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Preparation and bonding techniques in tooth fragment reattachment: Fracture resistance and SEM analysis

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Abstract:
Tooth fragment reattachment often fails because the effects of different tooth preparation designs and bonding techniques on fracture resistance remain uncertain. Therefore, it is of interest to evaluate the four tooth preparation techniques and two bonding approaches using 106 extracted permanent maxillary central incisors, including 10 intact controls and 96 fractured specimens. The 96 fractured teeth were allocated to four preparation groups of 24 specimens each, further divided into 12 specimens restored with either total-etch or self-etch bonding and assessed by universal testing machine and scanning electron microscope. Internal dentinal groove and over-contour preparations showed greater fracture resistance than simple reattachment and external chamfer, while the self-etch technique produced higher fracture resistance with fewer interfacial gaps than the total-etch technique. These findings identify an effective combination of tooth preparation and bonding strategy for improving the durability of tooth fragment reattachment and provide evidence to optimize restorative treatment protocols.

Keywords: Fracture resistance, reattachment, internal dentinal groove, tooth fragment

Background:
Traumatic dental injuries are the most disruptive and distressing emergencies in dental practice and has severe impact on the social and psychological well-being of patient **[1].** The majority of dental injuries involve anterior teeth, especially the maxillary central incisors, because of its position in the arch **[2].** The coronal tooth fractures are either restored using dental composite resin or ceramic crown, the former do not adequately provide long-term esthetics and the later requires significant reduction of tooth structure during preparation **[3].** Therefore, the primary objective of dental clinicians should be to preserve tooth structure, re-establish the natural esthetic of traumatized teeth and maintain dental arch integrity, several factors influence the management of coronal tooth fractures, extent of fracture (violation of biological-width, endodontic involvement, fracture of alveolar bone), pattern of fracture, fractured tooth fragment and its condition for use (fit between fragment and the remaining tooth structure), restorability of fractured tooth, occlusion, esthetics and prognosis **[2].** Re-attachment of fractured tooth fragment has been the most preferred treatment choice among the clinicians, because of its advantages over conventional dental composite restorations, as it's a more conservative treatment procedure, maintains original tooth contours and translucency, colour stability over time, less chair-side treatment time, reduces cost of treatment and wearing off incisal edge at similar rate to its adjacent teeth **[4].** The technique of re-attachment of fractured tooth fragments was first described in 1964 **[5]**. The most common reason for failure of the re-attached tooth fragment is a new traumatic injury or excessive masticatory forces on the restored tooth fragment. The area of re-attached tooth fragment to the remaining tooth structure is still the weakest area **[6]**. The four most commonly used techniques for re-attachment of fractured tooth fragment include; Simple re-attachment, External chamfer, Over-contour and Internal dentinal groove tooth preparation techniques, but both the tooth preparation techniques and also the type of adhesive and composite resin used to re-attach the fractured tooth fragment to the intact tooth structure showed significant effect on the fracture resistance of restored teeth **[7].** The composite resin to be used for re-attachment of fractured tooth fragment should have optimum fracture resistance to resist the forces acting on the tooth structure. However, the clinical success of composite resin also depends upon the efficiency and quality of the dental adhesive used for a more effective bond between the composite resin and tooth structure **[8].** The total-etch technique (Etch-and-rinse approach) completely dissolves the smear layer. To reduce the negative effects of multi-step etch and rinse technique, simplified single-step adhesive approach was developed, which is a combination of etch and adhesive in one-step **[9].** Self-etch adhesives partially dissolve the smear layer and result in less dentin demineralization than the etch-and-rinse adhesive systems. Self-etch adhesives are available in one bottle, allowing the etching, priming and application of dental adhesive to be performed in one step. It can be used reliably in Total-etch, Self-etch or Selective-etch modes for both direct and indirect composite resin restorations **[10].** Universal Testing Machine (UTM) is used to test the fracture resistance of the re-attached fractured tooth fragment. *In situ* analysis of micro-areas is done by Scanning Electron Microscope (SEM). It has the advantages of higher resolution, larger depth of field with magnification ranging 2000X to 20,000X and it was used to measure the interfacial gaps at the tooth-composite resin interface **[11].** Therefore, it is of interest to evaluate fracture resistance and to investigate the integrity of tooth-composite resin interface of tooth fragment reattachment in maxillary central incisors using four different tooth preparation and two different bonding techniques with Universal testing machine and Scanning electron microscope analysis.

