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ORIGINAL RESEARCH

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Shear bond strength of composite resin, Cention N, and Stela to different pulp capping materials: an *in vitro* study

Menekşe Alim[1,*], Sena Karakaya[2], Kübra Karaosmanoğlu[3], Şükriye Türkoğlu Kayacı[4]

[1]Private Practice, 06560 Ankara, Turkey
[2]Çankırı Oral and Dental Health Center, 18312 Çankırı, Turkey
[3]Department of Restorative Dentistry, Faculty of Dentistry, Ankara University, 06560 Ankara, Turkey
[4]Department of Pediatric Dentistry, Hamidiye Faculty of Dental Medicine, University of Health Sciences, 34668 Istanbul, Turkey

***Correspondence**
dt.alimmenekse@gmail.com
(Menekşe Alim)

Abstract

Background: The bond strength between pulp capping and restorative materials is critical for successful pulp therapy. This study aims to evaluate and compare the shear bond strengths (SBS) between three pulp capping materials (Mineral Trioxide Aggregate (MTA), Biodentine, and TheraCal PT) and three restorative materials (composite resin, Cention N, and Stela). **Methods**: A total of 90 acrylic samples were prepared with a central hole of 4 mm in diameter and 2 mm in height. The samples were randomly divided into three groups based on the pulp capping materials, *i.e.*, MTA, Biodentine, and TheraCal PT. After completecuring of the pulp capping materials, each group was divided into three subgroups (n = 10) based on the restorative materials, *i.e.*, composite resin, Cention N, and Stela. The samples were kept for 24 hours at 37 °C and 100% humidity. A shear test was conducted for each sample using a universal testing machine at a crosshead speed of 1 mm/min. Different failure modes were visualized under a stereomicroscope and scanning electron microscope (SEM). Data were analyzed by two-way analysis of variance (ANOVA) and Tukey's *post hoc* test. **Results**: Two-way ANOVA showed that SBS values ($p < 0.05$) were significantly affected by both the pulp capping material and the restorative material. The SBS of TheraCal PT along with restorative materials was significantly higher ($p < 0.001$) compared to MTA and Biodentine. Among the restorative materials, the SBS between Stela Automix and MTA or Biodentine was significantly higher than those of the other restorative materials ($p < 0.001$). The highest SBS was observed for the TheraCal PT-composite group (24.56 $\pm$ 2.89), whereas the lowest was observed in the MTA-Cention N group (6.02 $\pm$ 1.40). **Conclusions**: The 10-MDP monomer in the adhesive system of Stela Automix chemically binds with calcium in hydroxyapatite, providing strong adhesion to calcium-rich surfaces such as MTA and Biodentine. Within the limitations of this *in vitro* study, TheraCal PT shows favorable binding comparable to other pulp capping materials. The TheraCal PT–composite combination may reduce microleakage and improve permanent restorations compared with other pulp capping materials; however, clinical validation is vital.

Keywords

MTA; Biodentine; TheraCal PT; Shear bond strength; Vital pulp therapy; Bioactive materials

1. Introduction

The affected pulp is preserved through vital pulp therapies (VPT) while treating deep carious lesions. The primary objective of VPT is to preserve the remaining healthy tooth structure and ensure the vitality of dental pulp damaged by caries, trauma, or other factors [1]. In VPT, a protective material is placed over the pulp after removing local irritants. This material preserves pulp vitality, prevents bacterial microleakage, allows placement of restorative material, withstands functional forces, and promotes dentin bridge formation [2]. VPT preserves the natural regenerative and sensory capacities of the pulp, prevents the need for more invasive endodontic procedures, and contributes to the structural strengthening and overall lifespan of permanent dentition [1, 2].

Calcium hydroxide has traditionally been the gold standard; however, its limitations, such as high solubility and lack of adhesion, have led to the development of calcium silicate-based bioceramics, *e.g.*, Mineral Trioxide Aggregate (MTA) and Biodentine [3–5]. They undergo hydration to form calcium hydroxide, which is increasingly used in VPTs [6]. Recent studies suggest that MTA shows superior clinical and

histological outcomes in treating exposed pulps compared to calcium hydroxide. MTA is biocompatible. It stimulates hard tissue formation and possesses sealing properties along with high alkalinity, antibacterial activity, and low solubility [7, 8]. However, MTA has several limitations, including handling, setting time, difficulty in removal after setting, and tooth discoloration [8, 9].

MTA drawbacks have been overcome by introducing Biodentine (Septodont, France) as a tricalcium silicate-based cement in 2009. It has several advantages such as shorter setting time, improved compressive strength, enhanced handling properties, higher density, increased calcium ion release, and ease of application [10, 11]. TheraCal LC (Bisco, Schaumburg, USA) was launched in 2011 to address poor binding between calcium silicates and resin-based materials [12].

