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Fracture Resistance of Cuspal Coverage of Endodontically Treated Maxillary Premolars with Combined Composite-Amalgam Compared to Other Techniques

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Clinical Relevance

Combined composite-amalgam for cuspal coverage of endodontically treated premolars was similar to direct composite coverage in strengthening restored teeth; however, composite onlay had the highest fracture resistance.

SUMMARY

This *in vitro* study investigated the fracture resistance of teeth restored with combined composite-amalgam for cuspal coverage compared to direct coverage with composite (with or without an amalgam base) and composite onlay. Seventy-two intact maxillary premolars were randomly divided into six groups (n=12). The two control groups were G1, intact teeth (negative control), and G2, mesio-occlusodistal preparation only (positive control). Each of the four experimental groups used a different type of restoration for the prepared teeth: G3, direct composite cusp coverage; G4, composite onlay; G5, direct composite coverage with an amalgam base; and G6, combined composite-amalgam cuspal coverage. After thermocycling, fracture strength was tested. The data were analyzed with analysis of variance and the least significant differences *post hoc* tests (α=0.05). Mean fracture resistance in the six

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groups (in N) were G1, 1101 ±1 86; G2, 228 ± 38; G2, 699 ± 161; G4, 953 ± 185; G5, 859 ± 146; and G6, 772 ± 154. There were significant differences between G1 and all the other groups except for G4 and between G2 and all the other groups. Fracture strength in G3 also differed significantly compared to G4 and G5. The difference between G4 and G6 was statistically significant ($p<0.05$), but the difference between G3 and G6 was not ($p>0.05$).

INTRODUCTION

The choice of an optimal restorative method for nonvital teeth is still a major challenge in the clinical setting. The success of endodontic treatment depends on the quality of the coronal restoration,[1,2] which should provide functional, esthetic marginal sealing and protect the remaining tooth structure.[3] Coronal leakage may lead to bacterial contamination, resulting in failure of a well-done endodontic treatment.[3,4]

Numerous studies have reported a high incidence of fracture in endodontically treated maxillary premolars.[2,5,6] Susceptibility to fracture is the result of the loss of marginal ridges and the pulp chamber roof during access preparation[2,7,8] and is a concern, particularly in maxillary premolars, because their anatomy facilitates separation of the cusps during mastication.[9] Fractures in the unsupported tooth structure can lead to restorative difficulties and even extraction if the tooth is unrestorable.[3,6] Therefore, endodontic treatment in combination with wide mesio-occlusodistal (MOD) preparation creates a situation where the remaining cusps should be protected to prevent fracture under occlusal loading.[8]

Routinely, these teeth are restored with a conventionally prefabricated or custom-made metallic post in combination with a cemented full crown;[10] however, this treatment has several disadvantages. Crown preparation is associated with considerable cutting of the tooth structure, resulting in the need for a post for core retention[11] and the risk of dislodgement, root fracture, and root perforation.[12] Furthermore, dental laboratory processing and the longer time needed for complex restorations after endodontic treatment make them extremely costly.[13] Moreover, the preservation of sound tooth structure is considered of primary importance to increasing the survival rate of nonvital teeth.[11] The type of restoration used may be affected by the amount of tooth structure remaining after preparation.[14] Although there is an increasing trend toward minimal-intervention dentistry, full-coverage crowns with a post and core are recommended to restore teeth with extensive loss of structure. Cuspal coverage is necessary to restore nonvital teeth without extensive structure loss.[3,8,10,15,16] However, cusp coverage with a metal casting or amalgam may not satisfy esthetically conscious patients, particularly if maxillary premolars are involved.[5]

In recent years, materials with mechanical properties more like dentin (such as composites), instead of very rigid materials (such as ceramics), have been preferred when restoring nonvital teeth.[17] In addition, resin composites with good bonding ability transmit and distribute functional stresses and hold the potential to reinforce weakened tooth structure.[18] Nevertheless, in large cavities, cusp coverage with direct or indirect composite restoration seems to be a more secure option.[19,20] This procedure takes the restoration margins to the axial surfaces, protecting the adhesive interface from early marginal discrepancies under loading.[19]

