



Figures (6, 7); photographs showing MOD cavity preparation technique.

4.4 Grouping of the specimens:

The prepared teeth were grouped into 4 groups of 12 teeth according to the access cavity design,

- **T**raditional **A**ccess **C**avity (**TAC Group)**: MOD cavity preparation with traditional access cavity preparation.
- **A**rtificial **T**russ **R**estoration **(ATR Group)**: MOD cavity preparation with traditional access cavity preparation and restored with horizontally placed glass fiber post.
- **N**atural **T**russ **A**ccess cavity (**NTA Group)**: MOD cavity preparation with conservative access cavity preparation.
- **C**ontrol group **(C Group)**: MOD cavity preparation without access cavity preparation.

Unlike the control group, additional preparation in MOD cavities were done as follows

- In the **TAC & ATR Groups**; the cylindrical bur was placed on the distal surface of the mesial proximal boxes of the teeth at a distance 4.0 mm. from the central fissure of the occlusal surface. Then, the hand piece was activated and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface to complete the MOD cavity (2.5 mm. in width × 4 mm. in length).
- In **NTA Groups**; the cylindrical bur was placed on the distal surface of the mesial proximal boxes of the teeth at a distance of 4.0 mm from the central fissure of the occlusal surface. Then, the hand piece was activated and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface for a distance of 2 mm to create the mesial proximal box (2.5 mm. in width × 4.0 mm. in depth × 4.0 mm. in length). After that, the hand piece was stopped and the cylindrical bur was placed on the mesial surface of the distal proximal boxes of the teeth at a distance of 4.0 mm. from the central fissure of the occlusal surface. Then, the hand piece was activated and by rotation of the horizontal connecting screw, the vice was moved in a horizontal direction and the bur was left to cut the tooth surface also for a distance of 2 mm. to create the distal proximal box (2.5 mm. in width × 4.0 mm. in depth × 4.0 mm. in length). The remaining tooth structure between the mesial and distal proximal boxes was measured using a stainless steel crown gauge caliper to ensure that the remaining thickness of dentin is 2 mm. If it was not, further preparation was done to adjust it to be 2 mm in width.

4.5 Root canal treatment of the specimens:

4.5.1 Access cavity refinement phase.

During the MOD cavity preparation for the teeth in the TAC, ATR and NTA groups, access to the pulp chamber was achieved by default. The teeth blocks were removed from the parallelometer device and the access cavities for each group were done as follows according to the type of treatment modality.

- **In the TAC & ATR Groups;**

  Access cavity refinement was done by complete de-roofing of the pulp chamber with exposure of all pulp horns and straight-line access into the canals **(Fig. 8)**.

Fig. (8): A photograph (occlusal view) showing traditional access preparation.

- **In the NTA Groups;**

  Access cavity refinement was done by smoothening of pulp chamber walls to facilitate instrumentation for the mesial and distal canals and by leaving the intervening dentin intact **(Fig. 9).**

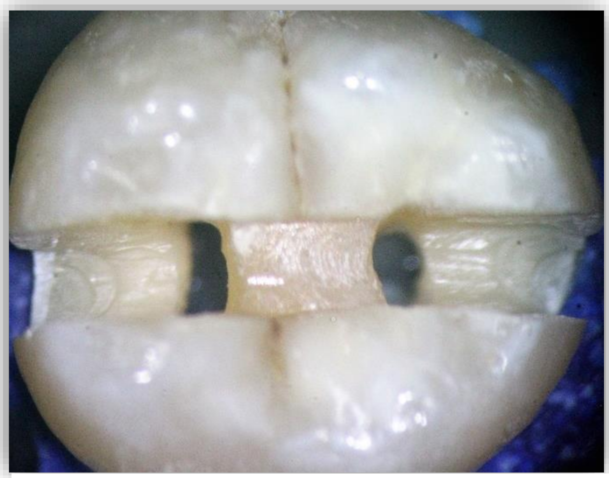


Fig. (9): A photograph (occlusal view) showing Truss access cavity preparation.

All access refinements were done using Tungsten Carbide Endo-Z Bur * for complete de-roofing and finishing of the walls.

* **Dentsply, Endo-Z Carbide Bur (E0152)**

4.5.2 Root canals cleaning and shaping phase.

Canal negotiation and patency was done using a size #10 and #15 K file[*]**.** The working length was estimated from CBCT and confirmed by placing of a size #15 K file to reach that length and exposing radiographs[†]. Mechanical preparation was performed using the Protaper rotary system[‡] according to the manufacturer's instruction. The preparation was finished at a size corresponding to F2 or F3 file according to the initial canal size. Canals were intermittently irrigated throughout instrumentation with 3 ml of sodium hypochlorite solution 5.25% NaOCl[§] between each file using a side vented 30 gauge needle[**].