Materials and Methods:
One-hundred six freshly extracted Human Permanent Maxillary Central Incisor teeth were collected from the Department of Oral

and Maxillofacial Surgery, Triveni Institute of Dental Sciences, Hospital and Research Centre, Bodri, Bilaspur, Chhattisgarh. All patients were informed about the use of their extracted teeth in our research study and gave informed consent. The study was approved by the Institutional Ethical Committee and the Scientific Committee of TIDSHRC (TIDSHRC/IEC/2023/D006). Teeth without any previous; caries or non-caries lesions, fractured, restored, endodontically treated, cracked, without any developmental defects or anomalies associated with the tooth crown and only the periodontally compromised teeth were included in our study. All specimens were cleaned off their superficial debris, calculus and residual tissue tags using ultrasonic instruments. The collection, storage, sterilization and handling of all extracted teeth were done following the Occupational Safety and Health Administration (OSHA) recommendations and guidelines **[12].** The teeth were then stored in 0.5% thymol solution (Chembur, Maharashtra, India) at room temperature until use. All teeth were then individually embedded in self-cure acrylic resin (DPI-RR Cold Cure, Dental Product of India, Mumbai) blocks up to the level of cementoenamel junction leaving the anatomical crowns exposed, numbered randomly 1 to 106, with the numbers written on the cervical-thirds of teeth using a marker pen (Kokuyo Camlin Pvt. Ltd). All teeth, except in the control group (n=10) were subjected to fracture protocol as previously described by Reis *et al.* **[13]** the labial surface of each tooth (n=96) was divided into transversal and longitudinal thirds to standardize the area (point) for the perpendicular load applied between the incisal and proximal (mesial or distal) thirds, in labial-to-lingual direction using a reinforced stainless-steel pin with a $2mm^2$ diameter ball tip at a cross-head speed of 0.6 mm/minute in Universal testing machine (Instron, Acme Engineers, India). The fractured teeth and the tooth fragments were examined at 3.5X magnification with Magnifying loupes (Endoking, Foshan Horyn Medical Equipment Company Limited, Luocun, China) to ensure that the specimens have perfect fragment fit, paired and labelled. All teeth had uncomplicated crown fractures (enamel and dentin only) and the fracture line was in an oblique labial to lingual direction. To prevent any artifacts due to dehydration, all samples were stored in glass beakers containing distilled water (Agrawal Pharmaceuticals, New Delhi, India) to keep them moist during the experimental procedure. All the specimens (n=96) were randomly divided into four groups based on the type of tooth preparation technique used: Group 1 (n=24), Group 2 (n=24), Group 3 (n=24) and Group 4 (n=24). Whereas in Control group (n=10), teeth were not fractured and retained intact.

Group 1 (Sample size 24):
Simple re-attachment technique; No tooth preparation was done either on the tooth fragment not on the remaining intact tooth structure, the tooth fragment was directly attached to the remaining intact tooth using dental adhesive and composite resin. Depending upon the type of dental adhesive and composite resin used for re-attachment of the tooth fragment, specimens were randomly divided into 2 Sub-groups; 1a and 1b, 12 specimens each. Sub-group 1a (n=12); Tooth fragment re-attachment was done following Total-etch technique. The tooth fragment and the remaining intact tooth were first acid etched with 37% Phosphoric acid (Actino gel, Prevest, DenPro and Jammu, India) for 15 seconds and then rinsed with water for 10 seconds to remove all the etchant and gently blot dried with sterile dry cotton pellet. Adper Single Bond 2 adhesive (3M ESPE, St Paul MN, USA) was then applied both on the surface of intact tooth and fractured tooth fragment, rubbed using a micro brush (Reach-Global India Pvt Ltd, Pune), gently air-dried for 5 seconds and light cured for 10 seconds using LED (Light Emitting Diode) dental composite curing light (SAAB, China) following manufacturer instructions. A thin layer of Filtek Supreme Flowable restorative composite resin (3M ESPE, St Paul MN, USA) was then placed on the fractured tooth fragment using a Teflon coated composite carrier instrument (Hu-friedy, Chicago, USA) and re-attached to the remaining intact tooth with gentle finger pressure. The excess composite resin was removed with composite carrier instrument and cured for 20 seconds using LED dental curing light as per manufacturer's instructions, with gentle finger pressure applied to the incisal edge of the tooth-fragment. Sub-group 1b (n=12); Tooth fragment re-attachment was done following Self-etch technique using Scotch bond Universal dental adhesive (3M ESPE, St Paul MN, USA) and RelyX Ultimate adhesive composite resin (3M ESPE, St Paul MN, USA). The dental adhesive was first applied on both fractured tooth-fragment and the remaining intact tooth using a microbrush, slightly agitated for 20 seconds and gently air-dried for 5 seconds until a glossy, uniform layer of adhesive was clinically visible and cured using LED dental curing light for 10 seconds following manufacturer instructions. A thin layer of RelyX Ultimate adhesive composite resin was then applied to the fractured tooth fragment with Teflon coated composite carrier instrument and re-attached to the remaining intact tooth with gentle finger pressure. Excess resin cement was removed with composite carrier instrument and cured using LED dental light for 20 seconds following manufacturer's instructions with gentle finger pressure exerted on the incisal edge of tooth-fragment.

