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Fracture resistance of endodontically treated molars restored with horizontal fiberglass posts or indirect techniques

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Endodontic treatment should be completed as soon as possible by means of a permanent coronal restoration to prevent tooth fractures, recurrent carious lesions around provisional restorations, and marginal leakage.[1] The quality of the coronal reconstruction directly affects the success and the longevity of endodontic treatment.[2,3] Parameters for an acceptable restoration include adequate anatomy, function, proximal contacts, and occlusal stability.[3] However, the type of material and restoration technique are still controversial for endodontically treated teeth. What is known is that a well-done final restoration involves tooth form, function, proximal contacts, and occlusal stability.[3]

Possible causes of tooth fracture are coronal destruction by caries, excessive removal of dentin during therapeutic procedures, trauma, previous restorations, prolonged use of sodium hypochlorite and ethylenediaminetetraacetic acid, and endodontic over-instrumentation.[2,4] There seems to be a direct relationship between the number of residual walls and fracture resistance[5,6] because the removal of 1 marginal ridge results in 46% loss of tooth rigidity and removal of 2 marginal ridges leads to a 63% loss of rigidity.[7] Therefore, the residual coronal tooth structure is a key factor for the choice of restorative material and technique.[5,8]

Preservation of tooth structure and adequate adhesion between restorative material and the tooth are

ABSTRACT

Background. Because of the many possibilities for endodontically restoring the posterior teeth and the high prevalence of restoration failures, this topic continues to be of major concern. A composite resin (CR) restoration reinforced by a horizontal fiberglass post may improve the fracture resistance of endodontically treated teeth. The authors investigated this possibility by comparing the fracture resistance of molars restored with direct techniques with that of molars restored with indirect techniques.

Methods. The authors divided 50 extracted sound third molars into 5 groups: sound teeth, onlay (ON), inlay (IN), direct CR, and transfixed fiberglass post (TFP) plus direct CR. The authors performed standardized mesio-occlusodistal cavity preparations and endodontic treatments. The authors cemented indirect restorations of Lava Ultimate (3M ESPE) adhesively in the ON and IN groups. The authors restored CR group teeth directly with Filtek Z230 XT (3M ESPE). In the TFP group, the authors transfixed 2 fiberglass posts horizontally and restored the teeth directly with CR. Thereafter, the authors submitted the teeth to cyclic fatigue loading with 500,000 cycles at 200 newtons. The authors tested fracture resistance in newtons in a universal testing machine. The authors analyzed data with 1-way analysis of variance and a Tukey test ($P < .05$).

Results. Sound teeth had the highest fracture resistance. ON had the highest recovery of resistance, followed by TFP. CR had the lowest recovery, which was similar to that of IN.

Conclusions. Endodontically treated molars restored with TFP plus CR had fracture resistance similar to those restored with ON, which was higher than that for IN or CR only.

Practical Implications. Horizontal TFPs placed inside a composite restoration had the same performance as did ON restorations.

Key Words. Fracture resistance; molar; endodontic treatment; composite resin; CAD/CAM; fiberglass post.
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important elements for the success and longevity of restorations.[9] Proper adhesion eliminates the need for macromechanical retention, enabling more conservative cavity preparations. In this sense, direct composite restorations are a viable treatment, avoiding the removal of healthy tooth structure that occurs in cavity preparation for onlays (ONs).[3,10] Direct composite restorations seem to increase fracture resistance in endodontically treated teeth and have a low cost.[10,11] Plotino and colleagues[7] observed similar fracture resistance of molars with extensive loss of tooth structure when restored with direct or indirect composite, reinforcing the possibility of direct composite restorations as an option for teeth with great loss of tooth structure.[12] However, indirect composite restorations seem to provide better distribution of tension in mesio-occlusodistal (MOD) caries.[13] Ilgenstein and colleagues,[14] comparing the fracture resistance of composite and ceramic ONs manufactured by means of a computer-aided design and computer-aided manufacturing (CAD/CAM) system, observed higher fracture resistance with the former.