4.5.3 Obturation phase.

A size #25 and #30 of 0.2 tapered master cones[††] was fitted into the canals according to the size of the master apical file. The length of the master cone was confirmed by exposing radiographs. Then, the canals were dried using paper points size #25 or 30[‡‡]. A resin-based root canal sealer[§§] was mixed. The mixture was applied into the root canals using a size #25 lentulo spiral[***]. The canals were obturated with gutta percha points according to the size of the master apical file using the lateral compaction technique. A size #25 finger spreader[†††] was used and the accessory gutta-percha points size #20 of .02 taper[‡‡‡]. Excess gutta percha was removed from the pulp chamber using a hot instrument. The access cavities were cleaned of

---

[*] Mani Inc.,Tochigi, Japan.
[†] Carestream Kodak RVG System. 14 lp/mm, 1200 x 1600 pixels.
[‡] Dentsply Maillefer, Switzerland.
[§] Clorox, Clorox Inc.
[**]Dentsply Tulsa Dental Specialties, Tulsa, Ok.
[††] Dentsply Maillefer, Ballaigues, Vd, Switzerland
[‡‡] Dentsply Maillefer, Ballaigues, Vd, Switzerland
[§§]Adseal Meta, Biomed, Cheongju, South Korea
[***] Dentsply Maillefer, Lentulo spiral filler #1 (red) 25mm
[†††]Mani Inc.,Tochigi, Japan.25mm.
[‡‡‡]Dentsply Maillefer

remnants of gutta percha using handle excavators and cleaned of sealer using a wet cotton pellet. The filled teeth were stored in 100% humidity at 37_C for one day to allow complete seating of the sealer. **Fig (10 &11)**

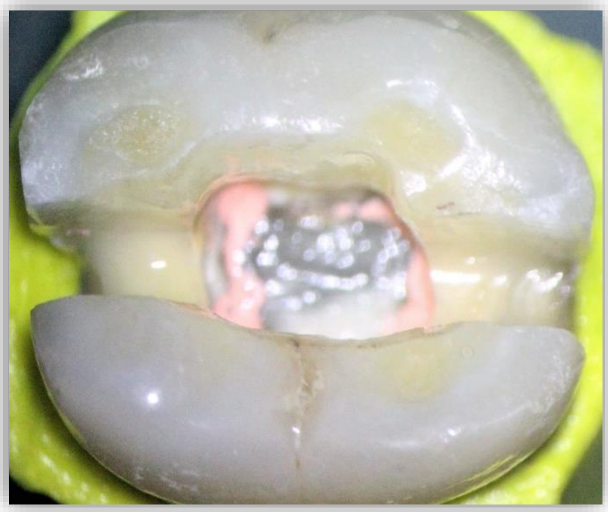


Fig. (10): A photograph (occlusal view) showing Traditional access cavity in obturation phase

Fig. (11): A photograph (occlusal view) showing Truss access cavity in the obturation phase

4.6 Restoration of the specimens.

4.6.1 Restoration of the specimens in the TAC Group:

Prior to restoration of the specimens, the specimens were dried using an air/water syringe. Then, a tofflemire matrix* band #8 (universal) and a tofflemire retainer† were placed around the teeth and adapted by tightening of the tofflemire screw. The enamel surface was etched with 37% phosphoric acid ‡ for 15 s. After that, the etched surfaces were rinsed for 20 sec. and dried using an air/water syringe. A bonding agent § was applied to the prepared surfaces with a micro-brush ** in compliance with the manufacturer's

*** J – Band ® Tofflemire Matrix Bands**
† Patterson® Tofflemire Matrix Retainer
‡ Meta Biomed Co.Ltd. Meta Etchant
§ Solobond M. Voco. Germany
**** Bibodent, purple, Micro Sized Microbrush**

instructions [*], then thinned a with gentle air stream from the air/water syringe, then light cured for 20 s using a LED curing device[†]. Flowable composite [‡] was placed in a one 4 mm increment on the floor of the pulp chamber and the proximal boxes to a level 1 mm. below the DEJ then light cured for 40 s. After that, the rest of the cavity was filled with composite resin[§] to the level of the occlusal surface with preservation of the occlusal anatomy. The composite was applied in 2 mm increments; each increment was light cured for 40s. The matrix band was removed and the restoration was finished using a fine diamond burs[**]. **Figures (12 - 15).**

Fig. (12): A photograph showing etching of the enamel surfaces.

Fig. (13): A photograph showing bonding of the prepared surfaces

Fig. (14): A photograph showing flowable composite application for the pulp chamber and the proximal boxes.

Fig. (15): A photograph showing restoration of the cavity with the composite.

---

[*] **www.voco.com/in/product/solobond_m/index.html**
[†] **Elipar Freelight 2, 3m Espe, Seefeld, Germany**
[‡] **x-tra base bulk fill flowable composite. Voco.. Germany**
[§] **Polofil Nht. Voco.. Germany**
[**] **Diamond FG Dental Burrs Flame (Extra Fine)**

4.6.2 Restoration of the specimens in the ATR Group:

The specimens in this group were restored with a horizontally placed parallel part of a fiber post as well as composite resin. Prior to restoration of the specimens, two holes were drilled in the both buccal and lingual walls at a point 2.5 mm below cavo-surface angles between mesial and distal cusps. This point was marked on the internal surface and reflected to external surface using stainless steel crown gauge caliper[*]. A size # 7 rounded diamond bur [†] attached to a high speed handpiece was used to create the holes (2 mm. in diameter). Furthermore, the two holes were washed and dried using an air/water syringe for 3 sec. and the parallel part of a Fiber Post [‡] size 3 (1.9 mm. in diameter) was trial fit into the two holes then removed, cleaned with alcohol and dried. Self-adhesive resin cement[§] capsule was activated then agitated for 15 sec. in an amalgamator [**] in accordance with the manufacturer's instructions[††]. Then, the capsule was attached to the applicator [‡‡] and the cement was dispensed into the two holes followed by placement of the fiber post. A tack cure for 3 sec. was done to allow slightly hardening of the cement and the excess cement was removed with a sharp probe. Then, the cement was left to completely sit for 5 mins and the extremities of post were cut near the buccal and lingual surfaces using fine tapered stone. After that, a tofflemire matrix band #1 and a tofflemire retainer were placed around the teeth and adapted by tightening of the tofflemire screw. The enamel surface was etched with 37% phosphoric acid for 30 s. After that, the etched surfaces

