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Comparative evaluation of shear bond strength for four different restorative materials: An *in vitro* study

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Abstract:
The bonding between pulp capping materials and overlying restorative materials is a key factor in the success of vital pulp therapy. The introduction of bioactive and resin-based restorative materials has made it important to assess the compatibility with the most used pulp capping materials like TheraCal LC, Bio dentine and Mineral Trioxide Aggregate (MTA). Therefore, it is of interest to compare the shear bond strength of four different restorative materials (Bio-glass restorative glass ionomer cement, fiber reinforced composite, universal croma composite with nano fillers, resin modified glass ionomer cement) bonded to the above pulp capping materials. Acrylic blocks were prepared in total 120 blocks were divided into 12 groups. Shear bond strength tests were conducted on the specimens with a universal testing machine and failure mode analysis was performed under a stereomicroscope. Thus, this data will help clinicians to choose the best combinations of materials for better clinical results.

Keywords: Shear bond strength, TheraCal LC, Biodentine, mineral trioxide aggregate, fiber reinforced composite, bio-glass GIC, RMGIC, nano composite, pulp capping materials

Background:
Maintenance of pulp vitality is a basic goal in conservative dentistry and endodontics. The use of vital pulp therapy (VPT), including direct pulp capping and indirect pulp capping, has been accepted because of the development of bioactive materials that encourage dentin formation and pulpal healing **[1].** The success of these procedures is not only dependent on the biological properties of the pulp capping material, but also on the quality of the bond formed with the overlying restorative material **[2].** Mineral Trioxide Aggregate (MTA) is one of the most popular pulp capping materials and has been regarded as a gold standard because of its excellent biocompatibility, sealing ability and its ability to form hard tissue **[3].** But there are some drawbacks like long setting time and handling difficulties which have resulted in the development of newer materials such as Bio dentine and TheraCal LC **[4].** Biodentine is a material with calcium silicate-based properties that shows better mechanical properties and a shorter setting time than MTA, which is a good alternative **[5].** Light-cured resin-modified calcium silicate materials (TheraCal LC) have been developed with a number of benefits, including rapid setting and ease of placement **[6].** Sealing of the interface between the pulp capping materials and the restorative materials is of great importance in order to prevent microleakage and long-term success. Poor bonding can result in bacterial infiltration, secondary caries and ultimately failure of the restoration **[7].** Thus, the shear bond strength between these materials is of utmost importance. Several new materials have been developed as a result of the developments in restorative dentistry. Bio-glass restorative glass ionomer cement has been attracting attention because it has bioactivity, fluoride release and chemical bond with tooth structure **[8].** The use of reinforcing fibers in the resin matrix has been found to improve the mechanical properties and fracture resistance of fiber reinforced composites **[9].** The unique shade-matching ability and the enhanced filler technology of universal croma composites make them more esthetic and adaptable **[10].** Resin modified glass ionomer cements (RMGICs) are a combination of the properties of conventional GICs and resin, which gives them better mechanical properties and better bonding characteristics **[11].** In previous studies, bond strength values have been reported to vary with the different pulp capping and restorative materials, suggesting that compatibility is material dependent. Further, the surface properties, setting time and chemical composition of pulp capping agents are all important factors affecting adhesion. The bond strength results are also significantly influenced by immediate versus delayed restoration placement **[12].** Therefore, it is of interest to compare the shear bond strength of four restorative materials to TheraCal LC, Biodentine and MTA under standardized *in vitro* conditions.

Materials and Methods:
Study design:
This study was designed as an *in vitro* experimental study to evaluate and compare the shear bond strength of four restorative materials bonded to three different pulp capping agents under standardized laboratory conditions.

Source of data:
A total of 120 acrylic blocks were fabricated using self-cure acrylic resin obtained from the Department of Conservative Dentistry and Endodontics, New Horizon Dental College and Research Institute, Sakri, Bilaspur, Chhattisgarh.

Sample size and grouping:
The samples were divided into 12 groups (n = 10 per group) based on the combination of pulp capping materials and restorative materials.
[1] **Group A–D:** TheraCal LC + 4 restorative materials
[2] **Group E–H:** Biodentine + 4 restorative materials
[3] **Group I–L:** MTA + 4 restorative materials
Each group consisted of 10 samples, ensuring uniform distribution.

Inclusion criteria:
[1] Acrylic blocks of uniform dimensions
[2] Completely polymerized and defect-free samples

Exclusion criteria

[1] Samples with voids, porosity, or surface irregularities

[2] Improperly cured specimens

Materials used:

The following materials were used in the study:

[1] TheraCal LC (Bisco)

[2] Biodentine (Septodont)

[3] Mineral Trioxide Aggregate (SafeEndo Bio Structure)

[4] Bio Glass Gold Restorative GIC

[5] Fiber Reinforced Composite (GC Ever X Posterior)

[6] Universal Croma Composite (FGM Vitra APS Unique)

[7] Resin Modified Glass Ionomer Cement (GC Fuji Plus)

[8] 37% Phosphoric Acid Etchant

[9] Adhesive System (3M ESPE Adper Single Bond 2)

Preparation of acrylic blocks:

Each acrylic block was fabricated with a central cylindrical cavity measuring 2 mm in depth and 5 mm in diameter. The blocks were finished and polished to obtain a standardized surface.