Another frequent discussion is the need of cusp coverage in endodontically treated teeth, with controversial results. According to Jiang and colleagues,[13] a tooth restored with ON has a more favorable stress distribution than with inlay (IN), regardless of the material used. Teeth with cusp coverage restored with composite resin (CR), either directly or indirectly, have a higher fracture resistance than do teeth without cusp protection.[11] Conversely, Stappert and colleagues[15] observed that total coverage of the cusp for ceramic restorations did not increase fracture resistance compared with less invasive restorations that covered only the functional cusp.

A restorative alternative that aims to increase the fracture resistance of endodontically treated teeth is the use of fiberglass posts horizontally transfixed to the buccal and lingual walls. Beltrão and colleagues[16] and Favero and colleagues[17] advocated that transfixing posts with composite restorations enhances the fracture resistance of the tooth when compared with restorations with no post transfixed.

Considering the lack of consensus on the restorative alternatives for endodontically treated teeth, we aimed in this in vitro study to assess the maximum fracture load of endodontically treated molars restored with indirect techniques with or without cusp coverage and with direct techniques involving with or without transfixation of fiberglass posts. The initial null hypothesis was that there is no statistically significant difference in the fracture resistance of endodontically treated teeth restored with INs, ONs, or direct CR with or without a transfixed fiberglass post (TFP).

METHODS

The local ethics committee approved the protocol of this study (ethics committee certificate of approval, 52088315000005336). We calculated sample size on the basis of a pilot study and considered the following parameters: type I error probability of .05, nominal test power of 0.8, difference between groups of 230 newtons, and average standard deviation of 90 N. The minimum sample size was of 10 specimens per group.

We cleaned 50 human third molars extracted for a therapeutic indication and stored them in a 0.5% chloramine solution for 24 hours for disinfection. After this period, we recorded the buccolingual and mesiodistal dimensions of each tooth with a digital caliper. The selected teeth had a mean (standard deviation) mesiodistal distance of 10.81 (1.14) millimeters and a buccolingual distance of 10.55 (0.82) mm, with coefficients of variation of 10.59 and 7.78, respectively. We divided the teeth randomly into the study groups described in Table 1.

We embedded the teeth and prepared their cavities on the basis of the protocol described by Beltrão and colleagues.[16] We labeled each specimen as described in Table 1 and stored the specimens in distilled water at 4°C.

MOD cavity preparation. We prepared cavities with a device adapted to a microscope table in which a high-speed dental handpiece was adapted. We defined references for each tooth to receive a MOD cavity preparation standardized in width and depth. The buccolingual width corresponded to two-thirds of the intercuspal distance, and we set the depth at 4 mm.

We selected an 845 KR diamond bur (Gebr. Brasseler) to perform the cavity preparation, which consisted of buccal and lingual walls, a common floor extended from the mesial to distal aspects, and internal rounded angles. We replaced the diamond bur after every 5 preparations, which a single operator (C.R.B.) performed. After preparing the teeth, we stored them in distilled water at 4°C.

Endodontic therapy. An endodontics specialist (C.B.A.) performed the endodontic treatments. The specialist opened the crown with 1012 and 1014 round diamond burs (KG Sorensen) at high speed under water and air cooling. She performed stepback shaping by using burs (Endo-Z, Dentsply Maillefer) at high speed under water and air cooling. She used 1% sodium hypochlorite for irrigation. Next, she explored the canals with a file (15 Flexofile, Dentsply Maillefer) and prepared for access to the canals with drills (01 and 02 Gates Glidden, Dentsply Maillefer) with irrigation with 1% sodium hypochlorite. She eliminated the hypochlorite through abundant irrigation with saline solution. She dried the root canals with paper cones. She vertically condensed the gutta-percha with a condenser (2 Paiva, S.S. White Duflex). She filled the pulp chamber with a resin-reinforced glass ionomer cement (Riva Light Cure,

ABBREVIATION KEY. CAD/CAM: Computer-aided design and computer-aided manufacturing. **CR:** Composite resin. **IN:** Inlay. **MOD:** Mesio-occlusodistal. **ON:** Onlay. **SBU:** Single Bond Universal. **TFP:** Transfixed fiberglass post.