[*]Stainless Steel Crown Gauge Caliper Dental/ Dentist Lab Products
[†] Diamond Bur,001/BR-28 Series,Round,Medium,FG.
[‡] Relyx™ Blue, 1.9 mm
[§] G-CEM™ Corporation, Self-Adhesive Capsule, Tokyo, Japan
[**] Ultramat 2 Amalgamator,SDI, Australia
[††] www.gcamerica.com/products/operatory/G-CEM_Capsule_IFU.pdf
[‡‡] G-CEM™ Corporation, GC Capsule Applicator, Tokyo, Japan

were rinsed and dried using an air/water syringe. A bonding agent was applied to the prepared surfaces with a small sized micro-brush in compliance with the manufacturer's instructions then thinned a with gentle air stream from the air/water syringe, then light cured for 20 s using a LED curing device. Flowable composite was placed in a one 4 mm increment on the floor of the pulp chamber and the proximal boxes to a level 1 mm. below the DEJ surrounding the glass fiber post then light cured for 40 s. After that, the rest of the cavity was filled with composite resin to the level of the occlusal surface with preservation of the occlusal anatomy. The composite was applied in 2 mm increments; each increment was light cured for 40s. The matrix band was removed and the restoration was finished using a fine diamond burs. **Figures (16 - 20).**

Fig. (16): A photograph showing drilled holes in the both buccal and lingual walls.

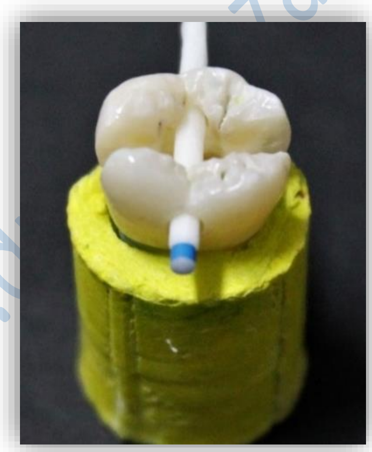


Fig. (17): A photograph showing fiber post placement.

Fig. (18): A photograph showing fiber post cementation.

Fig. (19): A photograph showing complete restoration of the specimens.

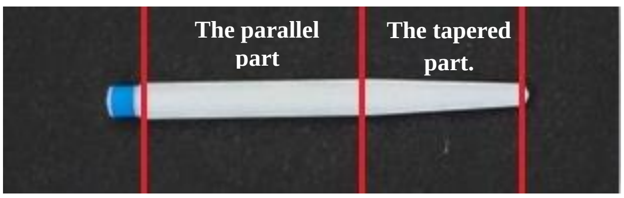


Fig. (20): A photograph showing glass fiber post, including both of parallel and tapered parts.

4.6.3 Restoration of the specimens in the NTA Group;

A tofflemire matrix band #1 and a tofflemire retainer were placed around the teeth and adapted by tightening of the tofflemire screw. The enamel surface was etched with 37 % phosphoric acid for 30 s. After that, the etched surfaces were rinsed and dried using an air/water syringe. A bonding agent was applied to the prepared surfaces with a small sized micro-brush in compliance with the manufacturer's instructions then thinned a with gentle air stream from the air/water syringe, then light cured for 20 s using a LED curing device. Flowable composite was placed in a one 4 mm increment on the floor of the pulp chamber and the proximal boxes to a level 1 mm. below the DEJ surrounding the inter dentine bridge then light cured for 40 s. After that, the rest of the cavity was filled with composite resin to the level of the occlusal surface with preservation of the occlusal anatomy. The composite was applied in 2 mm increments; each increment was light cured for 40s. The matrix band was removed and the restoration was finished using a fine diamond burs. **Figures (21& 22)**

Fig. (21): A photograph showing Truss access cavity was luted with bonding agent.

Fig. (22): A photograph showing Truss access cavity with flowable composite applied to the pulp chamber and the proximal boxes.

4.6.4 Restoration of the specimens in the Control Group;

A tofflemire matrix band #1 and a tofflemire retainer were placed around the teeth and adapted by tightening of the tofflemire screw. The enamel surface was etched with 37 % phosphoric acid for 30 s. After that, the etched surfaces were rinsed and dried using an air/water syringe. A bonding agent was applied to the prepared surfaces with a small sized micro-brush in compliance with the manufacturer's instructions then thinned a with gentle air stream from the air/water syringe, then light cured for 20 s using a LED curing device. Flowable composite was placed in a one 4 mm increment on the proximal boxes to a level 1 mm. below the DEJ then light cured for 40 s. After that, the rest of the cavity was filled with composite resin to the level of the occlusal surface with preservation of the occlusal anatomy. The composite was applied in 2 mm increments; each increment was light cured for 40s. The matrix band was removed and the restoration was finished using a fine diamond burs.

After that all teeth blocks were stored in a normal saline at room temperature to be ready for testing.

