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Comparative Evaluation of Shear Bond Strength of MTA, Biodentine, and Thera Cal-LC to Different Permanent Restorative Materials: An in Vitro Study

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Abstract

Aim: To evaluate and compare the shear bond strength (SBS) of three calcium silicate-based pulp capping materials—Mineral Trioxide Aggregate (MTA), Biodentine, and Thera Cal-LC—to three different restorative materials: nanocomposite, Amalgomer CR, and resin-modified glass ionomer cement (RMGIC).

Materials and Methods: A total of 45 acrylic blocks were prepared with standardized central cavities (4 mm diameter × 2 mm depth). These were divided into three groups based on the liner material used: MTA, Biodentine, and Thera Cal-LC. Each group was further subdivided based on the restorative material used: nanocomposite, Amalgomer CR, or RMGIC ($n = 5$ per subgroup). The restorative materials were applied after complete setting of liners. All specimens were stored at 37°C and 100% humidity for 72 hours, followed by shear bond strength testing using a universal testing machine at 1 mm/min crosshead speed. Data were analyzed using SPSS 26.0, applying ANOVA and Bonferroni post hoc tests ($p < 0.05$).

Results: Thera Cal-LC demonstrated the highest bond strengths across all restorative materials, followed by Biodentine and MTA. The nanocomposite showed significantly higher SBS values compared to RMGIC and Amalgomer CR within all groups. Among the base materials, significant differences were observed particularly in combinations with RMGIC.

Conclusion: Nanocomposite restorations over TheraCal-LC provided the highest SBS, indicating superior compatibility. Amalgomer CR and RMGIC showed lower SBS values with all liners. This suggests TheraCal-LC combined with nanocomposites may offer enhanced performance in clinical scenarios requiring strong adhesion.

Keywords: Shear bond strength, MTA, Biodentine, Thera Cal-LC, nanocomposite, RMGIC, Amalgomer CR.

Introduction

The primary goal of treating deep carious lesions is to preserve pulp vitality using minimally invasive preparation techniques and biocompatible materials that provide a strong seal, as well as osteoconductive and inductive properties.[1] Ideally, the treatment should promote the formation of a dentinal bridge, ensuring the continued health of the pulp.[2] Over the past two decades, calcium silicate based cements, also known as bioceramics, have gained significant attention due to their biocompatibility and excellent physicochemical characteristics. Studies[3–5] have explored the bonding of bioceramics to restorative materials, as this remains a key clinical concern. The selection of a bioceramic material should be based on its bond strength with the overlying coronal restoration.[5] Among the commercially available bioceramics, MTA and Biodentine are the most commonly used, with Theracal-LC recently emerging as another option.[6] The success of a pulp capping procedure depends on the bond between restorative materials and pulp capping agents, as inadequate sealing can allow microbial infiltration, ultimately leading to failure. Nanocomposites, widely used in restorative dentistry due to their aesthetic appeal, serve as permanent restorative materials.[7] These advanced composites were introduced to address the limitations of earlier generations and have since been evaluated for clinical effectiveness.[7] Resin-modified glass ionomer cements (RMGICs) were developed to overcome the low early mechanical strength and moisture sensitivity of traditional glass ionomer cements while retaining their clinical advantages. However, they still present drawbacks such as low wear resistance and polymerization shrinkage.[8] A new ceramic-reinforced glass ionomer, Amalgomer-CR, has recently been introduced to the dental market. According to the manufacturer, this tooth-colored material combines the durability of metallic restoratives with the aesthetics and benefits of glass ionomer cements.[9] Therefore, it would be advantageous if pulp capping materials such as MTA, Biodentine, and Theracal-LC demonstrated optimal bond strength with nanocomposites, ceramic-reinforced GICs, and RMGICs

Materials and Methods

Study Design and Setting: This in vitro study was conducted in the Department of Conservative Dentistry and Endodontics, Sree Anjaneya Institute of Dental Sciences, Calicut, Kerala, and testing was performed at the Centre for Biomechanics, NIT Calicut.

Sample Size Calculation: Using power analysis (Altunsoy et al.), with $\alpha = 0.05$ and power = 90%, a sample size of 15 per group (total N = 45) was calculated.

