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Fracture resistance of class II mod cavities restored with direct and semi direct short fiber reinforced composite techniques: An *in vitro* study

Dr. Monica R[1], Moksha Nayak[2]
[1] Department of Conservative Dentistry and Endodontics, KVG Dental College and Hospital, Kurunjibagh, Sullia, Karnataka, India
[2] Principal and Professor, Department of Conservative Dentistry and Endodontics, KVG Dental College and Hospital, Kurunjibagh, Sullia 574327, Karnataka, India
Corresponding Author: Dr. Monica R
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Abstract
Background: Extensive mesio occluso distal cavities reduce cuspal stiffness and increase the risk of fracture. Short fiber reinforced composite may improve crack resistance, while semi direct fabrication may reduce polymerization stress. Aim: To compare fracture resistance and failure patterns among direct and semi direct restorations prepared with and without a short fiber reinforced composite substructure. Materials and Methods: Twenty-two extracted intact mandibular molars received standardized Class II MOD preparations and were allocated to direct SFRC (G1, n=8), direct conventional composite (G1C, n=3), semi direct SFRC (G2, n=8), or semi direct conventional composite (G2C, n=3). Restored specimens underwent axial compressive loading in a universal testing machine until fracture. One-way analysis of variance and Tukey HSD tests were applied at alpha=0.05. Results: Mean fracture resistance was 635.0 ± 33.73 N for G1, 580.0 ± 20.58 N for G1C, 761.0 ± 35.60 N for G2, and 623.0 ± 16.09 N for G2C. The overall group effect was significant ($F(3,18)=35.25$, $P<0.001$). G2 exceeded G1, G1C, and G2C (all Tukey adjusted $P<0.001$), whereas G1 did not differ significantly from G1C or G2C. Semi direct SFRC specimens showed a more favorable, repairable fracture pattern on descriptive assessment. Conclusion: Within the limits of this *in vitro* study, semi direct SFRC restorations produced the highest fracture resistance. The findings support further fatigue and clinical evaluation before routine clinical recommendations are made.

Keywords: Direct composite, fracture resistance, mesio occluso distal cavity, semi direct restoration, short fiber reinforced composite

Introduction
Preparation of a mesio occluso distal (MOD) cavity interrupts both marginal ridges and reduces the stiffness of a posterior tooth. The resulting cuspal deflection and altered stress distribution increase susceptibility to fracture, particularly when the remaining walls are thin [1, 2]. Resin composites preserve tooth structure and provide an adhesive restorative option, but large direct restorations remain affected by polymerization contraction and stress concentration at the bonded interface [3, 4].
Short fiber reinforced composites (SFRCs) contain randomly oriented glass fibers within a resin matrix. Fibers that meet an effective aspect ratio can transfer stress across the matrix, hinder crack propagation, and act as a dentin replacing substructure beneath a conventional particulate composite surface [5, 7]. Laboratory studies have reported improved load bearing capacity and more repairable failure patterns when SFRC is used in extensive posterior restorations [8, 9].
A semi direct approach permits extraoral contouring and additional polymerization before adhesive luting. This may increase conversion and reduce the volume of material polymerized within the cavity [10, 12]. Evidence directly comparing direct and semi direct SFRC techniques in standardized MOD cavities remains limited. The present study therefore compared fracture resistance and failure patterns of direct and semi direct restorations prepared with and without SFRC. The null hypothesis was that restorative technique and SFRC incorporation would not influence fracture resistance.

Materials and Methods
Study design and specimen selection
This laboratory study used 22 extracted, non-carious, intact human mandibular molars. Teeth with cracks, restorations, caries, developmental defects, or marked dimensional variation were excluded after visual examination. After debridement, the teeth were stored in distilled water at room temperature until preparation. The study used anonymized teeth extracted for therapeutic reasons unrelated to the investigation and recorded no patient identifiers; therefore, institutional ethical approval was not required.