4.7 Loading of the Specimens :

Once the specimens were restored with the composite restorations, the specimens were ready for fracture resistance testing. The teeth blocks were individually mounted in a computer controlled materials testing machine [*] (load cell of 5 N) and data were recorded using computer software[†]. The teeth blocks were secured to the lower fixed compartment of testing machine by tightening of the screws. Long stainless steel rod with rounded tip (5.6 mm diameter × 10 mm length)

---

[*] **Instron Industrial Products, Model 3345; Norwood, Ma, Usa,**
[†] **Instron® Bluehill Lite Software**

was positioned on the center of occlusal surface of the specimens touching the inclined surfaces of the both buccal and lingual cusps, touching only tooth structure. The teeth blocks were submitted to a vertical compressive force loaded at a crosshead speed of a 1 mm/min. parallel to the long axis of the tooth until fracture. The fracture incidence was manifested by an audible crack and confirmed once an abrupt change at the load deflection curve that recorded using computer software. **Figures (24 & 25).**

Fig. (24); a photograph showing Instron testing machine.

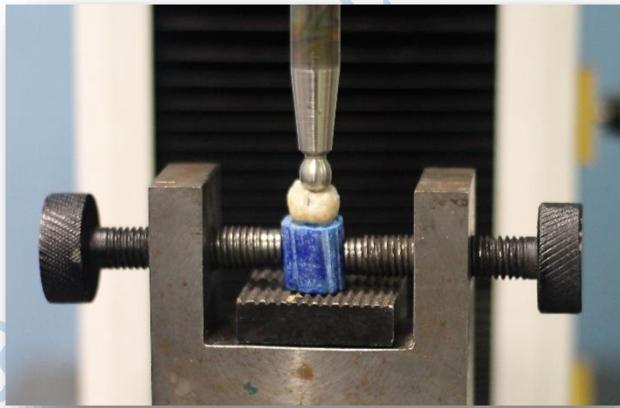


Fig. (25); a photograph showing stainless steel rod with rounded tip touching the occlusal surface of specimen.

After mechanical testing, all the specimens were visually inspected under DOM to determine the fracture patterns which classified into;

(i) Favorable fracture: It was considered when the level of fracture above or at least 1 mm below the cervical margin of the specimen. At the same time, the level of the fracture was above the pulp chamber floor

(ii) Un-favorable fracture: it was considered when the level of fracture 2 mm. below the cervical line of the specimen irrespective of whether it occurred in the bucco-lingual or mesio-distal direction. Also, when the level of the fracture was below the pulp chamber floor.

4.8 Statistical analysis for the data:

Data were collected, tabulated and statistically analyzed in several steps. Firstly, the descriptive statistics for each group. Then a One way ANOVA followed by pair-wise Tukey's post-hoc tests to detect significance between groups. Statistical analysis was performed using Asistat 7.6 statistics software [(*)]. P values ≤ 0.05 are considered to be statistically significant in all tests.

[*] Campina Grande, Paraiba state, Brazil

Discussion

Conservation of tooth structure is one of the most important factors that affects the survival of endodontically treated teeth. The benefits [58, 66] and possible drawbacks of the conservative endodontic access cavity concept has not been well supported by research data [67]. This study was done to evaluate the fracture resistance of endodontically treated mandibular molars with truss access cavity preparations as well as artificial truss restorations.

Sixty six recently extracted first mandibular molars were collected, eighteen molars were excluded and forty eight molars were used in the study **(Table 4)**. First mandibular molars were used in the study because they are more susceptible to fracture (wider occlusal tables, which increase the occlusal stresses) [68]. They are also the most commonly endodontically treated posterior teeth and often require cuspal protection [67]. **Krishan et al.** [58] concluded that endodontically treated mandibular molars were benefited of conservative access cavity design more than premolar and anterior teeth. Others research done in this field have also used the first mandibular molars to evaluate fracture resistance [69, 70].

The teeth were collected from patients with ages ranging between 20 and 45 years to minimize variation in dentin nature [32] as a result of secondary and sclerotic dentin deposition [71, 72]. The external and internal anatomy of the molars were evaluated to standardize the dimensions of the molars used in the study (to limit the variation of the occlusal table and dentin thickness) [73].

The external dimensions of the molars were measured using a digital caliper. Molars with bucco-lingual widths between 10.29 mm. and 11.17 mm. and also with mesio-distal widths between 10.47 mm. and 11.35 mm only were considered in the study.

The internal dimensions of the molars were measured with the aid of a CBCT scan. Molars with mesiodistal dimensions of the pulp chamber between 3.74 and 4.44 mm. and also with distance between occlusal surface (central fissure) and roof of the pulp chamber between 4.02 mm. and 4.36 mm. were considered in the study. These dimensions were determined based on previous research [74-76]. Any molars not within these sizes were excluded from the study. **(Table 4)**

Table (4): Different causes and numbers of excluded teeth within the study.

Teeth excluded due to deep cracks and sever attritions.	**4**
Teeth excluded due to larger or smaller external dimensions.	**6**
Teeth excluded due to larger or smaller internal dimensions.	**3**
Teeth excluded due to faults during root canal preparation (broken instruments)	**2**
Teeth excluded due to faults during preparation for ATR	**3**
Total	**18**

With regard to MOD cavity preparation, MOD cavity preparations were done to create a standardized starting point for all specimens to eliminate the effect of intervening tooth structure between the buccal and lingual cusps on the fracture resistance. MOD cavities with dimensions were performed using a custom made parallelometer device to obtain cavities with the same dimensions for standardization purposes. Therefore, burs were replaced after 6 preparations to ensure high cutting efficacy. Also, this is similar to other research done in this field [12, 48].

