A comparative evaluation of the fracture resistance of endodontically treated teeth with simulated invasive cervical resorption cavities restored with different adhesive restorative materials: An *in vitro* study

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**Abstract**

Aim: The aim of the study was to compare the fracture resistance of endodontically treated teeth with simulated invasive cervical resorption cavities, restored with different restorative materials, namely, conventional glass-ionomer cement (CGIC), resin-modified glass-ionomer cement (RMGIC), flowable composite (FC), and giomer.

Methods: Sixty extracted human permanent maxillary central incisor teeth were assigned to six groups, which were, Group 1 (intact teeth, control), Group 2 (teeth with biomechanical preparation and resorption cavity), Group 3 (CGIC), Group 4 (RMGIC), Group 5 (FC), and Group 6 (giomer). Except for Group 1, other groups were subjected to endodontic treatment. Teeth of Group 2 were left unobturated and teeth of Groups 3–6 were obturated. A simulated resorption cavity was prepared labially in the specimens belonging to Groups 2–6 and restored with respective restorative materials. The specimens were subjected to compressive load until failure in an Instron testing machine and the load at failure was recorded in Newtons.

Statistical Analysis: The data obtained were statistically analyzed using one-way ANOVA, pair-wise comparison was made with Tukey’s multiple comparison test, and *P* < 0.05 was considered statistically significant.

Results: There was a statistically significant difference in the fracture resistance of intact teeth and endodontically treated teeth with simulated invasive cervical resorption cavities restored with different adhesive restorative materials. Among the restored teeth, there was no significant difference.

Conclusion: Intact teeth were found to have the highest resistance to fracture followed by those restored with giomer, FC, RMGIC, and CGIC in that order.

**Keywords:** Endodontically treated teeth; flowable composite; giomer; glass-ionomer cement; invasive cervical root resorption; resin-modified glass-ionomer cement

**INTRODUCTION**

Invasive cervical root resorption (ICR) is an insidious and aggressive form of external root resorption. The potential predisposing factors of ICR are orthodontics, dental trauma, intracoronal bleaching, delayed eruption, surgery involving cementoenamel junction (CEJ), bruxism, developmental defects, and deep root scaling.[1] Clinically, ICR may present as a pink spot next to the cervical margin and seen radiographically as a radiolucent lesion, which penetrates the tooth through small denuded areas.[2,3]
According to Heithersay, ICR can be classified as follows:41

- Class 1: a small invasive resorption lesion near the cervical area with shallow penetration into the dentin;
- Class 2: a well-defined invasive resorptive lesion that has penetrated close to the coronal pulpal chamber but shows little or no extension into the radicular dentin;
- Class 3: a deeper invasion of dentin by resorbing tissue, not only involving the coronal dentin but also extending at least to the coronal third of the root; and
- Class 4: a large invasive resorptive lesion that has extended beyond the coronal third of the root.

The basic aim of the treatment of ICR is to inactivate all the active resorbing tissues by nonsurgical or surgical approach and restore the ICR cavities with a suitable restorative material.23 Various materials used for the restoration of ICR cavities are as follows: glass-ionomer cements (GICs), resin composite, amalgam, mineral trioxide aggregate, and giomer to enhance the resistance to fracture of endodontically treated teeth by bonding to weakened tooth structure.44–7

The objective of the study was to compare the fracture resistance of endodontically treated teeth with simulated ICR cavities when restored with different adhesive restorative materials, namely conventional GICs (CGIC), resin-modified GICs (RMGIC), flowable composite (FC), and giomer. The null hypothesis tested was there would be no difference in the fracture resistance of endodontically treated teeth with simulated ICR cavities restored with different adhesive restorative materials.

**METHODS**

Sixty caries-free extracted (<3 months) human permanent maxillary central incisors with single root of similar dimensions were included in the study. They were immersed in 5% sodium hypochlorite (NaOCl, Prime dental products Pvt Ltd, Thane Bhiwandi Road, Kalher, Bhiwandi, Thane-421302, Maharashtra, India) for an hour to remove any organic debris on it. All the teeth were cleaned free of calculus and tissue tags using hand scalers, along with curettage of the root surface to remove any soft-tissue remnants, without causing undue damage to the tooth. The teeth were examined under a dental operating microscope for preexisting resorptive defects, craze lines, or cracks. Radiographs of the teeth were taken to exclude teeth with preexisting resorptive defects, canal calcifications, canal abnormalities, multiple canals, bifurcations, and previous endodontic treatment. Teeth were stored in 0.9% normal saline solution (Althea Pharma Private Ltd, 501, Aston Tower, Shastri Nagar, Andheri W, Mumbai 400053, Maharashtra, India) at room temperature to prevent dehydration before and during the experimental procedures. The selected teeth were randomly assigned to the following six groups (n = 10):