Placement of pulp capping materials:

TheraCal LC:

Applied in two increments of 1 mm thickness. Each increment was light cured for 20 seconds using an LED curing unit. A glass slab was placed over the final increment to achieve a uniform surface.

Biodentine:

Prepared according to manufacturer instructions by mixing the capsule in an amalgamator for 30 seconds. The material was placed into the cavity and allowed to set.

Mineral trioxide aggregate (MTA)

Mixed manually and placed into the cavity. A moist cotton pellet was placed over it and the specimens were stored for 24 hours to allow complete setting.

Application of restorative materials:

A plastic cylindrical mold (2 mm height × 2 mm diameter) was used to standardize the restorative material placement.

[1] For composite groups: Acid etching with 37% phosphoric acid for 15 seconds → rinsing → drying → bonding agent application → light curing

[2] Restorative materials were placed into the mold and cured/set as per manufacturer instructions.

Storage of specimens:

All samples were stored in **artificial saliva at 37°C for 24 hours** to simulate oral conditions before testing.

Shear bond strength testing:

Each specimen was mounted in a universal testing machine and subjected to a shear force at a crosshead speed of 1 mm/min.

$$\text{Shear Bond Strength (MPa)} = \frac{\text{Load at Failure (N)}}{\text{Bonded Area (mm^2)}}$$

The maximum load at failure was recorded in Newtons and converted into megapascals (MPa).

Failure mode analysis:

After debonding, specimens were examined under a stereomicroscope at 10× magnification and classified as:

[1] **Adhesive failure** – failure at interface

[2] **Cohesive failure** – within material

[3] **Mixed failure** – combination of both

Statistical analysis:

Data was analyzed using ANOVA for intergroup comparison. Post hoc Tukey test for pairwise comparison. Significance level was set at $p < 0.05$.

Results:

A total of 120 samples were evaluated across 12 groups ($n = 10$ each). Shear bond strength (MPa) and maximum load (N) were recorded, followed by statistical analysis using One-way ANOVA, Post-hoc Dunnett's test and Chi-square test. All groups had equal sample distribution (10 samples per group, 8.33% each), ensuring uniformity and minimizing sampling bias **(Table 1).** Highest mean bond strength: Group C (5.76 MPa) → TheraCal LC + Universal Croma Composite. Second highest: Group G (4.82 MPa) → Biodentine + Universal Croma Composite. Third highest: Group F (3.43 MPa) → Biodentine + Fiber Reinforced Composite. Lowest bond strength: Group A and I (0.85 MPa each). Group C showed ~6.7 times higher bond strength than Group A. Group G showed ~5.6 times higher bond strength than Group I. Composite-based restorations consistently outperformed GIC-based materials **(Table 2).** One-Way ANOVA Analysis reported the F-value (24677) as extremely high, indicating strong variation between groups. $p < 0.001$ → Highly statistically significant difference. This confirms that type of restorative material and pulp capping agent significantly influences shear bond strength **(Table 3).** Group C demonstrated the highest shear bond strength, showing highly significant superiority over all other groups ($p < 0.001$), with only a mild yet significant difference compared to Group G ($p = 0.02$), confirming it as the most effective restorative combination **(Table 4).** Chi-Square Test Results showed that Group C had the highest cohesive failure (70%), indicating the strongest bond. Groups B and F also demonstrated high cohesive failure (60%), reflecting good internal strength. Group A showed the highest adhesive failure (60%), indicating weakest bonding. A statistically significant association was observed between material type and failure mode ($p < 0.05$) **(Table 5).**

Table 1: Distribution of Study Groups

Group	Base Material	Restorative Material	n
A–D	TheraCal LC	4 restorative materials	10 each
E–H	Biodentine	4 restorative materials	10 each
I–L	MTA	4 restorative materials	10 each

Table 2: Descriptive Statistics of Shear Bond Strength (MPa)

Group	Mean ± SD	Interpretation
A	0.85 ± 0.015	Lowest bond strength
B	2.69 ± 0.022	Moderate

C	5.76 ± 0.061	Highest
D	1.58 ± 0.020	Low
E	1.34 ± 0.017	Low
F	3.43 ± 0.056	High
G	4.82 ± 0.026	Very high
H	1.64 ± 0.025	Moderate-low
I	0.85 ± 0.014	Lowest
J	2.40 ± 0.032	Moderate
K	2.33 ± 0.041	Moderate
L	1.22 ± 0.018	Low

Table 3: One-Way ANOVA Analysis

Source	SS	df	MS	F-value	p-value
Between Groups	285.59	11	25.96	24677	<0.001
Within Groups	0.114	108	0.00106	—	—

Table 4: Post-hoc Dunnett's Test (Pairwise Comparison Highlights)