Specimen mounting and cavity preparation
Each tooth was embedded in acrylic resin with the long axis perpendicular to the base and the cemento enamel junction positioned above the resin surface. Standardized Class II MOD preparations measured 4 mm buccolingually and 4 mm in depth, with gingival margins 1 to 1.5 mm coronal to the cemento enamel junction. At least 2 mm of cusp thickness was retained. One operator prepared all cavities using a water-cooled cylindrical diamond bur and a periodontal probe as the dimensional guide. A new bur was used after every five preparations to limit variation caused by bur wear.

Group allocation
The 22 specimens were assigned identification numbers and allocated to four groups by a computer-generated random sequence. Allocation was completed after cavity standardization.

Group	Restorative method	n
G1	Direct restoration with an SFRC dentin substitute and nanohybrid composite surface layer	8
G1C	Direct conventional composite restoration without SFRC	3
G2	Semi direct restoration with an SFRC substructure and composite surface layer	8
G2C	Semi direct conventional composite restoration without SFRC	3

Restorative procedures

For G1 and G1C, Scotchbond Universal Adhesive (3M ESPE, Seefeld, Germany) was applied according to the manufacturer instructions. Proximal walls were established first. In G1, everX Posterior SFRC (GC Corporation, Tokyo, Japan) was placed as the dentin replacing component and covered with Filtek Z250 XT nanohybrid composite (3M ESPE). G1C received the conventional composite without an SFRC layer. Each increment was light cured for 20 seconds with an LED curing unit delivering approximately 1200 mW/cm²; output was checked with a radiometer before specimen preparation. For G2 and G2C, a thin layer of petroleum jelly was applied as a separating medium before extraoral fabrication. G2 incorporated the same SFRC substructure and composite surface material, whereas G2C used conventional composite alone. The restorations received additional polymerization for 5 minutes in a Solidilite V laboratory light curing unit (Shofu Inc., Kyoto, Japan).

After removal of the separating medium, the intaglio surfaces and tooth preparations were cleaned and conditioned according to the manufacturer's instructions. The restorations were luted with Fusion Ultra dual cure resin cement (Prevest DenPro, Jammu, India). Excess cement was removed before final polymerization. All specimens were stored in distilled water at 37°C for 24 hours before fracture testing, consistent with commonly used laboratory conditioning protocols [15].

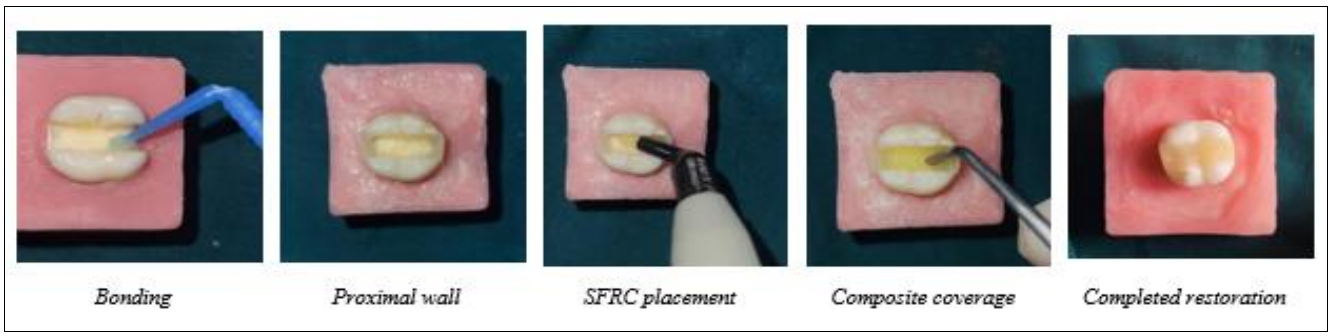


Fig 1: Direct SFRC restoration sequence.