The major shortcoming of resin composite is high polymerization shrinkage stress, resulting in marginal gaps and microleakage, especially when the gingival margin is located in dentin. To overcome this problem and the technical difficulties associated with placement of extensive restorations, indirectly placed resin composite onlays have been proposed.[20-22] This treatment requires more than one appointment and is costly. Furthermore, there is controversy regarding significant benefit of extraoral polymerization on the mechanical properties of different resin composites.[23,24] Secondary curing can be performed using laboratory equipment and methods recommended by the manufacturers: heat alone, heat and light, heat and pressure, and light and vacuum.[23,24]

Combined composite-amalgam restorations may be a promising alternative. These hybrid restorations have been used for several years in extended or deep cavities.[25,26] A combination of favorable properties of two direct restorative materials may provide good esthetic results on both the labial and the occlusal aspects of extended or deep amalgam restorations.[27,28] A promising single-appointment technique for restoring nonvital maxillary premolars consists of reducing the two cusps, then covering the buccal cusp and veneering, and then covering the reduced cusp internally with resin composite. The remaining cavity and the reduced palatal cusp are restored with amalgam.[29] However, fracture resistance with this technique and with amalgam applied beneath the direct composite coverage is unclear. One study reported that applying amalgam under the composite to restore nonvital maxillary premolars with an MOD cavity without coverage increased resistance to fracture in the treated tooth up to 51% compared to teeth restored with amalgam alone.[28] The aim of the current study was to compare fracture resistance after restoration with these two combined composite-amalgam techniques and with direct or indirect composite application for cuspal coverage in nonvital maxillary premolars.

MATERIALS AND METHODS

Following approval of the research protocol by the local ethics committee, 72 sound, noncarious, single-root maxillary premolars extracted for orthodontic treatment were used. The root and crown of the teeth were similar in size and were stored in 0.5% thymol solution at 4°C. The cleaned teeth were carefully inspected under a stereomicroscope (Carl Ziess, Oberkochen, Germany) at 20× magnification to exclude teeth with defects, such as fracture lines. The teeth were then randomly divided into six groups of 12 teeth each and subjected to the following procedures:

Group 1

Unaltered intact teeth were used as the negative control (G1, NC).

Groups 2–6

Endodontic access cavities were prepared with a high-speed diamond bur under constant water cooling, and the canals were instrumented with #10 to #40 K-files (Mani Inc, Tochigi, Japan) and distilled water. The canals were dried with absorbent paper points and obturated with laterally condensed gutta-percha cones (Ariadent, Tehran, Iran) and AH26 sealer (Densply DeTrey, Konstaz, Germany). Mesio-occlusodistal cavities were prepared with the gingival margin located at the cemento-enamel junction. The buccolingual width of each cavity was half the intercuspal distance at the isthmus and two boxes, and the cavities extended into the pulp chamber. Measurements were made with a digital caliper (Mitutoyo Digimatic, Mitutoyo, Japan) at 0.1-mm sensitivity for proper and accurate standardization of cavity dimensions. In group 2, MOD-prepared only, these teeth were not restored and were used as the positive control (G2, PC). In groups 3–6, both the buccal and the palatal cusps were reduced in height to allow for 2-mm cuspal coverage except in group 6, where the palatal cusp was reduced 3 mm in each tooth. Prior to cavity preparation and cusp reduction, an impression of the crown was taken with a polyvinyl siloxane impression material (Speedex, Coltène Whaldent AG, Attstatten, Switzerland) to act as a guide for the original shape of the crown upon restoration.

Group 3: Direct Composite Coverage (G3, Di-Com)

A 1-mm layer of resin-modified glass ionomer (Vitremer, 3M ESPE, St Paul, MN, USA) was applied on top of the filled root canal. All cavity surfaces were etched with 37% phosphoric acid (3M ESPE) for 30 seconds (enamel) and 15 seconds (dentin), rinsed with a water spray for 20 seconds, and gently air-dried, leaving the tooth moist. Two consecutive coats of Single Bond (3M ESPE) were applied and gently dried for 2 to 5 seconds, then light-cured for 10 seconds with a halogen light unit (Coltolux, Coltène) at an intensity of 500 mW/cm^2. Light intensity output was checked every 10 restorations with a light meter from the same manufacturer. A matrix retainer system (Tofflemire, Miltex Inc, York, PA, USA) was set in place and stabilized, and a microhybrid resin composite (Z250, 3M ESPE) was placed using the oblique incremental technique. Each increment was no more than 1.5 mm and was polymerized for 40 seconds with the same light unit. The external layer was polymerized after application of a glycerin gel (Deox, Ultradent, South Jordan, UT, USA), permitting complete polymerization in an anaerobic environment. After removing the matrix, finishing, and polishing, further polymerization was done from each axial aspect for 60 seconds.