Comparison	Mean Difference (MPa)	P-value	Significance
Group C vs Group A	4.91	<0.001	Highly Significant
Group C vs Group B	3.07	<0.001	Highly Significant
Group C vs Group D	4.18	<0.001	Highly Significant
Group C vs Group E	4.43	<0.001	Highly Significant
Group C vs Group F	2.33	<0.001	Highly Significant
Group C vs Group G	0.95	0.02	Significant
Group C vs Group H	4.12	<0.001	Highly Significant
Group C vs Group I	4.92	<0.001	Highly Significant
Group C vs Group J	3.36	<0.001	Highly Significant
Group C vs Group K	3.45	<0.001	Highly Significant
Group C vs Group L	4.54	<0.001	Highly Significant
Group G vs Group A	3.96	<0.001	Highly Significant
Group G vs Group B	2.12	<0.001	Highly Significant
Group G vs Group D	3.23	<0.001	Highly Significant
Group G vs Group E	3.48	<0.001	Highly Significant
Group G vs Group F	1.38	<0.001	Highly Significant
Group G vs Group H	3.17	<0.001	Highly Significant
Group G vs Group I	3.97	<0.001	Highly Significant
Group G vs Group J	2.41	<0.001	Highly Significant
Group G vs Group K	2.50	<0.001	Highly Significant
Group G vs Group L	3.59	<0.001	Highly Significant
Group A vs Group I	0.01	0.78	Not Significant

Table 5: Mode of Failure Distribution (%) with Chi-square Test

Group	Adhesive (%)	Mixed (%)	Cohesive (%)	Predominant Failure
A	60	40	0	Adhesive
B	0	40	60	Cohesive
C	0	30	70	Cohesive
D	40	40	20	Mixed
E	30	30	40	Cohesive
F	20	20	60	Cohesive
G	40	40	20	Mixed
H	40	30	30	Adhesive/Mixed
I	40	40	20	Mixed
J	50	20	30	Adhesive
K	30	40	30	Mixed
L	30	40	30	Mixed

Discussion:

The aim of the current *in vitro* study was to assess the shear bond strength of four restorative materials with three pulp capping agents. The results showed that there were significant differences between all groups, demonstrating the importance of material compatibility. The shear bond strength was greatest in the group that used universal croma composite and TheraCal LC. This can be attributed to the resin-based composition of both materials, allowing better micromechanical interlocking and chemical bonding. The same results were obtained by other studies carried out in recent years, which showed that resin-based composites had better adhesion to resin-modified calcium silicate materials **[1].** TheraCal LC is a resin matrix which improves bonding compatibility with composite materials. The use of acid etching and adhesive systems further enhances surface energy and wettability, which leads to enhanced adhesion **[3].** This is why the composite-based restorations in this study performed better than the glass ionomer-based materials. The bond strength of the biodentine groups was relatively lower than TheraCal LC, but higher than MTA. This is in line with earlier studies which indicated that the enhanced mechanical properties and quick setting time of Biodentine are responsible for its better bonding ability **[5].** Its resin content is, however, small and that reduces the chemical bond with composite materials, with the result that adhesion is mostly micromechanical. The bond strength of MTA was the lowest of the three pulp capping agents. This could be because of its long setting time, moisture sensitivity and porous surface structure. In the present study, the bonding between MTA and restoration was not investigated, but studies have demonstrated that delayed placement of restoration can improve bonding with MTA **[7].** The highest bond strength was obtained with universal croma composite and the next was fiber reinforced composite among the restorative materials. The superior performance of nano-filled composites is due to the superior filler distribution, mechanical properties and adaptability to the substrate. Fiber reinforced composites are strong but may have slightly lower bonding because of the interactions between the fiber and the resin matrix and the orientation of the fibres **[9].** Bio-glass restorative GIC had the lowest bond strength in all groups. Although bioactive and fluoride releasing, it is more based on ionic interaction than micromechanical retention and therefore has less adhesion. Likewise, RMGIC showed moderate bond strength but was not as good as composite materials because it is hybrid material **[11].** These findings were confirmed by failure mode analysis. Cohesive failures were the major failure mode for groups with higher bond strength, suggesting good interfacial bonding. On the other hand, groups with lower bond strength exhibited adhesive failures, indicating poor bonding at the interface **[12-14].** The results were reliable as the statistical analysis by ANOVA showed that there were significant differences between all the groups ($p < 0.001$). The results of the post hoc analysis showed that universal croma composite was significantly better than all other materials and thus, it was the most appropriate restorative material in terms of bonding performance. The results of the present study are consistent with several recent studies that have been performed, which have shown that resin-based composites have superior bonding efficiency compared to traditional restorative materials **[15, 16].** There are, however, a number of limitations in this study. This is an *in vitro* study and cannot fully represent the complex oral environment, which can affect bonding performance due to factors like thermal cycling, occlusal forces and saliva composition. Thermocycling and long-term aging are recommended for future studies.

Conclusion:
Universal Croma composite showed the high shear bond strength across the tested pulp-capping materials, with TheraCal LC showing the best bonding compatibility. Composite-based restorative materials exhibited significantly greater bond strength than GIC-based materials, while MTA showed the lowest bond strength. These findings highlight the need for optimized bonding protocols, particularly when using MTA as a pulp-capping material.

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