The truss access cavity preparation was done by creating bilateral proximal boxes leaving approximately 2 mm. of intervening dentin intact to allow for adequate root canal preparation and obturation. Furthermore, the artificial truss restoration was done by creating two holes at a point 2.5 mm below the buccal and lingual cavo-surface angles of the cavities. The position of the artificial truss restoration was chosen, so that it would corresponded to the position of nature truss dentin in the other group. The drilled holes were approximately 2 mm. in diameter. These holes sizes were found to be compatible with the parallel part of glass fiber posts (1.9 mm in diameter) and also give space for resin cement. The glass fiber posts were selected because of their low elastic modulus similar to dentin unlike other posts materials [77, 78]. The parallel part of the post was used to create uniform thickness of artificial truss restoration.

Restoration of the remaining cavities were done using composite resin restoration, this similar to other research done in this field [12, 44, 45]. Although other researchers tested their specimens without restorations [12, 58]. Restoration of the cavities were preferred to be more closely mimic to the clinical situations.

In this study, the fracture resistance was tested using static compressive loading in universal testing machine. Static compressive loading was selected because of its ease availability and low costs. Also, this similar to other research done in this field [12, 44, 62]. Furthermore, the diameter of sphere head was selected to be 5.6 mm. to allow adequate contact with the cuspal inclines during testing. Also, this similar to other research done on molars for testing fracture resistance [59, 79].

In the present study, the Control group showed significant higher fracture resistance values than that for the TAC and ATR treatment modalities. This can be explained by the fact that access cavity preparation by itself reduces the fracture resistance of the teeth as a result of removal of strategic internal architecture at the center of the tooth (complete de-roofing of the pulp chamber) [3, 5]. Furthermore, another reason why the TAC group may have performed poorly is because the TAC group was restored using bonded composite restorations and the maximum bond strength between composite material and dentin is no more than 46.2 ± 7.9 MPa [80, 81], while the fracture strength of dentin is 212.9 ±41.9 MPa [82, 83]. Also this result is in agreement with main stream research in which the fracture resistance of traditional access cavity design were evaluated [12, 58, 62].

With regards to the ATR group, the teeth were restored using a horizontal glass fiber post as well as a bonded composite restoration to increase fracture resistance by preventing cuspal deflection [12, 44, 45]. The ATR demonstrated the lowest fracture resistance value, this result could have many explanations. Firstly, the point of contact (surface area) between glass fiber post and tooth structure in the periphery of the buccal and lingual holes is minimal hence not providing an adequate area for bonding. Secondly, the fiber post was cemented in place using resin cement, it has been established that the bond strength between the glass fiber post and resin cement ranges between 11.27 - 32.4 MPa [84, 85] which is weaker than the bond strength between the composite restoration and dentin. Thirdly, the process of creating buccal and lingual holes might have affected the fracture resistance of the teeth as result of further removal of tooth structure and micro-crazing within tooth structure during preparation [86, 87].

The research in this field is lacking but the few papers reviewed in this study showed contradicting results [12, 44, 45, 47]. This could be due to multiple reasons. The sizes of the posts used in these study were within the ranges between 1.1 mm. to 1.5 mm. in diameter, while in this study the post diameter were 2 mm. which necessitating preparation of larger holes may have resulted in further weakening of the tooth structure. Secondly, some of the research used two posts in the restoration protocols instead of one post (one below the mesial cusp and the other below distal cusp). Finally, some of the research had not done complete MOD cavities leaving the marginal ridge intact. **Reeh et al**. [29] reported that MOD preparation resulted in an average loss of 63% of fracture resistance of the tooth.

Moreover, no significant difference was found between the fracture resistance of the Control and NTA groups. This result may be explained by the fact that in the NTA group, dentin bridge still remained connecting the buccal and lingual surfaces of the tooth that improving the fracture resistance comparatively to the TAC and ATR groups. Up to date, no research is been found to supports or disprove this result.

After completion of the study, analysis of the fracture pattern was done to see if any of the treatment modalities altered the fracture pattern to a more favorable fracture. After statistical analysis, no significant difference between treatment modalities with regards to differences in fracture pattern.

Summary

The endodontic access cavity is considered one of the most important phases of nonsurgical root canal treatment that facilitates all subsequent phases. In this regard, preservation of coronal tooth structure during endodontic treatment procedures greatly impacts upon the restorative treatment that follows and it plays a crucial role in the survival of the tooth.

Sixty six recently extracted mandibular first molar teeth were collected from the outpatient clinic of the National institute of Diabetes and Endocrinology. Teeth were embedded in the soft acrylic resin to a level 2 mm below the CEJ. A CBCT scan was done followed by MOD cavity preparations for all teeth using a custom made parallelometer.

Teeth were divided into four groups according to the access cavity designs as follows; G1: Traditional access cavity following conventional guidelines outline (TAC Group), G2: Traditional access cavity restored with horizontal glass fiber post (ATR Group), G3: truss access cavity preparation following conservative outline (NTA Group) and G4: unprepared intact molars (Control group). Then access cavity preparation was done for all teeth except control group according to cavity designs followed by Root canal preparations to a size corresponding to F2 or F3 file according to the initial canal size. After that canals were obturated using gutta perchea and root canal based sealer.

In **G2** (ATR group), two holes were made on the center of the buccal and lingual walls of the teeth. Then, the parallel part of the fiber post was trial fit into the two holes and cemented using resin cement. After that, all teeth were filled with bonded composite restoration.