Sample Preparation: This study was carried out after obtaining ethical approval from the Institutional Ethics Committee of Sree Anjaneya Institute of Dental Sciences on 26th May 2023. The sample preparation was undertaken in the Department of Conservative Dentistry and Endodontics at, Sree Anjaneya Institute Of Dental Sciences. Shear bond strength (SBS) testing was performed using a universal testing machine at the National Institute of Technology (NIT), Kozhikode, Kerala, India. A total of 45 acrylic blocks were fabricated and evenly distributed into three experimental groups, each comprising 15 samples: Group I (MTA), Group II (Biodentine), and Group III (TheraCal LC). In each block, a standardized circular cavity was prepared at the center using a carbide bur, measuring 4 mm in diameter and 2 mm in depth, to accommodate the respective test materials. The materials Biodentine (Septodont, Saint-Maur-des-Fossés, France), Mineral Trioxide Aggregate [MTA] (White ProRoot MTA, Dentsply Sirona, Milford, USA), and TheraCal LC (Bisco, Schaumburg, Illinois, USA)—were manipulated strictly according to the manufacturers' guidelines. White ProRoot MTA is commercially supplied in sachets containing 0.5 grams of powder, accompanied by distilled water as the mixing liquid. For this study, the entire contents of the sachet were dispensed onto a mixing pad, and manual mixing was performed in accordance with the manufacturer's recommendations. The prepared cement was then carefully placed into the central cavity using a plastic filling instrument, followed by gentle condensation with a condenser to ensure proper adaptation within the cavity. Biodentine is commercially provided in capsule form, containing the powder component, along with a separate single-dose ampoule of liquid. Approximately five drops of the liquid were dispensed into the capsule, and the mixture was mechanically homogenized using an amalgamator set at 4200 rpm for 30 seconds, as per the manufacturer's instructions. The prepared cement was then introduced into the central cavity using the same placement and condensation technique employed for MTA. TheraCal LC (Bisco, Schaumburg, Illinois, USA) is a light-cured, resin-modified calcium silicate based liner that is dispensed directly from a syringe. Prior to application, the material was gently extruded onto a mixing pad to eliminate potential air bubbles. It was then placed into the central cavity preparation using a suitable applicator tip. The material was adapted to the cavity surface with a plastic instrument to ensure uniform distribution. Following placement, TheraCal LC was light cured for 20 seconds using an LED curing unit with an output of 1000 mW/cm², in accordance with the manufacturer's recommendations. Mineral Trioxide Aggregate (MTA), Biodentine, and TheraCal LC were carefully placed into the central cavities of the prepared acrylic blocks. Each specimen was appropriately labeled and subsequently covered with moistened cotton pellets to maintain a humid environment. The samples were then stored in an incubator at 37°C and 100% relative humidity for a period of three days to allow for adequate setting and maturation of the materials, in accordance with standardized in vitro protocols.

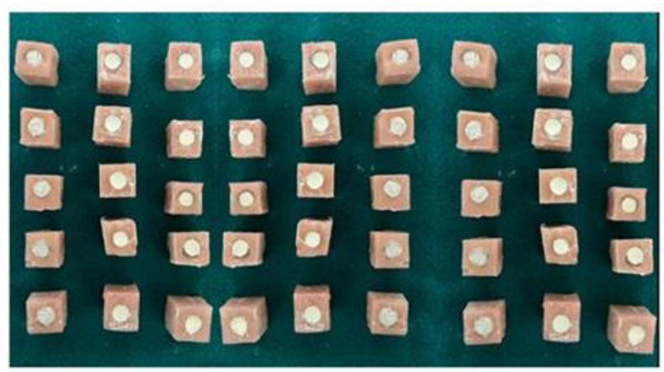


Figure 1:

The acrylic blocks containing MTA, Biodentine and TheraCal-LC will be divided into three groups and 3 subgroups (n = 5) as follows

- Group Ia—MTA + nanocomposite.
- Group Ib—MTA + RMGIC.
- Group Ic—MTA + Amalgomer-CR

- Group IIa—Biodentine + nanocomposite.
- Group IIa—Biodentine + RMGIC.
- Group IIb—Biodentine + Amalgomer-CR
- Group IIIa—TheraCal-LC + nanocomposite.
- Group IIIb— TheraCal-LC + RMGIC.
- Group IIIc— TheraCal-LC + Amalgomer CR

Total 45 specimen with 15 specimen in each group(15x3=45) and 5 in each subgroup (5x3x3=45) The adhesive system used in this study was Single Bond Universal (3M ESPE, Saint Paul, Minnesota, USA), applied in self-etch mode. In the nanocomposite (Filtek Z350XT, 3M ESPE, Saint Paul, Minnesota, USA) group, the bonding agent was applied over the MTA, Biodentine, or TheraCal LC surfaces. The adhesive was gently rubbed onto the materials for 20 seconds to ensure adequate wetting, followed by a 5-second air-drying period to facilitate solvent evaporation. Subsequently, the bonding agent was light-cured continuously for 20 seconds at an intensity of 1200 mW/cm² to ensure proper polymerization of the adhesive.