Fracture resistance testing

Each mounted tooth was positioned in a computer controlled universal testing machine. A compressive load was applied parallel to the long axis through a 6 mm diameter spherical stainless-steel loading tip contacting the buccal and lingual cuspal inclines.

Loading proceeded at a crosshead speed of 1 mm/min until fracture. The maximum load at failure was recorded in newtons. The examiner classified fractures above the cemento enamel junction as favorable and potentially repairable, and fractures extending below the cemento enamel junction as unfavorable.

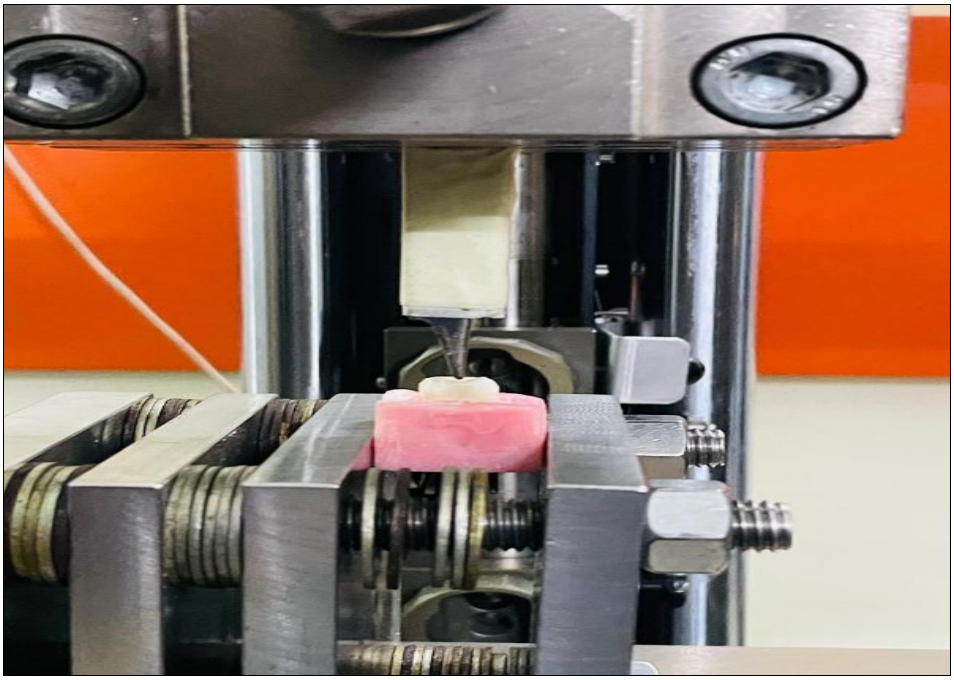


Fig 2: Specimen positioned for fracture resistance testing.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Group means and standard deviations were compared with one-way analysis of variance. Tukey HSD tests adjusted pairwise comparisons for unequal group sizes. The significance level was set at 0.05. The reported group n, means, and standard deviations yielded $F(3,18)=35.25$ and $P<0.001$. Failure patterns were summarized descriptively because the small control groups did not support a reliable categorical comparison.

Results

Fracture resistance differed significantly among the four groups ($F(3,18)=35.25$, $P<0.001$). G2 produced the highest mean fracture load (761.0 ± 35.60 N), followed by G1 (635.0 ± 33.73 N), G2C (623.0 ± 16.09 N), and G1C (580.0 ± 20.58 N) (Table 1).

Table 1: Descriptive fracture resistance values by group

Group	n	Mean ± SD (N)	Minimum (N)	Maximum (N)
G1	8	635.0 ± 33.73	596.57	684.29
G1C	3	580.0 ± 20.58	559.92	600.81
G2	8	761.0 ± 35.60	713.77	802.35
G2C	3	623.0 ± 16.09	604.09	642.45

Tukey adjusted comparisons showed that G2 had significantly greater fracture resistance than G1, G1C, and G2C (all $P<0.001$). G1 did not differ significantly from G1C ($P=0.085$) or G2C ($P=0.943$), and the G1C versus G2C comparison was not significant ($P=0.374$) (Table 2). Descriptive examination showed a greater tendency toward favorable fractures in the semi direct SFRC group, whereas the direct group showed more catastrophic fracture patterns. No inferential comparison of failure modes was undertaken because of the small and unequal group sizes.