TABLE 1

Study groups.

GROUP	DESCRIPTION	NO. OF TEETH
Sound	Control group, no treatment, sound teeth	10
Onlay	Endodontic treatment plus MOD* cavity preparation plus 1 cusp reduction plus CAD/CAM† indirect restoration‡	10
Inlay	Endodontic treatment plus MOD cavity preparation plus CAD/CAM indirect restoration‡	10
Composite Resin	Endodontic treatment plus MOD cavity preparation plus direct composite resin restoration§	10
Horizontally Transfixed Post	Endodontic treatment plus MOD cavity preparation plus direct composite resin restoration§ plus 2 horizontal fiberglass posts	10

* MOD: Mesio-occlusodistal.
† CAD/CAM: Computer-aided design and computer-aided manufacturing.
‡ Lava Ultimate (lot N719292, expiration date April 2020; 3M ESPE).
§ Filtek Z350 XT (shade A1E, lot 11295, expiration date December 2016; 3M ESPE).

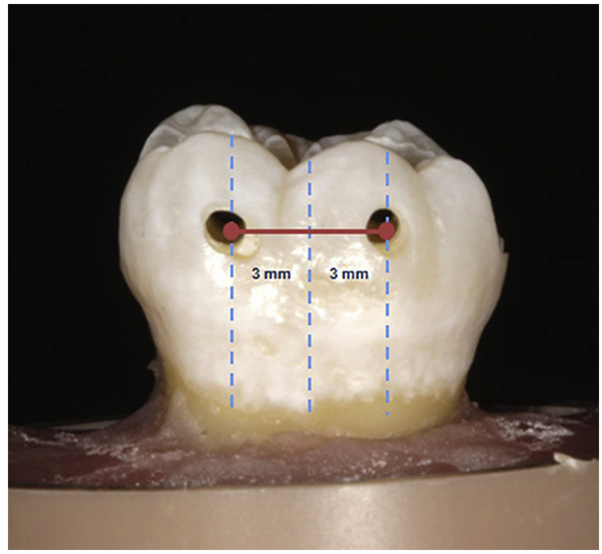

Figure 1. Cavity preparation for a transfixed fiberglass post. mm: Millimeters.

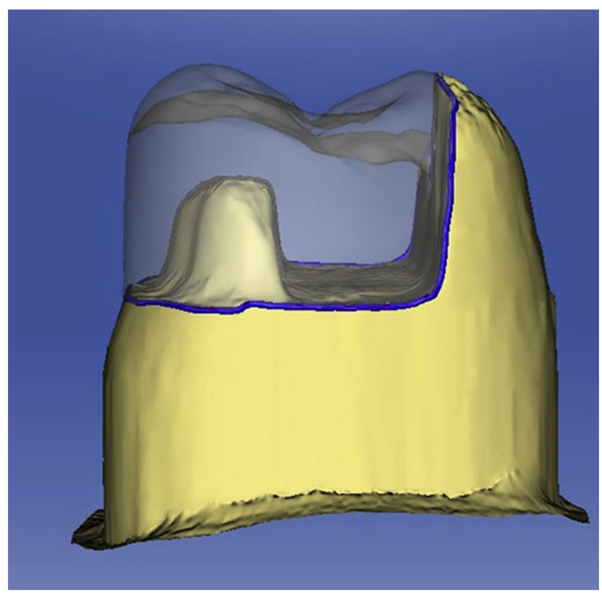

Figure 2. Cavity preparation for onlay group and computer-aided design.

SDI), which she inserted in a single increment and light cured for 40 seconds.