Shear Bond Strength Testing: The samples were mounted in a universal testing machine. A knife-edge blade applied shear load at the interface at 1 mm/min until bond failure. Load (N) was recorded and SBS calculated in MPa (Load/Area).

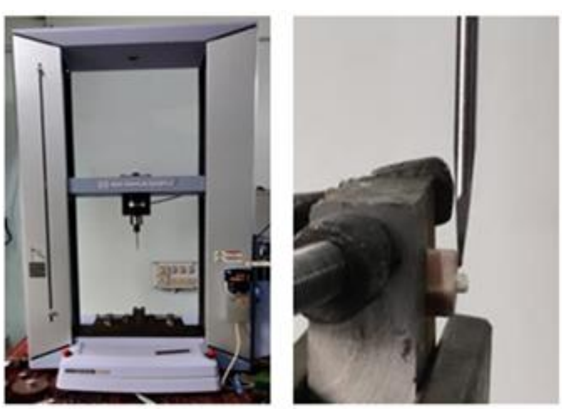


Figure 2:

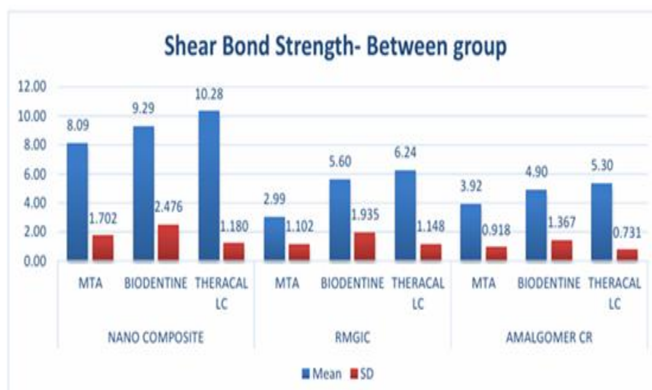
Statistical Analysis: Shapiro-Wilk and Kolmogorov-Smirnov tests confirmed normal distribution. ANOVA and Bonferroni post hoc tests determined intergroup differences ($p < 0.05$).

Results

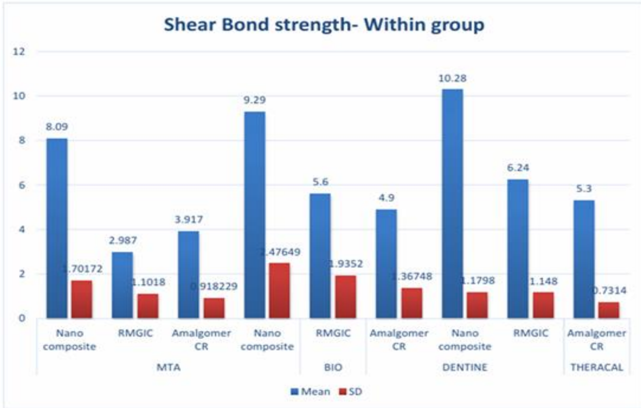
Table 1: Test Results

Test groups	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Group 1	6.97	6.2	9,01	7.77	10.5
Group 2	1.185	2.9	3.55	3.2	4.1
Group 3	2.82	3.4	4.585	3.68	5.1
Group 4	6	8.2	12.5	9	10.75
Group 5	2.5	5.2	7.5	6.8	6
Group 6	3	4.2	6.5	5	5.8
Group 7	8.7	9.9	10.1	10.8	11.9
Group 8	5.1	6.8	7.3	4.9	7.1
Group 9	4.2	5.8	6.1	5.3	5,1

TheraCal-LC consistently exhibited the highest mean SBS, especially with nanocomposites (10.28 MPa). RMGIC showed significant differences among base materials ($p = 0.009$). Amalgomer CR and RMGIC yielded lower SBS values across all groups. Nanocomposites had significantly higher SBS values than RMGIC and Amalgomer CR for each liner material.



