Evaluation of Fracture Resistance of Endodontically Treated Maxillary Premolars Restored with Different Restorative Materials - An In Vitro Study

Avaliação da resistência à fratura de pré-molares superiores tratados endodonticamente e restaurados com diferentes materiais restauradores – Estudo In vitro

Evaluación de la resistencia a la fractura de premolares maxilares tratados endodónticamente restaurados con diferentes materiales de restauración: Un estudio in vitro

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Abstract
Aim: In this study was evaluated the fracture resistance of endodontically treated maxillary premolars restored with different restorative materials. *Methods:* Sixty maxillary premolars were submitted to the same mesio-occlusal-distal cavity preparation, endodontic treatment and divided into 5 groups (n = 10): Coltosol Group – GCO restored with calcium silicate material; Glass Ionomer Cement Group – GGIC, restored with Maxxion R; Modified Glass Ionomer Cement – GMGIC, restored with Gold Label 2; Composite Group - GC, restored with Z100, and the positive control group (GP) - left unrestored. One group remained intact (n=10) serving as negative control (GN). Samples were subjected to fracture resistance testing by the universal testing machine until fracture occurred and was registered in newtons (N). Fracture pattern was assessed and described as favorable or unfavorable. The results were statistically analyzed by 1-way analysis of variance and the post hoc Tukey test with significant statistical difference at $P < 0.05$. *Results:* Higher fracture resistance results were found for GC ($1,128.35 \pm 249.17$), GMGIC ($1,250.77 \pm 173.29$), and GN ($1,277.22 \pm 433.44$) ($P < .05$). More favorable fractures were observed in the GCO (6), GC (7), and GN (7) ($P < .05$). *Conclusion:* Teeth restored with composite and modified GIC presented the same resistance as intact teeth. Teeth restored with Coltosol and GGIC presented similar resistance to unrestored teeth.
Keywords: Advanced restorative dentistry; Composites; Dental bonding; Dental cavity preparation; Dental restoration; Temporary restoration; Dental restoration failure.

Resumo

Objetivo: Neste estudo foi avaliada a resistência à fratura de pré-molares superiores tratados endodonticamente, e restaurados com diferentes materiais restauradores. Métodos: Sessenta pré-molares superiores foram submetidos ao mesmo preparo cavitário mésio-ocluso-distal, tratamento endodôntico e divididos em 5 grupos (n = 10): Grupo Coltosol - GCO restaurado com material de silicato de cálcio; Grupo de Cimento de Ionômero de Vidro - GCIV, restaurado com Maxxion R; Cimento de Ionômero de Vidro Modificado - GCIM, restaurado com Gold Label 2; Grupo resina composta - GC, restaurado com Z100, e o grupo de controle positivo (GP) - não restaurado. Um grupo permaneceu intacto (n = 10) servindo como controle negativo (GN). As amostras foram submetidas a teste de resistência à fratura pela máquina de teste universal até que a fratura ocorresse e fosse registrada em newtons (N). O padrão de fratura foi avaliado e descrito como favorável ou desfavorável. Os resultados foram analisados estatisticamente através da análise de variância unilateral e pelo teste post hoc de Tukey com diferença estatística significativa para P <0,05. *Resultados:* Resultados mais altos de resistência à fratura foram encontrados para GC (1.128,35 ± 249,17), GCIM (1.250,77 ± 173,29) e GN (1.277,22 ± 433,44) (P <0,05). Fraturas mais favoráveis foram observadas no GCO (6), GC (7) e GN (7) (P <0,05). *Conclusão:* Os dentes restaurados com resina e GCIM modificado apresentaram a mesma resistência dos dentes íntegros. Os dentes restaurados com Coltosol e CIV apresentam resistência semelhante aos dentes não restaurados.

Palavras-chave: Odontologia restauradora avançada; Compósitos; Colagem dentária; Preparação da cavidade dentária; Restauração dentária; Restauração temporária; Falha de restauração dentária.