Group 2 (Sample size 24):
Over-contour tooth preparation technique; Over-contour tooth preparation was performed only on the labial surfaces, 2.5mm from the fractured line and 0.3mm in depth on the fractured tooth fragment and the remaining intact tooth using cylindrical diamond finishing bur (TR-13EF, Mani, Japan) fitted to contra-angled airoter hand piece. Specimens were then randomly divided into 2 Sub-groups; 2a and 2b, 12 specimens each, depending upon the type of dental adhesive and composite resin used for re-attachment of the tooth fragment. Sub-group 2a (n=12); Tooth fragment was re-attached to the remaining intact tooth structure with Total-etch technique as in Sub-group 1a using Adper Single Bond 2 as adhesive and Filtek Supreme Flowable restorative composite resin. Sub-group 2b (n=12); Scotch bond Universal dental adhesive and RelyX Ultimate adhesive composite resin were used for re-attachment of tooth

fragment to the remaining intact tooth structure in the same manner as Sub-group 1b.

Group 3 (Sample size 24):
Internal Dentinal groove tooth preparation technique; Internal dentinal groove preparation was done on both the fractured tooth fragment and the remaining intact tooth structure, extending 1mm in depth and width using BR 31 round carbide bur (Mani, Japan) attached to contra-angled airoter hand piece. Specimens were then randomly divided into 2 Sub-groups; 3a and 3b, 12 specimens each, depending upon the type of dental adhesive and composite resin used for re-attachment of the tooth fragment. Sub-group 3a (n=12): Tooth fragment was re-attached to the remaining intact tooth structure using Total-etch technique as in Sub-group 1a, with the use of Adper Single Bond 2 as adhesive and Filtek Supreme Flowable restorative composite resin. Sub-group 3b (n=12); Tooth fragment was re-attached to the remaining intact tooth structure in Self-etch technique as followed in Sub-group 1b, using Scotch bond Universal as dental adhesive and RelyX Ultimate adhesive composite resin.