Graph 1: SBS between groups



Graph 2: SBS within groups

Discussion

Achieving a durable and effective bond between restorative materials and tooth structures—such as enamel, dentin, and underlying liners is a fundamental factor in the success of restorative dental procedures. Bond strengths within the range of 17–20 MPa are generally considered adequate to resist polymerization contraction forces and to ensure tight restoration margins without gaps. According to a systematic review and meta-analysis by Leloup et al., several elements significantly impact bond strength outcomes. These include the testing methodology (whether shear, tensile, or microtensile), the type of composite resin utilized, the crosshead speed during testing, and the size of the bonded surface area. Additionally, other contributing variables such as specimen storage conditions, characteristics of the bonding substrate, thermocycling processes, and the type of load-application device used can also influence the measured results. These findings emphasize the importance of standardized testing procedures when assessing adhesive performance. Although the reliability of bond strength tests in accurately predicting the clinical performance of dental adhesives remains a topic of debate, recent research indicates that laboratory findings may offer a reasonable approximation of clinical outcomes.[10,11] Among the various testing methods, the microtensile bond strength test is generally regarded as the most appropriate for evaluating adhesive performance in dentistry. However, this method is not suitable for materials like mineral trioxide aggregate (MTA), which exhibit brittle characteristics.[12] As a result, the current study employed the shear bond strength (SBS) test as a more appropriate alternative for assessing the bonding performance of such materials.

The shear bond strength (SBS) test is commonly used to evaluate the structural performance of bonding materials by determining the level of stress the adhesive layer can endure. A higher SBS value generally suggests a stronger adhesive bond and a lower likelihood of microleakage. However, the stress level that actually initiates crack formation may be significantly higher than the average stress reported. Differences in specimen preparation, the type of substrate used, testing methods, and storage conditions can all influence outcomes, making the nominal SBS an unreliable indicator of actual failure stress.[13] Because of these variations, the bond strength of a given cement can differ considerably across studies. In the current investigation, none of the tested groups demonstrated an ideal SBS value. Previous studies have shown variation in the dimensions of the central cavity preparation. For instance, Altunsoy et al.[14] employed a 3 × 1.5 mm central preparation, while Cantekin and Avci[15] utilized a 5 × 2 mm dimension. Similarly, Odabaş et al. and Çolak et al. adopted a 4 × 2 mm preparation in their respective studies. Based on a review of these prior works, the current study selected a 4 × 2 mm central preparation, aiming to enhance the retention of the filling material. Regarding the size of the restorative material (2 × 2 mm) placed over MTA/Biodentine/Theracal LC, the dimensions used in this study were consistent with those reported in previous research. A limited number of studies have employed prolonged water storage to simulate clinical aging or thermocycling of specimens.[16] These investigations consistently reported a decline in mechanical strength, with thermocycled specimens exhibiting a more significant reduction. Conversely, Hashem et al. found that the highest bond strength was recorded following 24 hours of water storage, with a progressive decrease observed over the subsequent months. According to Bachoo et al.[17] the initial setting reaction of Biodentine occurs approximately 12 minutes after manipulation. However, complete maturation of the material may require up to two weeks. Kaup et al.[18] observed a significant increase in the bond strength of Biodentine to permanent dentin following a storage period of 2 to 7 days. This observation is supported by findings indicating that the setting reaction of calcium silicate-based cements may extend beyond 30 days. Therefore, in the current study, restorative materials were applied over MTA/Biodentine/Theracal LC only after 96 hours. Additionally, the Biodentine, MTA and Theracal LC specimens were stored at 37°C in 100% humidity for 72 hours to ensure complete setting of the materials. Following pulp capping procedures, achieving an optimal restoration is essential, particularly in the esthetic zone where composite resin is often the material of choice. In contrast, resin-modified glass ionomer cement (RMGIC) may serve as a suitable alternative in cases where the preparation lacks sufficient surrounding enamel. In the present study, a novel restorative material—Amalgomer CR, a ceramic-reinforced glass ionomer—was utilized. In this study, among the groups containing MTA, the combination of MTA with nanocomposite exhibited the highest bond strength, followed by MTA paired with Amalgomer CR. The lowest bond strength was noted in the MTA combined with RMGIC group. Previous studies by Tulumbaci et al.[19] and Cantekin & Avci reported mean bond strengths of 18.68 MPa and 17.7 MPa, respectively, for the MTA and composite resin combination. Similarly, Tunc et al. observed a bond strength of 13.22 MPa using white MTA with composite resin, a material also utilized in the present study. They attributed the higher bond strengths to the minimal polymerization shrinkage and the presence of free-radical monomers in methacrylate-based composite resins. However, the current study reported a lower bond strength value of 7.77 MPa. This discrepancy could be due to the use of different bonding agents in previous studies, while the current investigation exclusively employed Single Bond Universal. A universal adhesive containing Methacryloyloxydecyl dihydrogen phosphate (MDP) and silanes (Single Bond Universal, 3M ESPE) was selected for this study. This self-etching adhesive, formulated with 10-MDP, is known for its ability to chemically bond with calcium ions, aluminum, and zirconia oxides. The methacrylate component within the bifunctional silane molecule enhances chemical interaction with resin-based substrates. Additionally, silanes act as adhesion promoters by enhancing the wetting properties of the bonding agent. The selection of this adhesive in our study aimed to facilitate additional chemical bonding with bioactive liners that release calcium. Based on the findings of the present study, within the Biodentine group, the combination of Biodentine with nanocomposite exhibited the highest bond strength, followed by the Biodentine paired with RMGIC. The lowest bond strength was recorded for the Biodentine and Amalgomer CR combination.