Table 2: Tukey HSD pairwise comparisons

Comparison	Mean difference (N)	Adjusted P value	Interpretation
G1 vs G1C	55.0	0.085	Not significant
G1 vs G2	-126.0	<0.001	Significant
G1 vs G2C	12.0	0.943	Not significant
G1C vs G2	-181.0	<0.001	Significant
G1C vs G2C	-43.0	0.374	Not significant
G2 vs G2C	138.0	<0.001	Significant



Type I-II favorable fracture (restoration or limited coronal fracture)	Type III favorable fracture (cuspal fracture above the CEJ)	Type V unfavorable fracture (catastrophic fracture below the CEJ)

Fig 3: Representative failure modes after loading: Type I-II and Type III repairable fractures, and Type V catastrophic fracture.

Discussion

The null hypothesis was rejected because fracture resistance differed among the restorative groups. The clearest separation occurred in G2: the semi direct SFRC restorations sustained a mean load of 761 N and exceeded all three comparison groups after Tukey adjustment. Direct SFRC specimens, although numerically stronger than the direct conventional composite controls, did not differ significantly from either conventional composite group. The findings therefore point to the restorative configuration as a whole - fiber reinforcement combined with extraoral processing and adhesive luting - rather than to the presence of short fibers as an isolated explanation for improved performance.

Loss of both marginal ridges in a MOD preparation alters the tooth from a mechanically integrated structure into two relatively flexible cuspal segments. Under occlusal loading, these cusps tend to separate, concentrating tensile stress at the pulpal floor, internal line angles, and bonded interfaces [1, 2, 14]. A successful restoration must consequently do more than occupy the cavity; it must limit cuspal movement and interrupt the pathway by which an incipient crack travels through the restoration into the remaining tooth. This biomechanical demand provides the context for the superior load-bearing behavior observed in the semi direct SFRC group.

The reinforcing action of SFRC is governed by the interaction between its resin matrix and randomly oriented glass fibers. When a developing crack reaches a suitably oriented fiber, energy is consumed through fiber-matrix debonding, crack deflection, fiber bridging, and eventual fiber pull-out or fracture. These events blunt the crack tip and make uninterrupted propagation less likely [5, 7]. Used as a dentin-replacing core, the fiber-rich layer can therefore function as a stress-modulating substructure, while the overlying particulate composite provides an enamel-like surface with improved polish and wear behavior. The significantly higher G2 value relative to G2C is consistent with this reinforcing contribution in the semi direct configuration [8, 9].

The advantage of G2 may also reflect the way the restoration was polymerized and incorporated into the cavity. Additional extraoral curing can improve conversion without simultaneously constraining the material between opposing cavity walls. Most polymerization contraction has already occurred before cementation, leaving only the comparatively small volume of resin cement to polymerize in situ. The luting layer may further compensate for minor interfacial discrepancies and distribute stress across the preparation. Together, these features could reduce residual contraction stress and create a more uniform restorative complex [10, 12]. Because conversion, interfacial stress, and marginal adaptation were not measured, these mechanisms should be regarded as biologically plausible explanations rather than direct observations from the present experiment.

The direct SFRC mean exceeded that of the direct conventional composite group by 55 N, yet the adjusted comparison was not significant. This result should not be interpreted as evidence that the two approaches are equivalent. The three-specimen control groups provide limited precision, and the unequal allocation reduces the power of individual contrasts. Direct placement may also be more sensitive to fiber adaptation, increment thickness, cavity geometry, and light access. Voids or incomplete adaptation within a deep MOD preparation can become local stress concentrators and may offset part of the theoretical benefit of fiber reinforcement. Balanced groups with prospectively calculated sample sizes are needed to determine the independent effects of technique and material and to test their interaction formally.