Group 4 (Sample size 24):
External Chamfer tooth preparation technique; All specimens were first randomly divided into 2 Sub-groups 4a and 4b, 12 specimens each, depending upon the type of dental adhesive and composite resin used for re-attachment of the tooth fragment. In Sub-group 4a (n=12), Tooth fragment was re-attached to the remaining intact tooth structure in Total-etch technique as followed in Sub-group 1a, using Adper Single Bond 2 as adhesive and Filtek Supreme Flowable restorative composite resin. In Sub-group 4b (n=12), Tooth fragment was re-attached to the remaining intact tooth structure using Self-etch technique as in Sub-group 1b with dental adhesive Scotch bond Universal and adhesive composite resin RelyX Universal. After the tooth fragment re-attachment, among the specimens in sub-groups 4a and 4b; Chamfer margin tooth preparation was done in 1mm depth along the re-attached fracture line only on the labial surface of teeth (at the bonding-interface of re-attached tooth fragment to the remaining intact tooth structure) using 856, size 12 diamond point (Hager and Meisinger GmbH, Germany). Among the specimens of Sub-group 4a (n=12); The chamfer margin prepared on the teeth was acid-etched following total-etch technique, Adper Single Bond 2 dental adhesive was applied, light cured and restored with Filtek Supreme Flowable restorative composite resin following manufacturer's instructions. The specimens of Sub-group 4b (n=12): Scotch bond Universal dental adhesive was applied on the chamfer margin prepared on the teeth, light cured and restored with RelyX Ultimate adhesive composite resin as per manufacturer's instructions. Among all the specimens, finishing and polishing of Filtek Supreme flow able restorative and RelyX Ultimate composite resins was done using Extra fine diamond points (TR -26 EF, Mani, Japan) and Sof-lex discs (3M ESPE, Dental products, St Paul, USA) attached to a low-speed contra-angled micromotor handpiece following manufacturer's instructions. All specimens were then incubated in 100% relative humidity at 37ºC for 48 hours and were then subjected to Thermocycling at 4º±2ºC and 56º±2ºC for 1000, two-minute cycles with a transfer time of five seconds and dwell time of 30 seconds as per International Organization for Standardization Standard 11405 **[14].** After thermocycling, two specimens from each sub-group (1a,1b, 2a,2b, 3a,3b, 4a,4b) were randomly allocated to investigate the integrity of tooth-composite resin interface of the restored teeth ultra morphologically under the Scanning Electron Microscope (SEM)(Quanta FEG 250, Thermo Fisher Scientific, Oregon, United States) analysis at a magnification of 2000X. The remaining eighty restored specimens were then individually mounted on a custom-made fixture in the Universal testing machine and perpendicular load was applied with the load increased progressively in labial-to-lingual direction at a cross-head speed of 0.6mm per minute using a reinforced stainless-steel pin until the re-attached tooth fragment was fractured, following the same procedure used earlier to obtain tooth fragments. The load applied to fracture each re-attached tooth fragment was recorded in Kilogram force (Kgf) **[13].** For the control group specimens (n=10), load was applied until tooth fracture, then the fracture resistance data of all the specimens (n=106) was recorded, tabulated and subjected to statistical analysis. The tabulated data in Microsoft excel was statistically analyzed with SPSS (Statistical Package for the Social Sciences) Version 24 software. One-way ANOVA (Analysis of Variance) test, independent 't' and turkey post-hoc tests were used for statistical analysis. P (Probability) value ≤0.05 was considered as statistically significant.

Results:
The mean value differed significantly among the five study groups ($p < 0.001$)**,** indicating a highly statistically significant (HS) difference**.** Group 1 showed the lowest mean value (70.00 ± 0.46), followed by Group 4 (107.00 ± 0.34) and Group 2 (114.00 ± 0.41). Group 3 showed a higher Mean (133.00 ± 0.35), whereas the Control Group (Group 5) exhibited the highest mean value (223.11 ± 1.75). These findings suggest that all treatment groups had markedly lower mean values compared to the control group, indicating a substantial effect of the interventions in reducing the measured parameter. The very small standard deviations across all groups reflect minimal variability and good consistency of the observations **(Table 1).** Within each experimental group, a highly statistically significant difference was observed between subgroups 'a' and 'b' ($p < 0.001$). In all four groups, the 'a' subgroups demonstrated substantially lower mean values than their corresponding 'b' subgroups**,** indicating a marked effect of the intervention or condition under study. Among the 'a' subgroups**,** Group 1a had the lowest mean value (60.82 ± 0.46), while Group 2a had the highest (71.41 ± 0.41). Among the 'b' subgroups**,** Group 3b exhibited the highest mean value (198.82 ± 0.51), followed by Group 2b (157.07 ± 0.26), Group 4b (149.02 ± 0.38) and Group 1b (81.25 ± 0.41). The consistently low standard deviations across all subgroups indicate minimal variability and excellent reproducibility of the measurements **(Table 2, Figure 1).** The inter-group pairwise

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comparison revealed significant differences among several study groups. Among the 'a' subgroups, Group 1a differed significantly from Group 2a (p = 0.001) and Group 3a (p = 0.004), while comparisons between Group 1a vs Group 4a, Group 2a vs Group 3a, Group 2a vs Group 4a and Group 3a vs Group 4a were not statistically significant (p > 0.05), indicating comparable outcomes among these groups. However, each 'a' subgroup showed a highly significant difference compared with the Control Group (Group 5) (p < 0.001), showing the effectiveness of the interventions relative to the control. Among the 'b' subgroups, all pairwise comparisons were statistically significant or highly significant. Comparisons involving Group 1b, Group 3b and Group 5 were highly significant (p < 0.001), while Group 2b vs Group 4b showed a significant difference (p = 0.001). Overall, these findings indicate marked differences among the 'b' subgroups, whereas the 'a' subgroups exhibited similar responses except for a few significant comparisons, with all experimental groups differing substantially from the control **(Table 3).**

Table 1: Comparison of fracture resistance in Kilogram force (Kgf) among the specimens of all five groups using One-way ANOVA test.