All the preparations and restorations were performed by the same operator. Throughout the experiment, in order to prevent dehydration of the teeth, they were handled in moist gauze and stored in an incubator at 37°C and 100% humidity.

Each tooth was embedded in a block of self-curing acrylic resin (Acropars, Tehran, Iran) surrounded by polyvinyl siloxane impression material up to 1 mm apical to the cemento-enamel junction (CEJ), with the long axis of the tooth perpendicular to the base of the block.

Group 4: Composite Onlay (G4, Com-Onlay)

After application of a layer of Vitremer, as in G3, a polyvinyl siloxane impression of the cavity was taken to produce a hard stone working model. The onlays were fabricated with the same resin composite and technique used for the direct restorations. The composite onlays were then removed from the model after initial curing and further polymerized in an oven. The internal surfaces of the onlays were sandblasted, washed, and air-dried, then a silane-coupling agent (ceramic primer, 3M ESPE) was applied. The tooth surface was prepared with etching and bonding, and the onlay was luted with a dual-cured cement (Rely X ARC, 3M ESPE) according to the manufacturer's instructions.

Group 5: Combined Amalgam-Composite (G5, Am-Com)

After completing the bonding procedures, as in G3, a 2-mm layer of a high copper admix alloy amalgam (GS-80, SDI Ltd, Melbourne, Australia) was condensed on the whole of the gingival floor. After initial setting, a second layer of Single Bond was applied to the condensed amalgam and light-cured, then the remainder of the cavity was restored with the same composite as in G3.

Group 6: Combined Composite-Amalgam (G6, Com-Am)

First, the entire remaining reduced buccal cusp was prepared for veneering, and bonding was done as in G3. This preparation and the internal surface associated with coverage of the reduced buccal cusp were restored incrementally with the same resin composite. The restored buccal cusp was finished and polished, then the balance of the cavity and the reduced palatal cusp were restored with an admix alloy amalgam (GS-80).

All specimens were stored for 24 hours and thermocycled for 1000 cycles at 5°C and 55°C prior to static fracture resistance testing using a universal testing machine (Zwick-Roell, Zwick, Ulm, Germany). The specimens were subjected to a compressive force at a crosshead speed of 1 mm/min. The force was applied by a 4.8-mm-diameter round metal bar positioned parallel to the long axes of the teeth, in contact with the occlusal slopes of the buccal and lingual cusps. Peak load to fracture for each tooth was recorded in Newtons (N). Statistical analyses consisted of one-way analysis of variance (ANOVA followed by the *post hoc* LSD test to compare differences between the groups at a significance level of 0.05. All statistical analyses were done with SPSS Version 11.5 software (IBM, Armonk, NY, USA).

The fractured specimens were then examined by two independent operators to determine whether the fracture mode was favorable (fractures ending above the CEJ [or less than 1 mm below the CEJ] or unfavorable [fractures ending more than 1 mm below the CEJ]).[30]

RESULTS

Fracture resistance in Newtons (mean ± SD) for the six groups is shown in Table 1. Comparisons with ANOVA revealed significant differences in fracture resistance among the six groups ($p<0.05$). Group 1 (intact teeth) had the highest fracture resistance (1101.75 N), which was significantly higher than in all the other groups ($p<0.05$), except group 4 (Com-Onlay, 953.17 N). Group 2 (PC) had the lowest fracture resistance (228.75 N), which was significantly lower than in all the other groups ($p<0.05$). The fracture strength of group 3 (Di-Com, 699.33 N) was significantly lower than in group 4 (Com-Onlay, $p<0.001$) and group 5 (Am-Com, 859.00 N) ($p<0.05$). However, the difference between group 3 and group 6 (Com-Am, 772.00 N) was not significant ($p>0.05$). Group 6 showed significantly lower fracture resistance compared to group 4 ($p>0.05$), but the differences between groups 4 and 5 and groups 5 and 6 were not significant ($p>0.05$).