- **Group 1:** Specimens were not prepared and served as control
- **Groups 2, 3, 4, 5, and 6:** Specimens were submitted to conventional endodontic treatment. Palatal access cavity was prepared, and working length was determined by no. 10 K file (Mani, INC, 8 3 Kiyohara Industrial Park, Utsunomiya, Tochigi, Japan).

The canal was enlarged to a master apical file size 40 K file followed by stepback preparation. During this process, the root canals were intermittently irrigated with 10 ml of 5% NaOCl. Later, the specimens were subjected to the following procedures group wise:

- **Group 2:** The specimens were left unobturated
- **Group 3, 4, 5, and 6:** The root canals were obturated with gutta-percha (Dentsply India Pvt Ltd Manesar, Gurgaon, India) and AH Plus sealer (Dentsply, India Pvt Ltd), by lateral compaction technique. The access cavities were sealed with Cavit (3M™ ESPE™ dental products, St. Paul, MN 55144-1000, USA). All the specimens including those of Groups 1 and 2 were stored for 72 h at 37°C and 100% relative humidity in an incubator (Dolphin Laboratories Ltd, Bhowanipur, Kolkata, West Bengal, India).

Simulated ICR cavity was prepared at the point of intersection of the long axis of the tooth and CEJ obtained using a surveyor (Paraflex BEGO USA. Inc.20 Albion Road, Lincoln RI 02865, USA). At the decided point, a circle of 3-mm diameter and 2-mm depth was drawn equidistant from the CEJ [Figure 1] using a customized template. Resorptive cavities were prepared with a round diamond point (BR 41ISO/001/014 Mani Inc 8-3 Kiyohara Industrial Park, Utsunomiya, Tochigi, 321–3231, Japan) on teeth belonging to Groups 2–6.

The simulated ICR cavity of Group 2 specimens was left unrestored. The ICR cavities of specimens belonging

**Figure 1:** Schematic diagram showing the simulated invasive cervical resorptive cavity prepared in the specimens
to groups 3, 4, 5, and 6 were rinsed with normal saline. The internal wall of the cavity was gently rubbed with 90% aqueous solution of trichloroacetic acid (TCA, Merck Specialties Private Limited, Mumbai, Maharashtra, India) for 2 min. The cavity was rinsed and freshened again with the round diamond point, rinsed, blot dried, and restored with respective restorative materials assigned to the groups according to the manufacturer’s instructions as given below:

Group 3: Cavity was conditioned with GC cavity conditioner (GC Corporation, Tokyo, Japan) followed by placement of CGIC (GC Gold label II Universal Restorative, GC Gold label II Universal Restorative, GC Corporation Itabashi-Ku, Tokyo, Japan). A protective layer of two coats of dentin bonding agent, Adper Single Bond 2 (3M ESPE St. Paul, MN 55144-1000, USA), was applied and cured with a light-emitting diode light-curing unit (DB-685 Penguin, Foshan city, Guangdong Province, China) for 20 s.

Group 4: The cavity walls were conditioned with GC cavity conditioner (GC Corporation, Tokyo, Japan) followed by placement of RHMGC (GC Gold label II LC, light-cured Universal Restorative, GC India Dental Pvt Ltd) and light cured for 20 s. A protective layer of two coats of dentin bonding agent (Adper Single Bond 2) was applied and cured for 20 s.

Group 5: The cavity walls were etched with 37% phosphoric acid (Scotchbond Etchant, 3M ESPE St. Paul, MN 55144-1000, USA) for 15 s and thereafter rinsed for 10 s. After blot drying, three consecutive coats of Adper Single Bond 2 adhesive was applied to the etched enamel and dentin for 15 s and light cured for 20 s. Filtek Z350 XT shade A3, a FC (3M ESPE St. Paul, MN 55144-1000, USA), was placed and light cured for 20 s.

Group 6: Three consecutive coats of the adhesive Beautibond (Shofu Inc. Kyoto, Japan) was applied on to the cavity walls for 15 s and light cured for 20 s. Beautiful II Giomer, shade A3 (Shofu Inc. Kyoto, Japan) was placed and light cured for 20 s.