We reduced the buccal surface of the ON preparations by 1.2 mm with a 6880 diamond bur (Gebr. Brasseler). We reduced the occlusal surface 1.6 mm with a 6847KR diamond bur (Gebr. Brasseler).

For the TFP group preparation, we perforated the buccal and lingual faces with a 6801 spherical diamond bur (Gebr. Brasseler) under constant irrigation as Figure 1 shows. We then inserted a drill with a diameter of 1.1 mm for the fiberglass post (Reforpost number 1, Angelus) into the holes.

ON group. We modeled Lava Ultimate (lot N719292, expiration date April 2020; 3M ESPE) ON restorations on a CAD/CAM system (CEREC, Sirona Dental Systems). We applied an antireflective spray (VITA Powder Scan Spray, VITA Zahnfabrik) to the cavity preparations and scanned the surface (Bluecam, Sirona Dental Systems). We modeled the restoration by using software (inLab 4.0.2, Sirona Dental Systems) with an 80-micrometer spacer (Figure 2). We then milled the model (MC XL unit, Sirona Dental Systems).

We abraded the internal surface of the restoration with 50-μm airborne particles of aluminum oxide and cleaned it with alcohol. We conditioned the enamel of the cavity preparation with 37% phosphoric acid (Bisco) for 20 seconds and rinsed by using air and water spray for 20 seconds. We then applied the adhesive system (Single Bond Universal [SBU], lot 582958, expiration date March 2017; 3M ESPE) and the resin cement (RelyX Ultimate, lot 589109, expiration date October 2016; 3M ESPE) according to manufacturer instructions. We seated the restoration under a 1-kilogram load (DL-2000, EMIC) and light cured it for 20 seconds per side with a light-emitting diode light-curing unit (Bluephase, Ivoclar Vivadent). We measured the light intensity in all studied groups by using a light-emitting diode radiometer (SDI) after every 5 restorations (mean [standard deviation], 1,248 [61] milliwatts per square centimeter).

IN group. We modeled and cemented IN restorations (Lava Ultimate) according to the same protocol as that of the ON group.

CR group. For cavity preparations in the CR group, we etched the enamel with 37% phosphoric acid for

20 seconds and rinsed with air and water spray for 20 seconds. Thereafter, we applied SBU according to manufacturer instructions followed by light curing for 20 seconds. We applied the CR (Filtek Z350 XT, shade A1E, lot 11295, expiration date December 2016; 3M ESPE) in 4 oblique increments[18] and light cured them for 40 seconds each.

TFP group. Cavity preparation and SBU application and light curing in the TFP group was similar to that in the CR group, only extending the sites of SBU application to the post holes. We applied a composite layer to the pulpal floor but did not light cure it. We cleaned the fiberglass post surface with alcohol and coated it with SBU. We inserted a flowable composite (PermaFlo, Ultradent Products) into the transfixing holes, positioned the fiberglass post horizontally, and light cured it for 40 seconds (Figure 3). We then inserted Filtek Z350 XT in 4 oblique increments[18] and light cured them for 40 seconds each (Figure 4). We cut the buccal and lingual post ends close to the buccal surface with an 856 bur (Gebr. Brasseler). We sealed the cut area of the post with adhesive and composite and light cured it for 20 and then 40 seconds.

We stored the specimens at 37°C for 24 hours and then submitted them to fatigue cycling with a vertical load of 200 N applied to the occlusal surface for 500,000 cycles at a frequency of 1 cycle per second. We applied the fatigue in distilled water at 37°C.[19]

After cycling the specimens, we fractured them in a universal testing machine (DL2000, EMIC) with a load cell of 10 kilonewtons at a speed of 1 mm per minute. We applied the load on the occlusal surface with a 6.95-mm-diameter steel ball. We applied the compressive load parallel to the long axis of the tooth until fracture. We recorded the maximum fracture load in newtons for each specimen.