The frequencies of favorable and unfavorable fractures are shown in Table 2. Most of the fractures in groups 1 and 2 (controls) were favorable (91.7% and 75%, respectively). In the four experimental groups, approximately 50% of the fractures were favorable (Figures 1 through 3).

DISCUSSION

Removal of the internal tooth structure during endodontic treatment, combined with MOD cavity preparation, significantly reduced fracture resistance in the current study's experimental model. This result is in agreement with the findings of Reeh

Table 1: *Fracture resistance (mean ± SD) in the six groups.*

Group	Group Code	Mean (SD) (Newtons)[a]	Minimum (Newtons)	Maximum (Newtons)
1	NC	1101.75 (186) A	868	1410
2	PC	228.75 (38) B	180	290
3	Di-Com	699.33 (161) C	459	990
4	Com-Onlay	953.17 (185) A	735	1360
5	Am-Com	859.00 (146) A,D	630	1060
6	Com-Am	772.00 (154) C,D	525	998

[a] *Groups with the same letter were not significantly different ($p>0.05$).*

Table 2: *Frequencies (Percentage) of favorable and unfavorable fractures in the six groups.*

Group	N	Favorable Fractures	Unfavorable Fractures
1	12	11 (91.7%)	1 (8.3%)
2	12	9 (75.0%)	3 (25.0%)
3	12	7 (58.3%)	5 (41.7%)
4	12	5 (41.7%)	7 (58.3%)
5	12	6 (50.0%)	6 (50.0%)
6	12	6 (50.0%)	6 (50.0%)

and others,[31] who reported a 69% reduction in fracture resistance in treated teeth compared to intact teeth. The important role of loss of the marginal ridges in reducing fracture resistance in endodontically treated teeth was also reported in other studies.[3,7,32-34] In the current study, cuspal reinforcement using bonded composite restoration can partially compensate for the compromised fracture resistance.[18,21] However, adhesive restoration alone is not capable of restoring fracture resistance to the level seen in intact posterior teeth.[20,21,31]

In light of these earlier findings, the authors of this study tested different modes of cuspal coverage in their experimental groups. The highest fracture