The intensity of the light-curing unit was checked by a digital light meter (Bluedent BG Light Ltd 155, Vasil Aprilov Blvd, 4027 Plovdiv Bulgaria) before curing each restoration. All the specimens were placed in light-proof containers and allowed to set for 24 h at 37°C and 100% humidity in an incubator. The teeth were mounted in acrylic blocks measuring 30 mm in height and 25 mm in diameter perpendicularly at the center of the acrylic resin using a surveyor with CEJ 2 mm coronal to the resin surface. The samples were stored in distilled water at room temperature for 24 h before subjecting to fracture testing. The specimens were submitted to compressive load in an Instron testing machine (Instron 5567, NVLAP, Norwood, MA, USA) with a jig that allowed loading at an angle of 135° to the long axis of the tooth. The load was applied 3 mm from the incisal edge on the palatal surface at a constant cross-head speed of 0.5 mm/min with a 45° beveled metallic rod until the first sharp drop of the load was observed on the displacement–load curve, indicating a sudden decrease in the specimen’s resistance to compressive loading (failure load) and was recorded in Newtons (N). Further, the failures observed were classified according to the level of fracture into favorable where the fracture line was at/above the CEJ (restorable) and catastrophic where the fracture line was below the CEJ (nonrestorable).

**Statistical analysis**

The data obtained were tabulated and subjected to statistical analysis using SPSS software version 16 (SPSS Inc., Chicago, IL, USA). The normality of data was tested using Kolmogorov–Smirnov and Shapiro–Wilks tests. The data were found to be normally distributed, and parametric tests were applied to compare the means between different groups. Further, pair-wise comparison for the significance for any two groups was done applying Tukey’s multiple comparison test. The level of significance was set at 5%, and $P < 0.05$ was considered statistically significant.

**RESULTS**

Table 1 shows the mean, standard deviation, and minimum and maximum load to failure of all the six groups. The highest mean fracture resistance was shown by the specimens of Group 1 followed by those of Groups 6, 5, 4, 3, and 2, as illustrated in Graph 1. The ANOVA test showed significant difference between the mean fracture load of all the six groups [Table 2]. Further, pair-wise comparison using Tukey’s honestly significant difference post hoc test [Table 2] showed statistically significant difference with higher fracture resistance of intact teeth (Group 1) when compared to that of Groups 2, 3, 4, 5, and 6. Specimens of Group 2 showed significantly lower load to failure when compared with...
that of Groups 1, 3, 4, 5, and 6. Specimens restored with giomer (Group 6) showed the highest resistance to failure. The fracture resistance of teeth restored with different adhesive materials (Groups 3, 4, 5, and 6) was statistically insignificant as observed in the pair-wise test [Table 2]. In addition, when comparing the mean values of Group 1 with those of Groups 5 and 6, it was statistically not significant [Table 2]. All the specimens underwent oblique horizontal crown-root fracture through cervical portion of the tooth with 38.3% favorable (restorable) and 61.7% catastrophic (nonrestorable) fracture.

### DISCUSSION

Invasive cervical root resorption causes progressive, destructive loss of tooth structure, and it can occur in any permanent tooth.\(^5\) Maxillary incisors are more prone to traumatic injuries, therefore ICR are more prevalent in them.\(^1,3\) Clinically, patients often present with Heithersay’s Class 3 resorption defect.\(^4\) Hence, recently extracted maxillary central incisors were included in the study and simulated ICR cavity was prepared in the cervical third of the tooth. The teeth were endodontically treated because teeth with Class 3 lesions may often require pulpectomy to get access to the resorptive tissue.\(^3,9\) The cavities were prepared after the obturation of root canals because prior preparation followed by restoration would have complicated the further endodontic steps. However, in clinical conditions, the resorptive cavities are usually present before the onset of pulpal involvement. The clinician may commence with the endodontic procedure and then proceed to treat the resorptive defect.\(^4\) The primary objective of the study was to check the fracture resistance of the tooth when the resorption cavities are restored by different adhesive materials.