We examined the fractured specimens under × 3 magnification for analysis and classification of the tooth fracture pattern. We classified fractures as 1 of 2 types: not repairable (fracture of the pulp chamber floor) or repairable (fracture line involving the cusps fully or partially).

We performed statistical analysis with software (Statistix for Windows, Version 8.0, Analytical Software). We tested normal distribution of data with a Shapiro-Wilk test, followed by 1-way analysis of variance and a Tukey test ($\alpha = .05$). We described fracture patterns as a frequency distribution.

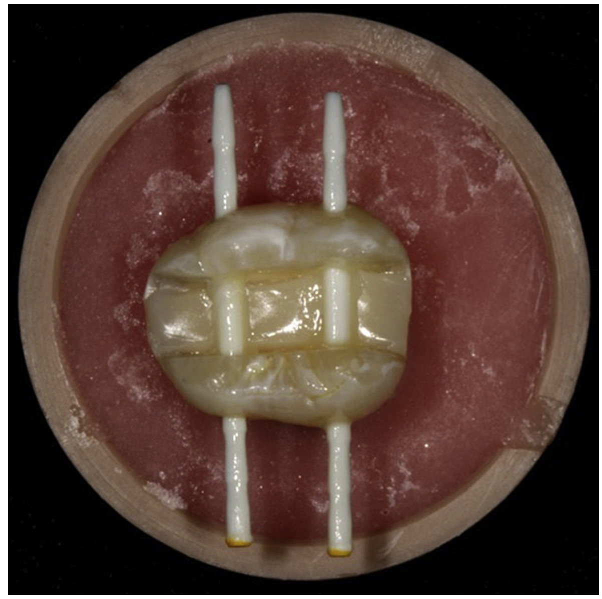

Figure 3. Fiberglass posts positioned.

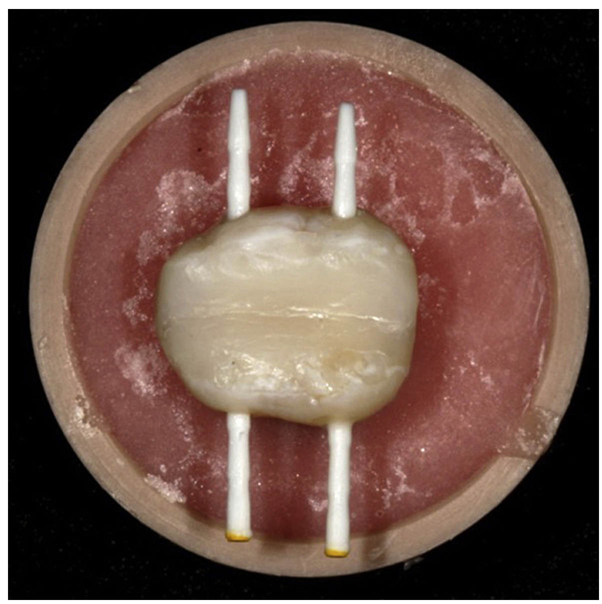

Figure 4. Posts covered by composite resin.

RESULTS

Variance analysis revealed that the positive control group of sound teeth had the highest mean fracture load (4,514 N), differing statistically from groups CR, ON, IN, and TFP (Table 2). The ON group had the highest percentage of fracture strength recovery (65%) compared with the control group, followed by the TFP group (60%); CR had the lowest percentage of recovery (37%).

The control group had the highest percentage of repairable failure. Among the restored groups, ON and TFP had the highest percentage of failures that were not repairable (Table 2).

DISCUSSION

The null hypothesis of this study was rejected because there were statistically significant differences in fracture

TABLE 2

Mean, coefficient of variation, percentage of fracture strength, and prognosis of failure.