Resumen

Objetivo: En este estudio se evaluó la resistencia a la fractura de premolares maxilares tratados endodónticamente restaurados con diferentes materiales restauradores. *Métodos:* Sesenta premolares maxilares fueron sometidos a la misma preparación de cavidad mesio-oclusal-distal, tratamiento endodóntico y divididos en 5 grupos (n = 10): Grupo Coltosol - GCO restaurado con material de silicato de calcio; Grupo de cemento de ionómero de vidrio - GCIV, restaurado con Maxxion R; Cemento de ionómero de vidrio modificado - GCIM, restaurado con Gold Label 2; Grupo compuesto - GC, restaurado con Z100, y el grupo de control positivo (GP) - dejado sin restaurar. Un grupo permaneció intacto (n = 10) sirviendo como control negativo (GN). Las muestras se sometieron a pruebas de resistencia a la fractura mediante la máquina de prueba universal hasta que se produjo la fractura y se registró en newtons (N). El patrón de fractura se evaluó y describió como favorable o desfavorable. Los resultados se analizaron estadísticamente mediante un análisis de varianza de 1 vía y la prueba de Tukey post hoc con una diferencia estadística significativa a P <0,05. *Resultados:* Se encontraron mayores resultados de resistencia a la fractura para GC (1.128,35 ± 249,17), GCIM (1.250,77 ± 173,29) y GN (1.277,22 ± 433,44) (p <0,05). Se observaron fracturas más favorables en el GCO (6), GC (7) y GN (7) (p <0,05). *Conclusión:* Los dientes restaurados con composite y CIV modificado presentaron la misma resistencia que los dientes intactos. Los dientes restaurados con Coltosol y GIC presentaron una resistencia similar a los dientes no restaurados.

Palabras clave: Odontología restauradora avanzada; Composicion; Adhesión dental; Preparación de la cavidad dental; Restauración dental; Restauración temporal; Fallo de restauración dental.

1. Introduction

Appropriate final restoration is paramount to reach success in endodontically treated teeth (Atlas et al., 2019; Sadaf, 2020). However, a temporary restoration might be required in some situations such as an additional appointment necessary for root canal therapy or when the final restorative procedure is performed by a different professional. This temporary restoration should be able to avoid microleakage and provide the best fracture resistance (FR) possible (Pai et al., 1999; Balkaya et al., 2019).

Loss of axial walls and their internal portion weakened by surgical access, associated with cusp deflection during mastication, may result in tooth fracture (Balkaya et al., 2019). These fractures might propagate to the root worsening significantly the outcomes (Milani et al., 2016). Different studies have assessed the effect of the design of the access preparation on the FR of endodontically treated teeth (Plotino et al., 2017; Krishan et al., 2014; Maske et al., 2021). A recent study, however, pointed that after proper restoration, the tooth resistance can be reestablished regardless of the access design (Moore et al., 2016).

Conventional glass ionomer cement (GIC), resin-modified glass ionomer cement (MGIC), light cured composite resin (CR), zinc oxide, and calcium sulfate materials are often used as temporary restorative materials between appointments (Jensen et al., 2007; Silva & Tolentino, 2021). The GIC features chemical adhesion to tooth structure, releases fluoride to buccal cavity

and, reasonable aesthetic (Wilson & Kent, 1971). However, it possesses unsatisfactory mechanical properties, moisture sensitiveness, and is time-consuming. Improvements in its composition, adding low molecular weight resin monomers, led to the development of light cured resin-modified GIC, enhancing some properties (Sidhu & Watson, 1995). Calcium sulfate materials, also called as zinc oxide without eugenol are known for good capacity for temporary sealing, easy handling and good mechanical strength within 7 days (Naseri et al., 2012).