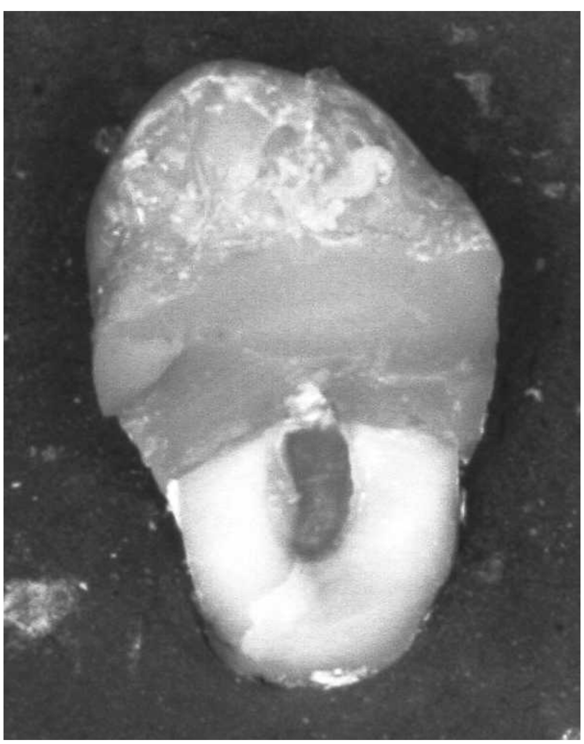

Figure 1. *Mode of failure: favorable.*

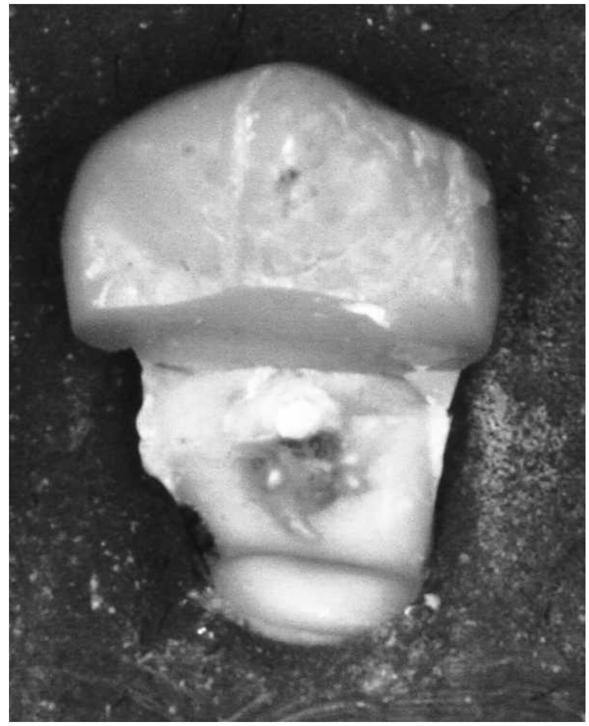

Figure 2. *Mode of failure: unfavorable from occlusal view.*

Figure 3. *Mode of failure: unfavorable from proximal view.*

resistance was found in teeth treated with a composite onlay. Fracture resistance in this group did not differ significantly from intact teeth and was significantly higher than in teeth treated with direct composite cusp coverage. Other studies also found higher or equivalent fracture resistance in teeth restored with composite onlays or direct composite coverage compared to intact, unrestored teeth.[19,35,36] Yamanda and others[37] reported significantly lower fracture resistance in onlay-restored premolars than in intact premolars. They suggested that this effect might be related to the reduction of two cusps to only 1.5 mm, that is, below the 2-mm minimum thickness needed according to Burke and others.[35]

In general, onlay preparations result in tooth restoration at the buccal and lingual surfaces. This effect prevents separation due to the wedge effect caused by cusp elongation and reduces cusp flexion.[19] Cuspal coverage by a resin composite onlay with good bonding to the tooth structure decreases stresses in the remaining tooth structure. This effect, in combination with the confining effect of onlay restorations, enhanced fracture resistance.[35] Additionally, resin composites can absorb compressive loading forces.[36] The higher fracture resistance of composite onlays compared to direct composite coverage in the current study contrasts with some earlier reports.[20,21,38,39] This discrepancy may be related to the type of restoration. In earlier studies, fracture resistance of premolars restored with composite inlays was similar to that of direct composite MOD restorations. Only one study found that fracture resistance was similar after coverage of two mesial cusps in nonvital molars with direct and indirect resin composite restorations. A comparison of these results with the current study is difficult because of differences in the experimental design regarding the type and size of the teeth used, the materials examined, the size and design of the cavities, and the direction and speed of the applied load. In the current study, although the same composite was used for two types of restorations (groups 3 and 4), the restorations were prepared and placed with different techniques.

Earlier studies have reported contradictory results regarding the effects of postcuring on the mechanical properties of resin composites. Some *in vitro* studies found that material properties, such as diametral tensile strength, elastic modulus, fracture toughness, flexural strength, and hardness, were improved by postcuring.[22,40] However, others found no or only slight improvements in mechanical properties.[23,24] The authors of this study postulate that fracture resistance of MOD restorations with cuspal coverage is influenced more by mechanical properties of the resin composite bulk than by the composite inlay. The higher fracture resistance of composite onlays might be attributable to toughening of the polymer matrix, resulting from the greater degree of conversion and cross-link density of the polymer.[41] In addition, postcuring can relieve stresses generated during the initial curing.[22]

In the current study, thermocycling was performed with water baths. Water may have different effects on the mechanical properties of the resin composites in the two types of restoration used. One earlier study found that water sorption decreased the modulus and ultimate strength of the resin composite, whereas it did not appear to affect strength to the same degree in restorations after postcuring.[23] Nevertheless, *in vivo* studies found no clinical advantages of composite inlays or onlays compared to direct composite restorations, and their fracture tendency after postcuring was equal to or slightly better than that of direct composite restorations.[22,42,43]