GROUP	MEAN (STANDARD DEVIATION), NEWTONS*	PS,† %	COEFFICIENT OF VARIATION, %	FAILURE,‡ %	
				Not Repairable	Repairable
Composite Resin	1,680 (454)^c	37	27	60	40
Transfixed Post Plus Composite Resin	2,693 (372)^b	60	14	70	30
Onlay	2,922 (774)^b	65	26	70	30
Inlay	2,053 (313)^c	45	15	60	40
Sound Tooth	4,514 (548)^a	Not applicable	12	40	60

* Means followed by the same letter did not show statistically significant difference (Tukey, $P > .05$).
† PS: Percentage of fracture strength relative to the sound teeth group.
‡ Prognosis of failure considering the fracture of the pulp floor (not repairable) or cusp fracture (repairable).

TABLE 3

Mechanical properties of Lava Ultimate* and composite resin Filtek Z350 XT.†,‡

MECHANICAL PROPERTIES	LAVA ULTIMATE	FILTEK Z350 XT
Fracture Toughness, K_{1c}§	2.02	1.84
Compressive Strength, MPa¶	383	370.56
Flexural Strength, MPa	204	165.14
Flexural Modulus, MPa	12,800	11,348
Elastic Modulus, Gigapascal	12.77	12.77#

* Lava Ultimate (3M ESPE).
† Filtek Z350 XT (3M ESPE). Also known as Filtek Supreme XT in the United States.
‡ All data are provided by the manufacturer except for Filtek Z350 XT elastic modulus.
§ K_{1c}: Stress intensity factor.
¶ MPa: Megapascal.
\# Source: Rosa and colleagues.[28]

resistance among the endodontically treated molars restored with direct or indirect techniques. Endodontic access by removal of the pulp chamber roof, root canal enlargement, and use of high-concentration chemicals for an extended time contribute to reducing the fracture resistance of teeth.[2,4,20] Also, MOD preparations have lower fracture resistance than do sound teeth.[7,11] This occurs because of the removal of the marginal ridge, no matter the amount of tooth structure removed.[21] This may explain why no restoration could recover the fracture resistance of a sound tooth fully (Table 2). Jiang and colleagues[13] and Plotino and colleagues[7] found a fracture resistance decrease of 42% in teeth restored with direct composite and 44% in teeth restored with indirect composite. Bassir and colleagues[11] found contrary results; they detected a fracture resistance improvement when posterior teeth were restored either directly or indirectly with cusp coverage, reaching the same level as the sound group.

The CR and IN groups had no statistically significant differences in fracture resistance, similar to the results of Plotino and colleagues.[7] According to Frankenberger and collegues,[22] teeth with at least 1 marginal ridge with considerable volume may be restored with less invasive techniques. However, when compared with the ON group, both techniques resulted in lower fracture resistance. For Bassir and colleagues,[11] a 2-mm cusp reduction in mesio-occlusal and MOD cavities enhanced fracture resistance when compared with no cusp reduction. Frankenberger and colleagues[22] also observed this when studying partial crowns of various restorative materials.

When we compared indirect Lava Ultimate restorations, teeth restored with ONs had higher resistance than INs, similar to the findings of Jiang and colleagues,[13] who observed a more favorable stress distribution with ONs. According to another study, when the loss of tooth structure is extensive, involving functional cusps, the restorative option should be a full-coverage crown.[8] However, Stappert and colleagues[15] found no statistical difference between partial and full coverage of the cusps. Regardless of the preservation of tooth structure and of the relevance of adhesion for endodontically treated teeth, when it comes to reduction of cusp deflection,[9,21] functional cusp protection is desirable.[22]

Given the importance of adhesion to restorative dentistry, we cemented the indirect restorations in this study with a resin cement after application of adhesive in both restoration and tooth structure. Adhesive resin cements, when compared with self-adhesive ones, produce higher fracture resistance and lower cusp deflection, which can occur because of a high-quality and stable adhesion between the cement and the tooth structure.[19,21-23]