Composite resins present proper mechanical strength and aesthetics, being recommended as a definitive restorative material; due to these properties recent studies indicate it as a temporary material in teeth presenting excessive loss of structure (Tortopidis et al., 1998; Daher et al., 2021).

The study aims to evaluate the FR of maxillary upper premolar teeth restored temporarily with four types of restorative materials – Coltosol, Maxxion R, GC Gold LC and Z100; respectively a calcium silicate, GIC, modified GIC and composite resin. Moreover, the pattern of the fracture was also assessed. The null hypothesis tested is that there is no difference among the tested materials.

2. Methodology

This "ex-vivo" study was reviewed and approved by the institutional ethics committee (#2.973.439). Sixty maxillary first and second premolar teeth, freshly extracted for orthodontic reasons were used in the present study. After the extraction the teeth were immersed in 0.1% thymol solution and had their crowns measured with a digital caliper (Craftright Engineering Works, Jiangsu, China). Samples obtained presented the intercuspal distance of 9.58 ± 0.67 mm, mesio-distal (MD) width of 7.41 ± 0.55 mm and bucco-palatal (BP) width of 6.22 ± 0.46 mm.

The inclusion criteria selected only intact teeth presenting two independent roots. All teeth were inspected under 16x magnification to exclude the ones presenting any signs of cracks or fractures in the crown or root. Two radiographs were taken in bucco-lingual and mesio-distal incidences to certify that the teeth had no signs of previous root canal therapy, internal or external root resorption, or any abnormal anatomy.

All specimens were stored in 0.9% saline at 4°C throughout the experiment. A mesial-occlusal-distal (MOD) cavity was performed with diamond burs in a high-speed handpiece under water cooling. This cavity extended from mesial to distal aspects with a depth of 5 to 6 mm flat and continuous, whose occlusal reference is the plane that tangent the cusp tips following the apical up to 1 mm above the cementoenamel junction (CEJ) line. BP width of the occlusal preparation and the proximal boxes was half of the intercuspal width (figure 1A-B), the cavosurface margins were prepared at 90° and all internal angles were rounded.

Figure 1. A) Image demonstrating width of wear of MOD in Y box in BP direction and intercuspal distance in X. B) Image showing the reference mode of the wear height of the mesio-occlusal-distal (M-O-D) boxes by a tangent plane to the cusp tips (α), boxes with the same depth indicated by the red lines.
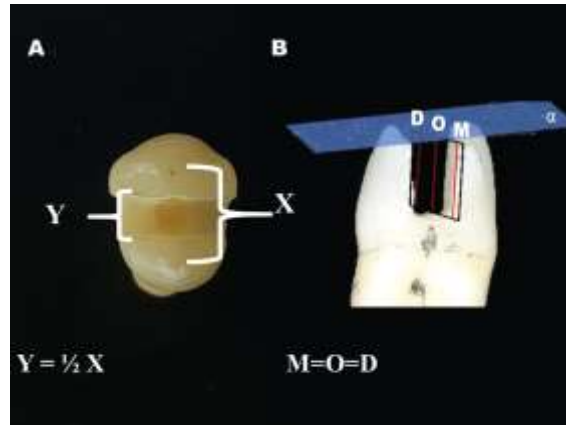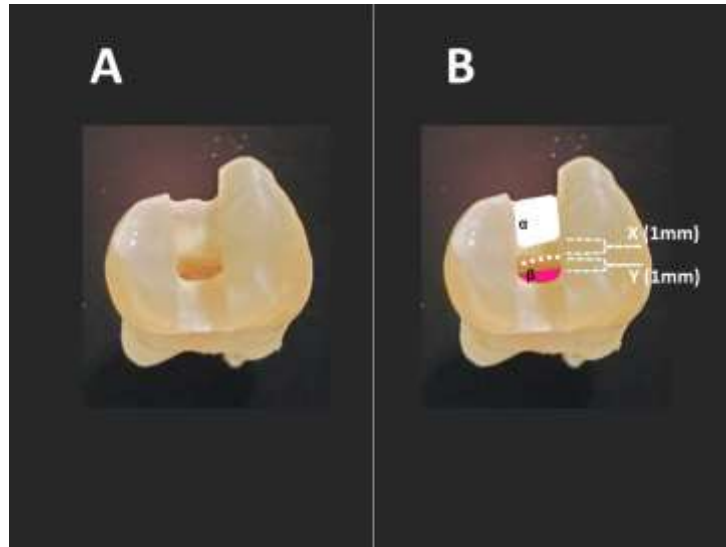

Source: Authors.