All specimens were subjected to compressive loads at 5 KN within a universal testing machine until failure. The results showed that the NTA Group recorded the highest fracture resistance mean values followed by the TAC Group, while the ATR Group recorded the lowest fracture resistance mean values. We concluded that NTA group improves the fracture resistance of the endodontically treated teeth.

Conclusions

Within the parameter of this study:

1. Nature Truss Access cavity preparation improves the fracture resistance of endodontically treated teeth.
2. Artificial truss restoration does not improve the fracture resistance of endodontically treated teeth.
3. None of the treatment modalities improve the fracture pattern of the endodontically treated teeth.

Recommendations

1. Clinicians should use the most conservative access cavities to improve the fracture resistance of the teeth.
2. Further research should be done to evaluate different post sizes and different bonding systems in conjunction with the horizontal post placement.
3. Further research should be done on Nature truss access cavity with regards to effectivity of cleaning and shaping and other aspects of conventional root canal treatment.

References

1 **Patel S, Rhodes J**. A practical guide to endodontic access cavity preparation in molar teeth, Br Dent J. 2007; 203:133-40.

2 **Ingle J, Bakland L, Baumgartner J, editors**. Ingle's Endodontics. 6th ed; 2008: 660-75.

3 **Shafiei F, Memarpour M, Karimi F.** Fracture Resistance of Cuspal Coverage of Endodontically Treated Maxillary Premolars with Combined Composite-Amalgam Compared to Other Techniques. Oper Dent. 2011; 36:439-47.

4 **Mondelli R, Barbosa W, Mondelli J, Franco E, Carvalho R.** Fracture strength of weakened human premolars restored with amalgam with and without cusp coverage. Am J Dent. 1998; 11:181-4.

5 **Reeh E, Douglas W, Messer H.** Stiffness of endodontically treated teeth related to restoration technique. J Dent Res. 1989; 68:1540-4.

6 **Ree M, Schwartz R.** The endo-restorative interface: current concepts. Dent Clin North Am. 2010; 54:345-74.

7 **Perrin P, Neuhaus K, Lussi A.** The impact of loupes and microscopes on vision in endodontics. Int Endod J. 2014; 47:425-9.

8 **Patel S, Durack C, Abella F, Roig M, Shemesh H, Lambrechts P, et al.** European Society of Endodontology position statement: the use of CBCT in endodontics. Int Endod J. 2014; 47:502-4.

9 **Plotino G, Pameijer C, Grande N, Somma F.** Ultrasonics in endodontics: a review of the literature. J Endod. 2007; 33:81-95.

10 **Clark, Khademi J.** Case studies in modern molar endodontic access and directed dentin conservation. Dent Clin North Am. 2010; 54:275-89.

11 **Buchanan S.** Everything's changed except the anatomy. Dent Today. 2012; 31:104-5.

12 **Karzoun W, Abdulkarim A, Samran A, Kern M.** Fracture strength of endodontically treated maxillary premolars supported by a horizontal glass fiber post: an in vitro study. J Endod. 2015; 41:907-12.

13 **Ellis S, McCord J, Burke F.** Predisposing and contributing factors for complete and incomplete tooth fractures. Dent Update 1999: 26: 150-8.

14 **Braly B, Maxwell E.** Potential for tooth fracture in restorative dentistry. J Prosthet Dent 1981: 45: 411–4.

15 **Helfer A, Meinick S, Schilder H.** Determination of moisture content of vital and pulpless teeth. Oral Surg Oral Med Oral Pathol 1972; 34:661–70.

16 **Rivera E, Yamauchi M.** Site comparisons of dentine collagen cross-links from extracted human teeth. Arch Oral Biol. 1993; 38:541-6.

17 **Fusayama T, Maeda T.** Effect of pulpectomy on dentin hardness. J Dent Res 1969; 48:452–60.

18 **Lewinstein I, Grajower R.** Root dentin hardness of endodontically treated teeth. J Endod 1981; 7:421–2.

19 **Huang T, Schilder H, Nathanson D.** Effect of moisture content and endodontic treatment on some mechanical properties if human dentin. J Endod. 1992; 18:209–15.

20 **Sedgley C, Messer H.** Are endodontically treated teeth more brittle? J Endod. 1992; 18:332-5.

21 **Papa J, Cain C, Messer H.** Moisture content of vital vs endodontically treated teeth. Endod Dent Traumatol 1994; 10:91–3.

22 **Kishen A, Asundi A.** Photomechanical investigations on post-endodontically rehabilitated teeth. J Biomed Opt 2002; 7:262–70.

23 **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.

24 **Kishen A.** Biomechanics of fractures in endodontically treated teeth. Endod Topics. 2015; 33: 3–13.

25 **Patel D, Burke F.** Fractures of posterior teeth: a review and analysis of associated factors. Prim Dent Care 1995; 2: 6–10.

26 **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; 106:31–5.

27 **Ree M, Schwartz RS.** The endo–restorative interface: current concepts. Dent Clin North Am 2010; 54:345–74.

28 **Larsen T. Douglas W, Geistfeld R.** Effect of prepared cavities on the strength of teeth. Oper Dent 1981; 6:2-5.

29 **Reeh E, Messer H, Douglas W.** Reduction in tooth stiffness as a result of endodontic and restorative procedure. J Endod 1989;15:512-6.

30 **Panitvisai P, Messer H.** Cuspal deflection in molars in relation to endodontic and restorative procedures. J Endod. 1995; 21:57-61.