Groups	Mean ± S.D	P value
Group 1 (n=20)	70 ± 0.46	<0.001 (HS)
Group 2 (n=20)	114 ± 0.41	
Group 3 (n=20)	133 ± 0.35	
Group 4 (n=20)	107 ± 0.34	
Group 5 Control (n=10)	223.11 ± 1.75	

P: Probability; SD: Standard Deviation; HS: Highly Significant

Table 2: Intra-group comparison of fracture resistance in Kilogram force (Kgf) among the specimens of Group 1–4 using Independent 't' test

Groups	Mean ± SD	P value
Group 1a (n=10)	60.82 ± 0.46	<0.001 (HS)
Group 1b (n=10)	81.25 ± 0.41	
Group 2a (n=10)	71.41 ± 0.41	<0.001 (HS)
Group 2b (n=10)	157.07 ± 0.26	
Group 3a (n=10)	68.37 ± 0.35	<0.001 (HS)
Group 3b (n=10)	198.82 ± 0.51	
Group 4a (n=10)	66.96 ± 0.34	<0.001 (HS)
Group 4b (n=10)	149.02 ± 0.38	

Table 3: Inter-group pair-wise comparison of fracture resistance in kilogram force (Kgf) using Turkey post-hoc test among the five groups

Inter-group Pair-wise comparison	P value
Group 1a *Vs* Group 2a	0.001 (S)
Group 1a *Vs* Group 3a	0.004 (S)
Group 1a *Vs* Group 4a	0.07 (NS)
Group 1a *Vs* Group 5	<0.001 (HS)
Group 2a *Vs* Group 3a	0.07(NS)
Group 2a *Vs* Group 4a	0.06(NS)
Group 2a *Vs* Group 5	<0.001 (HS)
Group 3a *Vs* Group 4a	0.07 (NS)
Group 3a *Vs* Group 5	<0.001 (HS)
Group 4a *Vs* Group 5	<0.001 (HS)
Group 1b *Vs* Group 2b	<0.001 (HS)
Group 1b *Vs* Group 3b	<0.001 (HS)
Group 1b *Vs* Group 4b	<0.001 (HS)
Group 1b *Vs* Group 5	<0.001 (HS)
Group 2b *Vs* Group 3b	<0.001 (HS)
Group 2b *Vs* Group 4b	0.001 (S)
Group 2b *Vs* Group 5	<0.001 (HS)
Group 3b *Vs* Group 4b	<0.001 (HS)
Group 3b *Vs* Group 5	<0.001 (HS)
Group 4b *Vs* Group 5	<0.001 (HS)