Fracture load alone does not fully describe restorative performance; the level and direction of failure determine whether the tooth remains treatable. The representative specimens showed Type I-II and Type III failures confined to the restoration or coronal tooth structure, which are considered favorable because repair or replacement remains feasible. Type V failure extended apical to the cemento enamel junction and represented an unfavorable, catastrophic fracture. The semi direct group showed a descriptive tendency toward Type I-III repairable patterns, whereas catastrophic Type V failures were more evident with the direct approach. A possible explanation is that the better-polymerized restoration and fiber-mediated crack deflection retained damage within the coronal restorative complex instead of transferring it deeply into the root [8, 9, 13]. This interpretation remains descriptive because individual failure counts were not available for a valid inferential comparison.

From a clinical perspective, the semi direct method may be useful when a large posterior defect requires an adhesively retained restoration but greater control over proximal form, occlusal anatomy, and polymerization is desired. Its potential value lies not only in resisting a higher single load but also in shifting failure toward a repairable level. It should not, however, be presented as a substitute for cuspal coverage in every extensively compromised tooth. Remaining wall thickness, crack status, pulpal and periodontal condition, occlusal loading, isolation, and the feasibility of adhesive bonding must still guide case selection. The present findings support the technique as a conservative restorative option worthy of further study, not as definitive evidence of clinical superiority.

Several limitations restrict clinical interpretation. Static axial loading represents an endpoint test and cannot reproduce the repeated low-magnitude, oblique, and multidirectional forces of mastication. The specimens were not subjected to thermomechanical aging, and acrylic mounting did not reproduce the viscoelastic behavior of the periodontal ligament. Natural variation in tooth dimensions and dentin quality may persist despite cavity standardization. Only one SFRC system, one adhesive strategy, one cement, and one preparation design were evaluated. In addition, the small and unequal groups widened uncertainty around the control comparisons and precluded robust statistical analysis of fracture modes.

Future investigations should use equal, adequately powered groups, periodontal ligament simulation, cyclic fatigue, and thermocycling before monotonic fracture testing. Reporting confidence intervals, standardized effect estimates, and specimen-level failure classifications would improve interpretation. Microcomputed tomography and fractographic analysis could reveal where cracks initiate and whether they are redirected at the fiber layer or cement interface. Ultimately, prospective clinical studies are required to establish whether the higher immediate fracture resistance and apparently more favorable failure pattern translate into improved survival, reparability, and patient-centered outcomes.

Conclusion

Within the limitations of this *in vitro* study, the semi direct SFRC group showed the greatest fracture resistance and differed significantly from the other three groups. Direct SFRC did not produce a statistically significant advantage over the conventional composite controls after Tukey adjustment. Semi direct SFRC restoration warrants further investigation under fatigue and clinical conditions, with balanced group sizes and complete failure mode reporting.

Declarations

Ethical approval: Not required. The investigation used anonymized extracted teeth obtained for therapeutic reasons

unrelated to the study and involved no identifiable patient information.

Informed consent: Not applicable because no identifiable patient data were collected or reported.
Source of funding: Nil.
Conflict of interest: The authors declare no conflict of interest.

Data availability: The data supporting the findings are available from the corresponding author on reasonable request.

Author contributions: Monica R contributed to the experimental work, data acquisition, literature search, data analysis, and preparation of the first manuscript draft. Moksha Nayak contributed to the study conception and design, supervision, interpretation of findings, and critical revision of the manuscript. Both authors read and approved the final manuscript. Monica R, the corresponding author, accepts responsibility for the integrity of the work as a whole and serves as guarantor.

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