31 **Ibrahim A, Richards L, Berekally T.** Effect of remaining tooth structure on the fracture resistance of endodontically-treated maxillary premolars: An in vitro study. J Prosthet Dent. 2016; 115:290-5.

32 **Porter A, Nalla R, Minor A, Jinschek J, Kisielowski C, Radmilovic V, et al.** A transmission electron microscopy study of

mineralization in age-induced transparent dentin. Biomaterials 2005; 26:7650– 60.

33 **Mireku A, Romberg E, Fouad A, 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.

34 **de Noronha F, Scelza M, da Silva L, de Carvalho W.** Evaluation of compressive strength in the first premolars between young and elderly people: ex vivo study. Gerodontology. 2012; 29:898-901.

35 **Grigoratos D, Knowles J, Ng YL, Gulabivala K.** Effect of exposing dentine to sodium hypochlorite and calcium hydroxide on its flexural strength and elastic modulus. Int Endod J 2001; 34:113–9.

36 **Sayin T, Serper A, Cehreli Z, Otlu H.** The effect of EDTA, EGTA, EDTAC, and tetracycline-HCl with and without subsequent NaOCl treatment on the microhardness of root canal dentin. Oral Surg Oral Med Oral Pathol Oral Radiol. Endod 2007; 104:418–24.

37 **Ghisi A, Kopper P, Baldasso F, Stürmer C, Rossi-Fedele.** Effect of super-oxidized water, sodium hypochlorite and EDTA on dentin microhardness. Braz Dent J. 2014; 25:420-4.

38 **Ferrari M., Mason P., Goracci C., Pashley D, Tay F.** Collagen Degradation in Endodontically Treated Teeth after Clinical Function. J Dent Res. 2004; 83:414-9.

39 **Trabert K, Cooney J.** The endodontically treated tooth. Restorative concepts and techniques. Dent Clin North Am. 1984; 28:923-51.

40 **Freedman G.** Esthetic post-and-core treatment. Dent Clin North Am. 2001; 45:103-16.

41 **Duret B, Reynaud M, Duret F.** New concept of coronoradicular reconstruction: Chir Dent Fr. 1990; 60:131-41.

42 **Al-Omiri M, Al-Wahadni A.** An ex vivo study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems. Int Endod J. 2006; 39:890-9.

43 **Zhou L, Wang Q.** Comparison of fracture resistance between cast posts and fiber posts: a meta-analysis of literature. J Endod. 2013; 39:11–5.

44 **Beltrão M, Spohr A, Oshima H, Mota E, Burnett L.** Fracture strength of endodontically treated molars transfixed horizontally by a fiber glass post. Am J Dent. 2009; 22:9-13.

45 **Favero F, De Melo T, Stona D, Mota E, Spohr A, Burnett LH J.** Strengthening effect of horizontally placed fiberglass posts in endodontically-treated teeth restored with direct resin composite. Am J Dent. 2015; 28:143-9.

46 **Maccari PC, Cosme DC, Oshima HM, et al.** Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems. J Esthet Restor Dent 2007; 19:30–7.

47 **Liu C, Gao X, Lan J, Ji P.** Fracture behavior of mandibular premolars with flared root canals restored with different post-and-core systems and root rehabilitation. Hua Xi Kou Qiang Yi Xue Za Zhi. 2010; 28:286-9.

48 **Bromberg C, Alves C, Stona D, Spohr A, Rodrigues-Junior S, Melara R, Burnett L.** Fracture resistance of endodontically treated molars restored with horizontal fiberglass posts or indirect techniques. J Am Dent Assoc. 2016; 147:952-8.

49 **Christie W, Thompson G.** The importance of endodontic access in locating maxillary and mandibular molar canals. J Can Dent Assoc 1994; 60: 527–36.

50 **Scarfe W, Levin M, Gane D, Farman A.** Use of cone beam computed tomography in endodontics. Int J Dent 2009; 1-20.

51 **Cotton T, Geisler T, Holden D, Schwartz S, Schindler W.** Endodontic applications of cone beam volumetric tomography. J Endod 2007; 33:1121-32.

52 **Bowers D, Glickman G, Solomon E, He J.** Magnification's effect on endodontic fine motor skills. J Endod. 2010; 36:1135-8.

53 **Kim S, Kratchman S.** Modern endodontic surgery concepts and practice: a review. J Endod. 2006; 32:601-23.

54 **Bahcall J, Olsen E.** Integrating ultrasonic tips into your endodontic treatment armamentarium. Dent. Today 2007; 26:120-23.

55 **Paiva S, Siqueira J, Rôças I, Carmo F, Leite D, Ferreira D, et al.** Clinical antimicrobial efficacy of NiTi rotary instrumentation with NaOCL irrigation, final rinse with chlorhexidine and interappointment medication: a molecular study. Int Endod J. 2013; 46:225-33.

56 **Kishen A, Peters O, Zehnder M, Diogenes A, Nair M.** Advances in endodontics: Potential applications in clinical practice. J Conserv Dent. 2016; 19:199-206.

57 **Clark D, Khademi J.** Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010; 54:249–73.

58 **Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S.** Impacts of conservative endodontic access cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. J Endod. 2014; 40:1160-6.

59 **Moore B, Verdelis K, Kishen A, Dao T, Friedman S.** Impacts of Contracted Endodontic Cavities on Instrumentation Efficacy and Biomechanical Responses in Maxillary Molars. J Endod. 2016; 42:1779-83.