An alternative for the growing demand for conservative techniques could be the use of horizontal TFPs. In our study, this group had the second highest fracture resistance, which was not statistically different from that of the ON group. This technique has a lower cost than do indirect restorations, has satisfactory esthetics, and is easy to apply.[17] When compared with the CR group, the TFP group had more favorable results. The use of 2 posts led to recovery of approximately 60% of fracture strength when compared with the sound group and the

CR group at approximately 37% (Table 2). These results are similar to those of Beltrão and colleagues,[16] who observed a 29% fracture resistance recovery with direct composite restorations and 62% with the same technique with TFPs. Results from another study showed a 78% to 80% recovery of resistance by using 2 fiberglass posts with different diameters and 46% without the posts.[17] One possible explanation would be the reduction of cusp deflection caused by anchoring of the buccal and lingual walls of the cavity preparation.

The TFP procedure can be performed with either 1 or 2 posts. Beltrão and colleagues[16] obtained a mean resistance of 2,645 N by using a single fiberglass post, whereas Favero and colleagues,[17] using 2 posts of 1.1- or 1.5-mm diameter, produced 2,988 and 3,100 N, respectively. Despite the similarity, one can observe that using 2 posts produces higher fracture resistance. However, using a 1.5-mm post can increase technical complexity in short clinical crowns.[17]

All groups had fracture resistance higher than the maximum bite force in people with normal occlusion (630 N for men and 424 N for women),[24] so all the techniques used in this study can be used in these patients. In a study conducted in patients without bruxism and follow-up of 52 months, resin ONs had a survival rate of 96.8%.[25] For rehabilitation in patients with bruxism, it is wise to opt for treatments that have greater fracture resistance, such as the ON and TFP groups. From a biomechanical standpoint, the restoring decision should be made taking into account occlusal determinants, remaining dental structure, tooth position in the arch, and bruxism history.[5,9]

As to the failure patterns, similar to findings in prior studies,[6,14,26] groups restored with CR exhibited an increased number of nonrepairable failures compared with the sound group, which may have occurred because of the low modulus of these materials, which dissipate compression stress to the tooth structure.[13,21] Our results agreed with those of Ilgenstein and colleagues,[14] for whom Lava Ultimate had a high number of catastrophic failures. Failures occur because of the viscoelastic ability of composites, which accumulate a great amount of energy internally before breaking.[21,26,27]

Despite the manufacturer claim that they are different materials, the filler content of Lava Ultimate (80 weight percent) and Filtek Z350 XT (78.5 weight percent) is identical because it is composed of nonagglomerated 20-nanometer silicon particles, nonagglomerated 4- to 11-nm zirconia particles, clusters of zirconia, and a silicon compound. However, the manufacturer states that Lava Ultimate is a nanoceramic and that Filtek Z350 XT is a nanocomposite. Table 3[28] presents the mechanical properties of Lava Ultimate, which are slightly superior to those of Filtek Z350 XT. This improvement may occur because of the manufacturing process of both materials because Lava Ultimate is commercialized completely cured in a controlled environment by the manufacturer, which may generate a more stable polymer network not be as subject to early degradation as the direct CRs.[29] Regardless, our results had statistical similarity of fracture resistance in CR and IN with similar cavity preparations, despite the numerical superiority of Lava Ultimate. This discrete numerical superiority meets the comparisons between the mechanical properties described in Table 3[28] and allows one to speculate that in MOD preparations for INs, the professional may not have the benefits we imagined as a consequence of the supposedly superior mechanical properties. In an 11-year clinical study, van Dijken[30] compared direct and indirect composite restorations and also observed this.

A number of factors can interfere with the fracture resistance of endodontically treated teeth. Future clinical studies are required to be able to assess the long-term survival of direct and indirect MOD restorations of CR for CAD/CAM.

CONCLUSIONS

Endodontically treated molars have higher fracture resistance values when restored with ONs of Lava Ultimate or TFPs with direct CR. In comparison with results in the sound group, a higher number of nonrepairable fractures occurred in teeth restored with ONs or TFP plus CR, followed by IN and direct CR. ■

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