Traditional methods of ICR treatment involve curettage of the active tissue from the resorption cavity followed by restoring the defect with a suitable restorative material. An alternative method involves topical application of 90% aqueous application of 90% aqueous trichloracetic acid followed by curettage and restoration. TCA causes

### Table 1: Descriptive statistics

| Group | Mean (n) | Standard deviation | Maximum value in the group (n) | Minimum value in the group (n) |
|-------|---------|--------------------|-------------------------------|-----------------------------|
| Group 1 | 615.15  | 115.58             | 767.34                        | 428.26                      |
| Group 2 | 330.63  | 46.97              | 408.66                        | 249.90                      |
| Group 3 | 471.78  | 107.16             | 652.97                        | 325.11                      |
| Group 4 | 476.15  | 120.87             | 693.44                        | 322.12                      |
| Group 5 | 491.33  | 101.62             | 653.07                        | 324.28                      |
| Group 6 | 528.48  | 112.82             | 688.64                        | 361.91                      |

Group 1: Control, Group 2: Unobturated and unrestored, Group 3: Conventional glass-ionomer cement; Group 4: Resin-modified glass-ionomer cement, Group 5: Flowable composite, Group 6: Giomer

### Table 2: (a) One-way analysis of variance (ANOVA) (b) Tukey’s HSD multiple comparison test

**Fracture load**

| Between groups | SS     | Df  | MS     | F       | P     |
|----------------|--------|-----|--------|---------|-------|
| Within groups  | 582401.14 | 54  | 1013928.288 | 7.965  | 0.000 |

**Groups (I)**

- **Group 1**
- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**Groups (J)**

- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**Mean difference (I-J)**

- **Group 1**
- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**SE**

- **Group 1**
- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**P**

- **Group 1**
- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**Interpretation**

- **Group 1**
- **Group 2**
- **Group 3**
- **Group 4**
- **Group 5**
- **Group 6**

**Post hoc tests (Tukey’s HSD): P<0.05 indicates statistical significance of difference**

| Groups (I) | Groups (J) | Mean difference (I-J) | SE   | P     | Interpretation |
|------------|------------|-----------------------|------|-------|----------------|
| **Group 1** | **Group 2** | 284.5280*             | 46.44396 | 0.000 | Significant difference |
| **Group 2** | **Group 3** | 143.37200*            | 46.44396 | 0.036 | Significant difference |
| **Group 3** | **Group 4** | 139.00600*            | 46.44396 | 0.045 | Significant difference |
| **Group 4** | **Group 5** | 123.82500*            | 46.44396 | 0.099 | Nonsignificant difference |
| **Group 5** | **Group 6** | 197.85100*            | 46.44396 | 0.001 | Significant difference |
| **Group 2** | **Group 3** | 141.15600*            | 46.44396 | 0.040 | Significant difference |
| **Group 3** | **Group 4** | 145.52200*            | 46.44396 | 0.032 | Significant difference |
| **Group 4** | **Group 5** | 160.70300*            | 46.44396 | 0.013 | Significant difference |
| **Group 5** | **Group 6** | 197.85100*            | 46.44396 | 0.001 | Significant difference |
| **Group 3** | **Group 4** | -4.36600              | 46.44396 | 1.000 | Nonsignificant difference |
| **Group 4** | **Group 5** | -19.54700             | 46.44396 | 0.998 | Nonsignificant difference |
| **Group 5** | **Group 6** | -56.69500             | 46.44396 | 0.825 | Nonsignificant difference |
| **Group 4** | **Group 6** | -15.18100             | 46.44396 | 0.999 | Nonsignificant difference |
| **Group 5** | **Group 6** | -52.32900             | 46.44396 | 0.868 | Nonsignificant difference |

*The mean difference is significant at the 0.05 level. *P<0.05 indicate significance of difference.

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1. Bolli, et al.: Fracture resistance of endodontically treated teeth with simulated ICR cavities restored with adhesive restorations.
2. Conventional glass-ionomer cement; Group 4: Resin-modified glass-ionomer cement, Group 5: Flowable composite, Group 6: Giomer, SE: Standard error, HSD: Honestly significant difference, SS: Sum of squares, Df: Degrees of freedom, MS: Mean square.
coagulation necrosis, thus rendering the resorptive tissue avascular.\(^4\) By this approach, it was seen that hemorrhage could be controlled, which is essential for adequate treatment. Moreover, TCA prevents recurrence of ICR by the inactivation of adjacent potentially resorptive cells.\(^2\) Thus, in the present study, the simulated resorptive cavities were treated with TCA.