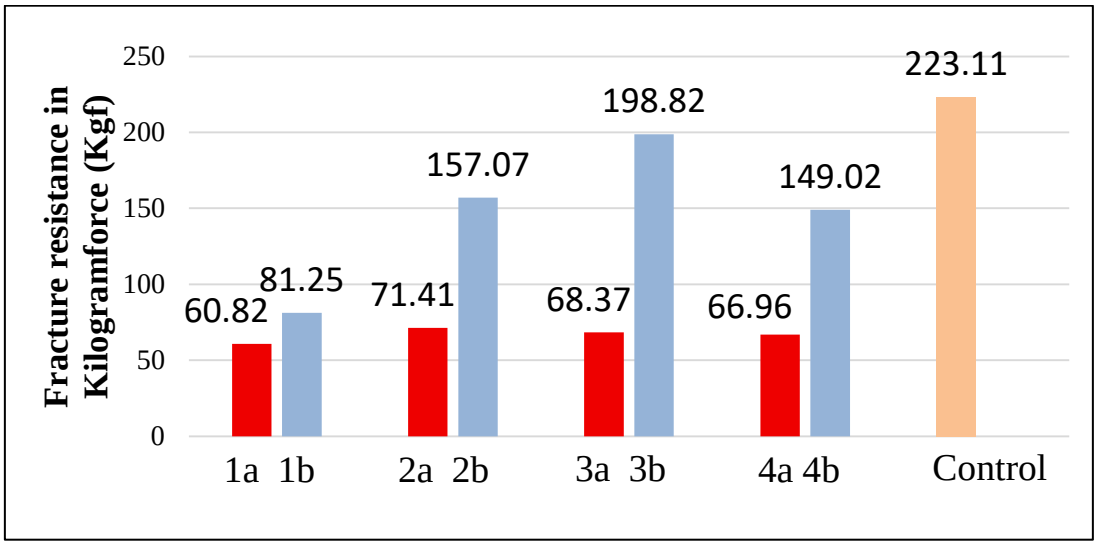


Figure 1: Vertical Bar graph representing Fracture resistance in Kilogram force (Kgf) among the specimens of five groups

Discussion:

Fractures that involve only enamel and dentin, but not dental pulps are the most common Traumatic Dental Injuries (TDI's). The International Association of Dental Traumatology (IADT) categorizes such injuries as 'Uncomplicated Crown fractures' and describes them as 'Coronal fractures where there is no pulp involvement or exposure **[15].** The fracturing protocol described by Reis *et al.* **[16]** is more similar to the clinical situation because it produces fractured tooth surfaces without smear layer, while the surface anatomy produced by sectioning of tooth completely differs from the fractured tooth surface, as the orientation of the latter is dictated by the alignment of the diamond saw used to section the tooth **[17].** The tooth sectioning technique, on the other hand, yields cut-surface of coronal dentin containing