The bond strength values observed with Biodentine in combination with the three restorative materials were higher than those recorded with MTA. This could be attributed to Biodentine's ability to undergo biomineralization. Additionally, its finer particle size and uniform composition may enhance its interaction with restorative materials, leading to better bonding performance. In the current investigation, the evaluation of bond strength within the Theracal LC group revealed notable differences among the restorative combinations. The pairing of Theracal LC with nanocomposite exhibited the highest bond strength values, indicating superior interfacial compatibility and potential for enhanced clinical performance. This was followed by the Theracal LC combined with resin-modified glass ionomer cement (RMGIC), which demonstrated moderate bond strength. In contrast, the lowest bond strength was recorded for the combination of Theracal LC with Amalgomer CR, suggesting comparatively weaker adhesion characteristics in this group. The higher bond strength observed in the combination of Theracal LC with nanocomposite can likely be attributed to the compatibility between the methacrylate monomers in both materials. The resin components in Theracal LC facilitate the formation of a robust chemical bond with the nanocomposite matrix, supporting effective co-polymerization and improved interfacial integration. This results in enhanced mechanical properties and clinical performance, consistent with findings from earlier studies that highlighted the increased bonding efficiency between resin based materials and light-cured calcium silicate cements. The moderate bond strength observed in the combination of Theracal LC with resin-modified glass ionomer cement (RMGIC) may stem from the partial chemical interaction between the resin components of Theracal LC and the ionic structure of RMGIC. Despite RMGIC containing both acidic and resin components that are capable of interacting with Theracal LC, the bond strength is limited by differences in polymerization processes and the reduced degree of resin interpenetration. This observation is supported by the findings of Miller et al., who noted that although RMGICs do demonstrate some adhesion to calcium silicate-based materials, their bond strength is typically lower than that achieved with composite resins. The lower bond strength recorded in the Theracal LC + Amalgomer CR combination may be due to the limited chemical interaction between Theracal LC and the glass carbomer components of Amalgomer CR. Although glass carbomer materials provide fluoride release, they lack the necessary resin-based functional groups to form strong chemical bonds with the resin matrix of Theracal LC. This limited compatibility likely contributes to the weaker bond strength observed, supporting previous studies that suggest glass carbomer materials tend to show reduced adhesion when combined with resin-based cements. The findings obtained in the present study must be interpreted with caution due to several limitations. Firstly, the experimental design involved the use of a flat surface with a single interface between the calcium silicate-based material and the restorative material, which may not accurately reflect the complexity of real-world clinical conditions. Furthermore, the effect of dentin, a crucial factor in bonding, was not considered in this investigation, potentially limiting the applicability of the results to natural tooth structures. Additionally, the in vitro conditions employed in this study do not replicate the dynamic and functional environment of the oral cavity, including factors such as masticatory forces, moisture fluctuations, and temperature variations, all of which influence the long-term performance of dental materials. Given these limitations, it is strongly recommended that future clinical studies be conducted to evaluate the impact of cyclic loading during mastication, as well as the effect of aging on the stability and durability of the bonding interface between the two materials under more realistic oral conditions.

Conclusion

TheraCal-LC combined with nanocomposite exhibited the highest shear bond strength among the tested combinations. MTA showed the weakest bond, particularly with RMGIC and Amalgomer CR. TheraCal-LC and Biodentine paired with nanocomposites may be recommended for clinical applications where strong adhesion is critical.

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