The ICR cavities were restored with RMGIC, CGIC, FC, and giomer. Glass-ionomer and resin composites are suggested for restoring cervical cavities, especially noncarious cervical lesions as they show satisfactory retention in cervical dentin; provide fluoride release; inhibit secondary caries; and possess optimum abrasion resistance, color match, marginal discoloration, and adaptation.\(^{10,11}\) One study recommended RMGIC over CGIC and composite resins in cervical cavities because of its improved bond strength, better physical proprieties, better polishing, wider color range and translucence, excellent long-term performance and fluoride release, good retention results, reduced superficial degradation, and increased wear resistance. In addition, use of conditioners and primers containing hydroxyethyl methacrylate prior to application of GICs promotes adhesion similar to the hybrid layer observed with the use of adhesive bond systems.\(^{12}\)

The low modulus of elasticity of restorative materials used in the current study allows deformation and absorption of induced stresses;\(^{13}\) helps resist polymerization shrinkage stresses; and favorably dissipates stresses produced by thermal variations, water absorption, and occlusal loads across the interface.\(^{14}\) It also allows the restoration to flex with tooth rather than de-bond.\(^{15-17}\) Therefore, in the present study, the simulated ICR cavities were restored with CGIC, RMGIC, FC, and giomer. It was observed that none of the restorative materials de-bonded spontaneously from the test samples during fracture testing, in agreement with the study by Xie et al.\(^{18}\)

In the current study, intact teeth (control) were observed to have the highest resistance to fracture [Table 1], indicating that endodontic treatment and ICR cavity probably weakened the tooth. Moreover, among the restored specimens, higher resistance to fracture was shown by those belonging to Group 6 (giomer). Giomer is a tooth-colored restorative material that is formulated by a unique resin base and prereacted glass (PRG) technology.\(^{19}\) This technology involves the prereaction of the surface of fluoro-aluminosilicate glass fillers with polyacrylic acid and a glass core remains, forming a stable phase of glass-ionomer in order to form the surface PRG (S-PRG) filler. These fillers are then incorporated into a resin matrix. The final product is composed of a stable phase of glass-ionomer suspended in resin matrix.\(^{20}\) The unique S-PRG technology, cross-linked polymer matrices, and modulus of elasticity could have contributed to obtain superior results in this group.\(^{21,22}\) However, there was no statistically significant difference in the load to failure among different restorative materials [Table 2]. Hence, the null hypothesis was not rejected.

In the current study, majority of the specimens showed catastrophic oblique fractures apical to CEJ (unfavorable – 61.7%). The maximum tensile and compressive stresses are noticed at the CEJ level, both on the buccal and palatal aspects of the root as the incisors bend in palatal to buccal direction. The increased stress state at CEJ is due to differential rigidity between the crown structure (higher rigidity) and the root structure (lower rigidity).\(^{23,24}\) The modulus of elasticity of CGIC is closer to dentin as compared to that of enamel, due to which the restoration flexes with dentin, thereby better absorbing the induced stresses at dentinal end rather than enamel end. This makes the enamel end weaker, making it a prone site for fracture line to pass through, resulting in higher favorable fractures,\(^{15}\) as observed in Group 3 (60% – CGIC).

The experiments of this study were carried out in in vitro conditions and circular cavities were prepared in order to standardize the preparations, which may not conform to clinical presentation. In addition, periodontal simulation was not done due to direction of load application of 135°, which might have resulted in inaccurate data.

Root fractures are one of the common causes of failure in teeth with ICR because of the weakened cervical coronal and radicular dentin. Hence, tooth needs to be adequately reinforced. In many instances, it is not possible to obtain a ferrule in the labial aspect, thereby making it difficult to place a full-coverage crown. As per the results of this study, the specimens restored with all the four adhesive restorative materials showed comparable fracture resistance values [Graph 1], which were higher than the fracture loads subjected to in normal physiological state intraorally.\(^{25,26}\) Moreover, specimens restored with giomer showed fracture resistance values closest to that of intact teeth. As there were no previous studies to test the fracture resistance of teeth with simulated ICR cavities, there could be no comparisons made. These results need to be further confirmed by in vitro studies and long-term clinical observations in order to establish a suitable material to be used in ICR cavities.

**CONCLUSION**

Within the limitations of this in vitro study, it was found that adhesive restorative materials placed in the simulated ICR cavities enhanced the fracture resistance of the teeth involved. The mean fracture resistance of endodontically treated teeth with simulated ICR cavities restored with
giomer was found to be the highest among the experimental groups followed by those restored with FC, RMGIC, and CGIC.

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Conflicts of interest
There are no conflicts of interest.

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