The authors of the current study found that placement of a layer of amalgam under the composite for cuspal coverage enhanced fracture resistance of the restored teeth. This layer of amalgam may decrease the bulk of composite at the base of the cavity and between cavity walls, reducing the amount of polymerization shrinkage stress. Furthermore, in clinical situations, this combination can improve marginal sealing, particularly at deep gingival margins. In these deep dentinal surfaces, it is difficult to provide adequate isolation and light intensity. Moreover, the durability of dentin bonding agents is unreliable. Improvements in dentinal marginal sealing of class II composite restorations were reported with amalgam filling of the gingival third of the proximal box.[44]

Fracture resistance after combined composite-amalgam cusp coverage in the current study's experimental restorations was similar to that of direct composite and amalgam-based composite coverage and lower than indirect composite onlays. In the former technique, coverage of the reduced buccal cusp and internal and external reinforcing of this cusp with composite were combined with coverage of the palatal cusp with amalgam. Both amalgam and composite cuspal coverage are capable of providing adequate fracture resistance in restored teeth. Despite the location of the interface between the two materials on the occlusal surface, the fracture resistance of combined restored teeth was similar to that of the other two experimental direct composite restorations. Despite the lack of chemical interaction between the two materials, intimate adaptation was reported at the interface in an *in vitro* study.[45] When the resin composite is first placed and polymerized, amalgam particles can intermix with the oxygen-inhibited layer during amalgam condensation. This interlocking may provide adequate bonding and sealing at the composite-amalgam interface.[27] Thus, compressive loading used during the fracture resistance test may be evenly distributed through the whole restored tooth by the two materials because amalgam has an elastic modulus close to that of resin composite and dentin,[46] preventing stress concentration and fracture. Fracture analysis revealed that in only one specimen in group 6 (Com-Am), amalgam separated from the composite at the interface without fracture of the remaining tooth structure, resulting in a restorable fracture.

The results of a recent three-year evaluation of a small sample of patients indicated acceptable clinical performance of endodontically treated maxillary premolars restored with combined composite-amalgam coverage.[29] A retrospective clinical assessment of 12 combined restorations in extended class II cavities of vital maxillary posterior teeth reported that the composite-amalgam interface in all restorations seemed to be clinically acceptable, even in a six-year-old restoration.[47]

It has been well established that axial forces are less detrimental than oblique forces for fracture resistance in restored teeth.[48] In particular, shear stresses applied to the cusps may result in mechanical failure of the composite-amalgam interface at the occlusal surface. Further studies are needed to investigate whether shear forces would affect the results of the current study.

In this study, minimum fracture resistance in all four experimental groups was greater than physiological mastication forces in the posterior region (300 N). A maximum biting load of 350–500 N was generated during function in the premolar region by a patient with no parafunctional habits.[49] In studies similar to this one, the specimens were loaded in a direction parallel to their longitudinal axis. This axial loading resulted in a more uniform distribution of the stresses, simulating normal occlusion.[1,50] However, these studies did not reproduce typical mastication forces because they applied a continually increasing force until fracture occurred. This compressive static loading is different from the dynamic fatigue loading typical of mastication, with a mixture of shear and compressive forces. Nevertheless, the fracture resistance test is the most appropriate model for determining clinical conditions under which fractures can occur[51] and is an important source of information on the structural integrity of restored teeth.

In clinical situations, the prognosis after restoration failure depends on the location of the fracture. A tooth with a fracture below the CEJ is difficult or impossible to restore. However, in all four experimental groups that the authors studied, approximately half the fractures ended more than 1 mm below the CEJ. Therefore, selection of the restorative technique should be based on other critical properties in clinical situations. In choosing the type of restoration, important clinical factors that should be considered include sealing ability of the restoration, handling characteristics, endodontic or periodontal prognosis, treatment time, number of dental appointments, dental laboratory support needs, and cost of the restoration. Further *in vitro* studies that more accurately simulate *in vivo* conditions and long-term clinical trials should be conducted to confirm the findings of the current study.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following can be concluded:

1. Endodontic treatment associated with MOD preparation significantly reduced the fracture resistance of maxillary premolars.
2. Although fracture resistance was better in all other restoration groups than in the MOD-only group, only the composite onlay was capable of completely restoring fracture resistance in endodontically treated maxillary premolars with MOD preparation.
3. Fracture resistance after combined composite-amalgam cuspal coverage was similar to that achieved with direct composite coverage and amalgam-based composite restorations.
4. No significant differences among the four restoration groups were seen in the frequency of favorable versus unfavorable fractures.

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