Following the preparation of the cavities, the root canals were instrumented. After the access of the pulp chamber the root canals were negotiated with size 10 K-files (VDW, Munich, Germany) up to the apical foramen. Then, the working length (WL) was established 0.5 mm short of the point the file was visible through the foramen at 16x magnification. The instrumentation was performed up to the WL with a WaveOne Gold Primary 25.07 (Dentsply Sirona, Ballaigues, Switzerland) under 2.5% NaOCL irrigation. After the root canal instrumentation, the canals were irrigated with 5 mL 17% EDTA, which remained inside the root canal for 3 minutes. Then, the canals were irrigated with 5 mL 0.9% saline, dried with Capilary Tips (Ultradent, South Jordan, UT) and paper points. Finally, the canals were filled with the single-cone technique using the AH Plus sealer (Dentsply Sirona). The coronal guta-percha was removed with a heated instrument up to 1 mm below the CEJ (Figures 2A-B).

After the root canal treatment, a 0.05 mm thick and 5 mm width matrix band was placed around the crown with a Tofflemire retainer prior to the restorative procedures. Specimens were randomly assigned to one of the groups (n=10) as follows: Coltosol Group (GCO), Glass Ionomer Cement Group (GGIC), Modified GIC Group (GMGIC) and Composite Group (GC) – Table 1. Ten specimens were left unrestored and served as positive control (GP); 10 intact teeth served as negative control (GN).

Figura 2. A) shows image height of the removal the endodontic filling material; B) α plan indicates gingival and pulpal MOD wall box; red dotted line indicates CEJ line height; β plan indicates filling material after cutting; blue lines y and x indicates the distance from the filling material surface to the gingival wall and pulp MOD box; at x = 1mm and y = 1mm.

Source: Authors.

In GCO the cavities were filled with Coltosol (Coltene, Rio de Janeiro, Brazil) that was gently placed in the cavities with the aid of a #1 titanium spatula (Prisma, São Paulo, Brazil). In the GGIC a type I GIC, Maxxion R (FGM/Dentscare, Joinville, Brazil) was handled following the instructions of the manufacturer and placed inside the cavity with a needle coupled to a Centrix (DFL, São Paulo, Brazil) syringe. After the initial setting of the material a thin layer of adhesive (Single Bond 2.1, 3M ESPE, Sumaré, Brazil) was used to cover the GIC which was light-cured for 15 seconds with a LED unit (Valo,1000mW/cm^2; Ultradent, South Jordan, UT). In the GMGIC the teeth were restored with the Gold Label 2 Light Cured Universal (GC Corporation, Tokyo, Japan). The material was handled according to the manufacturer's instructions and inserted in the cavities with a Centrix syringe and a needle. Then, the material was cured with the LED unit (Ultradent) for 20 seconds. In the GC, the cavities were restored with the Z100 Universal Light-Curing Composite Resin (3M ESPE). The cavity was etched with 37% orthophosphoric acid for 15 s, washed with distilled water for 30s and gently dried with absorbent paper. The adhesive system Single Bond 2 (3M ESPE) was spread in the walls with a micro brush and light-cured for 15 s. The composite resin was placed with a titanium #1 spatula (Prisma) in increments no larger than 2.5 mm and light-cured for 40 s each increment. In all groups, except GCO, finishing and polishing were performed using the Enhance tip (Dentsply Sirona) at low-speed.