60 **Yuan K, Niu C, Xie Q, Jiang W, Gao L, Huang Z, Ma R.** Comparative evaluation of the impact of minimally invasive preparation vs. conventional straight-line preparation on tooth biomechanics: a finite element analysis. Eur J Oral Sci. 2016; 124:591- 6.

61 **Fernandes C, Glantz P, Svensson S, Bergmark A**. A novel sensor for bite force determinations. Dent Mater 2003; 19:118–126.

62 **Plotino G, Grande N, Isufi A, Ioppolo P, Pedullà E, Bedini R., et al.** Fracture strength of endodontically treated teeth with different access cavity designs. J Endod. 2017; 30071-7.

63 **Naumann M, Sterzenbach G, Pröschel P.** Evaluation of load testing of postendodontic restorations in vitro: linear compressive loading, gradual cycling loading and chewing simulation. J Biomed Mater Res B Appl Biomater. 2005; 74:829-34.

64 **Krejci I, Reich T, Lutz F, Albertoni M.** An in vitro test procedure for evaluating dental restoration systems. A computer controlled mastication simulator. Schweiz Monatsschr Zahnmed. 1990; 100:953-60.

65 **Alkhawas M.** The effect of reciprocating motion used with NiTi instruments on canal preparation and instrument wear. Al Azhar University. 2011.

66 **Clark D, Khademi J.** Case studies in modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010; 54:275–89.

67 **Bovada C, Kishen A.** Contracted endodontic cavities: the foundation for less invasive alternatives in the management of apical periodontitis. Endodontic Topics 2015; 33:169–86.

68 **McDaniel R, Davis R, Murchison D, Cohen R.** Causes of failure among cuspal-coverage amalgam restorations: a clinical survey. J Am Dent Assoc 2000; 131:173–7.

69 **Eakle W, Maxwell E, Braly B.** Fractures of posterior teeth in adults. J Am Dent Assoc. 1986; 112:215-8.

70 **Fennis W, Kuijs R, Kreulen C, Roeters F, Creugers N, Burgersdijk R.** survey of cusp fractures in a population of general dental practices. Int J Prosthodont. 2002; 15:559-63.

71 **Talabani R, Baban M, Mahmood M.** Age estimation using lower permanent first molars on a panoramic radiograph: A digital image analysis. J Forensic Dent Sci. 2015; 7:158-62.

72 **Morse D.** Age-related changes of the dental pulp complex and their relationship to systemic aging. Oral Surg Oral Med Oral Pathol. 1991; 72:721-45.

73 **Rocha L, Sousa Neto M, Fidel S, da Costa W, Pecora J. External** and internal anatomy of mandibular molars. Braz Dent J. 1996; 7:33-40.

74 **Fernandes L., Veloso C., Oliveira J., Genu P., Santiago B, Rabello P.** Odontometric analysis of molars for sex determination. Braz J Oral Sci. 2016; 15:35-8.

75 **Babu S, Nair S, Gopakumar D, Kurian N, Parameswar A, Baby T.** Linear Odontometric Analysis of Permanent Dentition as A Forensic Aid: A Retrospective Study. J Clin Diagn Res. 2016; 10:ZC24-8.

76 **Reuben J, Velmurugan N, Kandaswamy D.** The evaluation of root canal morphology of the mandibular first molar in an Indian population using spiral computed tomography scan: an in vitro study. J Endod. 2008; 34:212-5.

77 **Schwartz R, Robbins J.** Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004; 30:289–301.

78 **Tang W, Wu Y, Smales R.** Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010; 36:609–17.

79 **Monga P, Sharma V, Kumar S.** Comparison of fracture resistance of endodontically treated teeth using different coronal restorative materials: An in vitro study. J Conserv Dent. 2009; 12:154-9.

80 **Kimmes N, Barkmeier W, Erickson R, Latta M.** Adhesive bond strengths to enamel and dentin using recommended and extended treatment times. Oper Dent. 2010; 35:112-9.

81 **Kamble S, Kandasamy B, Thillaigovindan R, Goyal N, Talukdar P, Seal M.** In vitro Comparative Evaluation of Tensile Bond Strength of 6(th), 7(th) and 8(th) Generation Dentin Bonding Agents. J Int Oral Health. 2015; 7:41-3.

82 **Plotino G, Grande N, Bedini R, Pameijer C, Somma F**. Flexural properties of endodontic posts and human root dentin. Dent Mater. 2007; 23:1129-35.

83 **Giannini M, Soares C, de Carvalho R.** Ultimate tensile strength of tooth structures. Dent. Mater 2004; 20:322-9.

84 **Sarkis-Onofre R, Skupien J, Cenci M, Moraes R, Pereira-Cenci T.** 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:E31-44.

85 **Daleprane B, Pereira C, Bueno A, Ferreira R, Moreira A, Magalhães C.** Bond strength of fiber posts to the root canal: Effects of anatomic root levels and resin cements. J Prosthet Dent. 2016; 116:416-24.

86 **Segarra M, Shimada Y, Sadr A, Sumi Y, Tagami J.** Three-Dimensional Analysis of Enamel Crack Behavior Using Optical Coherence Tomography. J Dent Res. 2017; 96:308-14.

87 **Padmanabhan S, Balakrishnan A, Chu M, Kim T, Cho S.** Micro-indentation fracture behavior of human enamel. Dent Mater. 2010; 26:100-4.