smear layer. As mentioned, it was reported that the bond strength to smear-free fractured tooth dentin was lower than that to smear-covered sectioned tooth dentin **[18],** which may be the reason for the lower fracture resistance values obtained when simple reattachment technique was used in our present study. There are several factors that determine the selection of fractured tooth fragment reattachment procedure. A close fit between the fractured tooth fragment and the remaining intact tooth structure is an important factor along with the bonding techniques used for reattachment preventing exposure of bonding material to the oral environment **[13].** Multiple variables influence the long-term prognosis of tooth fragment reattachment; tooth preparation technique, bonding technique, hydration of the fractured tooth fragment and material used to bond **[17].** However, bond strength of the reattached fractured tooth fragment depends upon both bonding material and tooth preparation technique used **[7].** However, no bonding technique or bonding material can exactly match to the fracture strength of a healthy intact tooth according to Bruschi-Alonso *et al.* **[19]** and nonetheless using an appropriate tooth preparation technique and bonding material could enable a reattached fractured tooth fragment to have near comparable fracture strength of a healthy intact tooth. To provide sufficient resistance to the functional forces exerted on the reattached fractured tooth fragment Andreasen *et al.* **[20]** recommended the use of composite resin and dental adhesive, instead of dental adhesive alone. Farik *et al.* **[21]** supported the idea that most dental adhesives increases the fracture resistance of reattached fractured tooth fragments when used in conjunction with composite resin. Mahale *et al.* **[22]** similarly showed that the bonding protocol significantly influences the fracture resistance of reattached anterior tooth fragments, with the total-etch technique producing greater fracture resistance than selective-etch and self-etch approaches, emphasizing the importance of appropriate adhesive selection during fragment reattachment. The findings of our study showed that the internal dentinal groove tooth preparation followed by the use of composite resin for reattachment of fractured tooth fragment enhanced its fracture resistance and these findings of Pusman *et al.* **[23].** Due to the increased adhesion area and permeability of an internal resin bar, which counteracts the load applied on the tooth structure. Furthermore, this technique ensures an accurate fit between the tooth fragment and the remaining intact tooth structure and the tooth segments fit together without any defects. The results of our study also concurred with the studies of AbdulKhayum *et al.* **[1]**, Reis *et al.* **[13]** and Loguercio *et al.* **[24]** which reported that the internal dentinal groove and over-contour tooth preparation techniques had the highest resistance to fracture load among the other tooth preparation techniques. In agreement with these findings, Nagi and Khadr **[25]** reported that over-contouring combined with nanohybrid composite produced the highest fracture resistance among the tested reattachment techniques, further supporting the role of additional tooth preparation and adequate composite reinforcement in improving the mechanical performance of reattached fragments. The findings of our study also showed lower resistance to fracture load among the specimens restored following simple re-attachment technique, as the fractured tooth fragment precisely fitted on the remaining intact tooth without any gap or disruption leading to very minimal thickness of composite resin along the interface and this could have contributed to its lower fracture resistance. Our results corroborate Sadana *et al.* **[26]** who observed that the survival rate was lower with the reattachment of fractured tooth fragments with composite resin without any additional preparation of the tooth. The findings of our study showed the use of Scotch bond universal adhesive in self-etch mode and RelyX Ultimate composite resin for reattachment of fractured tooth fragment showed significantly higher resistance against fracture load irrespective of tooth preparation technique used. More recently, Elgezawi *et al.* **[27]** reported that reinforcement of reattached incisal fragments with a polyethylene fiber band substantially improved fracture resistance compared with conventional fragment reattachment, highlighting the potential benefit of additional reinforcement strategies in restoring the mechanical integrity of fractured anterior teeth. In line with this, de Lima *et al.* **[28]** and Turkistani *et al.* **[29]** found that the RelyX Ultimate resin contains Vitre bond co-polymer which interacts with calcium ions to promote adhesion to the tooth surface via free carboxylic groups. It is composed of MDP (Methacryloyloxydecyl Dihydrogen Phosphate) and contains copolymers that react with the free carboxylic groups and calcium ions of the dentin of teeth via polyacids. The deposition of MDP salts and calcium causes increased bond strength of composite resin to the tooth and in addition, the adhesive has a rehydration effect on the collapsed collagen fibril network of dentin structure enhancing the formation of a hybrid layer. Weng *et al.* **[30]** also reported higher bond strength of RelyX Ultimate resin to the tooth structure compared to other composite resin and the improved mechanical properties of this dual cure resin helps in its closer adaptation of the fractured fragment to the remaining intact tooth. Its dual cure property; chemical cure followed by light-cure helps to attain higher bond strength and thereby increasing its fracture resistance against load. Demarco *et al.* **[31]** concluded in their study that the fracture resistances of reattached coronal tooth fragments using dual-cured composite resin produce lower failure loads compared to other dental composites and they exhibit better bond strengths over time than the simple light-cure composite resins. But Peroz *et al.* **[32]** reported that the Scotch bond universal self-etch adhesive has no multiple steps in its self-etch mode, which is responsible for its greater marginal seal. The close adaptation of composite resin is also influenced by its viscosity, RelyX Ultimate composite resin with its lower viscosity, penetrates into greater depths of dentin achieving enhanced micro-retention, thus in our present study RelyX Ultimate composite resin showed greater resistance against fracture load irrespective of tooth preparation technique used. In our present study, Ultra morphological examination using SEM have helped us in clear analysis in the presence of voids or microcracks, might act as the Achilles heel of the adhesive interface along tooth-composite resin, eventually leading to the failure of reattached fractured tooth fragment against fracture

load **[22, 33].** All specimens were treated by one operator in order to avoid inter-operator variability in the experimental procedures. In our study, all specimens were thermocycled prior to fracture resistance analysis test and SEM examination to simulate *in vivo* clinical conditions such as thermal stress and water absorption. Gale and Darvell **[34]** also reported that 10,000 thermal-cycles arbitrarily corresponds to one year of clinical service, implying that the 1000 thermal-cycles chosen in our study roughly represent to one month of thermal fluctuations intraorally. However on the use of thermal cycling among *in vitro* studies, Morresi *et al.* **[35]** in their literature review reported no established consensus on a specific number of thermal cycles to correspond to a specific time in the oral cavity. Limitations of our study includes; been *in vitro* study cannot completely simulate the complex oral conditions, masticatory forces and patient-related variables. Fracture resistance was tested under static loading conditions, which is not the most representative condition to the clinically functional dynamic loading applied to the reattached fractured tooth fragment.

Conclusion:

Internal dentinal groove preparation with self-etch bonding achieved the highest fracture resistance, confirming that both tooth preparation and bonding technique influence reattachment strength. The combination of Scotch bond Universal adhesive and RelyX Ultimate composite resin produced the fewest interfacial gaps, indicating superior bonding integrity and restorative performance. Thus, data support internal dentinal groove preparation with self-etch bonding for tooth fragment reattachment, although long-term clinical studies are needed to validate its durability.

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