Table 1. Materials and composition

Materials	Lot no.	Manufacturer	Composition
Coltosol	1600811	Coltene/Vigodent, Bonsucesso (RJ), Brazil	Zinc oxide, zinc sulfate monohydrate, calcium sulfate hemihydrate, ethylene-vinyl acetate resin
Maxxion R	191015	FGM/Dentscare Joinville (SC), Brazil	Alumina Fluorsilicate Glass, Acid. Polycarboxylic, Acid.Tartaric, Calcium Fluoride and Water
GC-Gold LC	1705131	GC Corporation Tokyo, Japan	Glass Ionomer Cement modified by light-curing radiopaque resin (composition not provided by manufacturer)
Z100	874182	3M do Brazil Sumaré (SP), Brazil	Silanized ceramic (80%). TEGMA* (1-10%), BisGMA (1-10%), 2-Benzotriazolyl-4-methylphenol (0,14%)

*TEGMA, triethylene glycol dimethacrylate; BisGMA, bisphenol A glycol dimethacrylate; Acid, acid. Source: Authors.

Fracture Resistance Test

For the fracture resistance test the specimens were inserted in an apparatus simulating the alveolus and periodontal ligament. A thin layer of wax (0.2 - 0.3 mm) was placed around the roots, the roots were inserted in polyvinyl chloride rings 25 mm high and 36.5 mm of diameter embedded with self-curing acrylic resin until setting. The wax layer was removed with warm water and the roots were again placed inside the acrylic resin cast filled with impression material (Express XT, 3M ESPE). Care was taken to place the acrylic resin 1 mm below the CEJ.

Specimens were mounted on the universal testing machine EMIC DL 2000 (Instron, Canton, USA) for the strength test (static load cells 20kN). A metal cylinder (7.5 mm – diameter, 16 mm – length) was centered on the occlusal surface of the teeth in contact with both buccal and palatal cusps; a compressive load was applied vertically along the long axis of the tooth at a crosshead speed of 1 mm/min until fracture occurred. The machine's software registered the load in which the fracture occurred; this value was recorded in newtons (N).

The fracture pattern was analyzed under optical microscopy and described as favorable (above the CEJ) and non-favorable (below the CEJ - Figure 3A-B).

The results were statistically analyzed by 1-way analysis of variance and the post hoc Tukey test with significant statistical difference at $P < 0.05$.

Figure 3. Teeth after fracture test showing fracture mode. A) Favorable fracture and B) Unfavorable fracture.
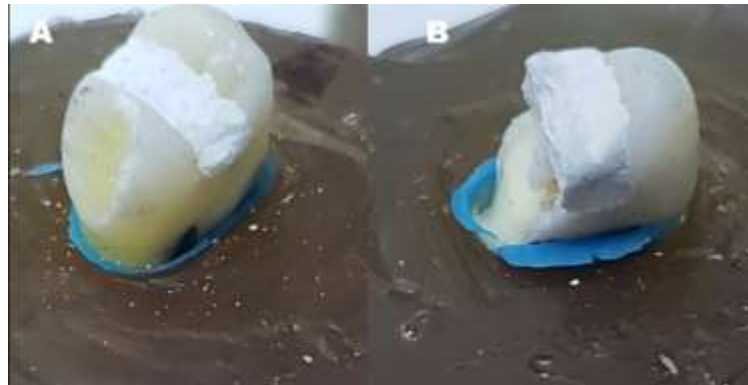
Source: Authors.

3. Results

The GN, GMGIC, and GC had the highest FR values and did not differ statistically among them ($p > 0.05$). The GP had the lowest FR value without statistical difference to GGIC and GCO ($p > 0.05$). The FR mean and standard deviation (SD) values are shown in table 2.

Regarding the fracture pattern, the groups GC and GCO had the highest number of favorable fractures and did not differ statistically. The CGIC and GMGIC had lower results of favorable fractures (Table 3).

Table 2. Fracture resistance values (N) of the different groups presented as Mean ± SD

Group (n=10)	Mean ± SD
Coltosol	560.44 ± 138.94^{b}
Maxxion R	719.58 ± 119.19^{b}
GC-Gold LC	$1,250.77 \pm 173.29^{a}$
Z 100	$1,128.35 \pm 249.17^{a}$
Positive Control (without restoration)	450.99 ± 97.48^{b}
Negative Control (intact teeth)	$1,277.22 \pm 433.44^{a}$

Different superscript letters show a statistically significant difference (P <0.05). Source: Authors.

Table 3. Distribution of the fracture types for each group.

Fracture Types	GCO	GGIC	GMGIC	GC	GP	GN
Favorable	6^{ABa}	3^{Cb}	4^{BCb}	7^{Aa}	4^{BCb}	7^{Aa}
Unfavorable	4^{BCb}	7^{Aa}	6^{ABa}	3^{Cb}	6^{ABa}	3^{Cb}

Horizontal line with different superscript uppercase letters shows a statistically significant difference (P <0.05).
Vertical line with different superscript lowercase letters shows a statistically significant difference (P <0.05).
Source: Authors.

4. Discussion

Temporary restorations used between RCT appointments should have good coronal sealing to prevent microleakage and also prevent fracture of the dental remnant during mastication (Milani et al., 2016). The clinical forces applied during mastication are difficult to be simulated in vitro. In the present study the forces were axially applied in a crown-apex direction using a 7.5 mm diameter cylinder touching only tooth surface. This dynamic promotes wedging action and decreases FR leading to tooth fracture (Balkaya et al., 2019). It is known that the average bite force in premolar region is around 428 N in 32-year-old male patients (Tortopidis et al., 1998). This value is similar to the 450.99 N required to fracture unrestored teeth; 560.44 N to fracture teeth restored with Coltosol and 719.58 N to fracture teeth restored with Maxxion R, findings of the present study. These results suggest the reliability of the methodological model herein adopted. Meanwhile, intact teeth, teeth restored with Z100 and, teeth restored with Gold Label 2 required respectively 1,277.22 N, 1,250.77 and 1,128.35 N to fracture, which was significantly higher than the aforementioned samples, therefore the null hypothesis was rejected.

Maxillary premolar teeth, extracted for orthodontic reasons, were chosen for this research due to possibility of proper control of the samples. All specimens were obtained from young patients, ranging from 15 to 18 years old, diminishing the co-found factor of using brittle teeth from old patients (Ivancik et al., 2012). Specimens were immediately placed in humidity after the extraction and stored at 100% in relative humidity and 37ºC during the whole experiment, decreasing the effects of dehydration of the samples (Soares et al., 2005). These teeth present a tendency of separation of the cusps during mastication, which is aggravated with increasing sizes of the MOD preparation; therefore, the cavity created could mimic a challenge situation in the clinical setting (Eapen et al., 2017; Taha et al., 2015).

Coltosol is a zinc oxide–based eugenol-free material and does not require handling, its setting occurs when in contact with moisture coming from oral fluids, optimizing clinical time. According to the manufacturer Coltosol expands around 17-20%, enhancing coronal sealing (Naseri et al., 2012). In the present study, teeth restored with Coltosol fractured with similar strength than unrestored teeth. It is worthwhile mention that in the present study the MOD preparation was 1/2 of the intercuspal distance. A previous study found Coltosol to be appropriate to restore MOD cavities of premolars when the preparation was 1/3 of the intercuspal distance. However, the results were significantly worse, and similar to the present study, when the preparation was 2/3 of the intercuspal distance, which is in accordance with results from previous studies (Balkaya et al., 2019; Milani et al., 2016). Therefore, the use of Coltosol should be restricted to small cavities because such expansion may be the cause of cracks in the tooth surface favoring fractures (Tennert et al., 2016).

In this study the GIC obtained FR results (719.58N) statistically lower compared to the GMGIC (1,250.77) and GC (1,128.35). These findings differ from a previous finding in the literature. Mincik et al. (2016) found similar FR in premolars with MOD preparation restored with either GIC (Iono Star Plus, VOCO - 352 N), or composite (GrandioSO 445.38 N and X-tra fil, VOCO 355.13 N). The lowest values obtained in this aforementioned study can be explained by the smaller size of the sphere (6 mm) used to deliver the load, increasing the wedging effect. However, the similarity found between GIC and composite in that study can be explained by the different brands used in both studies. Other study however, also concluded that GIC alone is not recommended to restore compromised teeth. The results of Pakdeethai et al. (Pakdeethai et al., 2013) also showed that GIC cannot properly reestablish fracture resistance of posterior teeth, unless cuspal reducing is performed.

The resin-modified GIC emerged to fill the gaps caused by GIC without losing their qualities and combined with the benefit of the resulting mechanical properties of composite resins (Young, 2002). The resin matrix generates a framework preventing structural changes by moisture and additional mechanical resistance in the early hours (Mitra, 1991). Indeed, the results of the present study suggest that teeth restored with MGIC present resistance similar to intact teeth. Similarly, a recent study also concluded that MGIC is superior to Coltosol to restore MOD cavities of endodontically treated premolars (Milani et al., 2016).

Composite resins have been extensively compared to other rehabilitation materials suggesting that they can be considered as primary choice for permanent restoration (Eapen et al., 2017; Karzoun et al., 2015). Composite resins reinforce weakened tooth structure and also offer appropriate coronary sealing (Ozsevik et al., 2016; Fathi et al., 2007). In the present study, the load required to fracture teeth restored with CR were similar to the force required to fracture intact teeth, therefore, one may conclude that proper restoration is paramount to prevent tooth fracture. Composite resins however require great amount of time to be properly placed and light-cured meanwhile GMGIC are faster to be placed and delivered similar resistance than CR.

Fractures above the CEJ level can be considered favorable because they can be easily restored. But when it extends up to the level of or below the CEJ, it requires more complex restorative procedures jeopardizing the tooth (Pakdeethai et al., 2013). Restorations without cuspal coverage and use of intracoronary or intraradiculars reinforcements are more likely to fracture with unfavorable characteristics (Braga et al., 2015). Balkaya et al. (2019) found a higher percentage of favorable fractures in all samples, contrasting with our study, just CR, PC, and CO had similar results. The reason for this may be to different types of restorative materials, design of MOD cavity and also the FR test cylinder format that was 7.5 mm in diameter in this study instead of 6 mm of that previous study.

In the present study GMGIC surprisingly obtained higher numbers of unfavorable fractures. It can be hypothesized that the chemo-mechanical union, in addition to the lower cusp deflection dissipates the forces below the dentin bonding area (Karaman & Ozgunaltay, 2013). Paradoxically, the GCO presented favorable fractures compared with the GC. It is befitting to say that the coronal cracks generated by its hygroscopic expansion make the surrounding dentin more friable and a greater tendency to fracture, yet not extending below the CEJ (Tennert et al., 2016). The GGIC had lower fracture resistance values and most unfavorable fractures; thus, correlating the type of fracture with fracture resistance, it is possible to say that this group is not able to resist heavy load forces.

This study has a static nature of fracture resistance medication, not faithfully simulating the dynamic oral conditions that exist in clinical reality. Further studies evaluating the influence of restorative materials on the mechanical behavior of endodontically treated teeth are necessary.

5. Conclusion

Within the limitations this "ex vivo" study, it can be concluded that teeth restored with composite and modified GIC presented the same resistance as intact teeth. Teeth restored with Coltosol and Glass Ionomer Cement present similar resistance to unrestored teeth.

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