TheraCal PT (Bisco, USA) as a dual-cure system has been developed in 2019. It minimizes the cytotoxic effects of unpolymerized residual monomers in TheraCal LC, which is a light-curing, resin-modified tricalcium silicate. TheraCal PT has initially been designed for pulpotomy procedures, however it is also used in direct and indirect pulp capping treatments. It may be put immediately onto the prepared tooth as it has a quick setting time and the final restorative material can be placed right after polymerization [13]. TheraCal PT has been promising in recent investigations because of the physical characteristics, low solubility, biocompatibility, and simple clinical administration [14–16].

The success of VPT depends on the individual properties of materials used and the complex interfacial interaction between pulp capping material and definitive restoration. Traditionally, restorative materials were expected to be biologically inert; however, contemporary restorative dentistry has increasingly focused on bioactive restorative materials, which are defined as materials capable of eliciting a specific biological response at the material–tissue interface, resulting in the formation of a biologically active bond [17]. These materials interact dynamically with the surrounding environment through the release of ions such as calcium, phosphate, and fluoride, thereby promoting remineralization, buffering acidic conditions, and supporting the formation of apatite-like structures at the interface [18, 19]. Such interfacial bioactivity may enhance sealing ability and improve the functional compatibility between pulp-capping materials and restorative systems following vital pulp therapy procedures. For example, Cention N (Ivoclar Vivadent, Schaan, Liechtenstein) is a resin-based aesthetic restorative material [17]. It has been termed as “Alkasite” material containing alkaline glass fillers releasing hydroxide, calcium, and fluoride ions [18]. Another aesthetic restorative material, *i.e.*, Stela Automix (SDI Ltd., Bayswater, Victoria, Australia), is marketed as an amalgam alternative, which is self-curing and easy to apply. It contains filler agents such as strontium fluoroaluminosilicate glass, ytterbium (III) fluoride, silica, and calcium aluminate. It is defined as a new generation, resin-based, bulk-fill restorative material having unique chemical and physical properties [19]. The new generation, injectable composites with high filler content such as G-aenial Universal Injectable (GC Corp., Tokyo, Japan) have superior wear resistance and are easy to use. The properties are enhanced because of the innovations in filler size, composition, filler silanization, and manufacturing process [20].

An adhesive connection is formed when restorative materials bind to pulp capping agents. Stress is uniformly distributed throughout the bonded surface [21]. Insufficient bonding between the tooth and restorative or pulp capping materials may cause bacterial and fluid penetration, which potentially compromises the pulp vitality [22]. Thus, the duration and predictability of restoration clinically depend on the quality and strength of the link between pulp capping materials and restorative ingredients [23].

SBS testing is a simple and rapid method to evaluate the bond strength [24]. Microscopic techniques assess the qualitative aspects of bonding [25]. Previous studies have investigated the SBS of composite resin and glass ionomer cements applied to pulp capping materials using adhesive systems [26–28]. However, traditional research has focused on the bonding of MTA and Biodentine to typical restorative materials. Data lacks regarding interfacial performance of ion-releasing existing restorative systems when paired with newer calcium silicate-based biomaterials. Understanding the bonding behavior of TheraCal PT with systems such as Cention N and Stela Automix is essential for optimizing the “monoblock” effect in VPT. From a pediatric dentistry perspective, selecting restorative materials with favorable bonding performance to contemporary pulp-capping agents is clinically important for maintaining pulp vitality and ensuring durable coronal sealing after vital pulp therapy in young permanent teeth. Therefore, evaluating the interfacial behavior of these materials may provide clinicians with evidence-based guidance for restorative material selection in pediatric patients.

This *in vitro* study aims to evaluate and compare the SBS of three pulp capping materials (ProRoot MTA, Biodentine, and TheraCal PT) when paired with three restorative materials (Cention N, Stela Automix, and G-aenial Universal Injectable). The null hypothesis was that there would be no significant difference in the SBS between tested pulp capping materials and the restorative materials.

2. Materials and methods

This *in vitro* comparative experimental study was designed to evaluate the shear bond strength (SBS) of pulp capping and contemporary restorative materials. The materials, compositions, application steps, and manufacturer details are given in Table 1. The power analysis was performed using G*Power software version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, NRW, Germany), and the sample size was calculated as n = 10 (Type I error level = 0.05). The power of the study was determined to be 86%. Institutional ethical approval was not required as this was an *in vitro* study conducted using acrylic blocks. It did not involve human or animal subjects or tissues.

2.1 Specimen preparation

The sample preparation and testing procedures were performed by a single experienced operator. A total of 90 samples were prepared using cylindrical acrylic blocks. The center of the blocks had cavities of 4 mm diameter and 2 mm deep.

TABLE 1. Composition, steps of application, and manufacturer details of the materials used in the study.

Material	Composition	Steps of application	Manufacturer
ProRoot MTA	Powder: tricalcium silicate, dicalcium silicate, tricalcium aluminate, bismuth oxide, calcium sulphate dehydrate or gypsum Liquid: water	Mix 1 pouch of powder with 1 microdose ampule of liquid for about 1 min	Dentsply, Tulsa Dental, Johnson City, TN, USA
Biodentine	Powder: tricalcium silicate, dicalcium silicate, calcium carbonate and oxide, iron oxide and zirconium oxide Liquid: calcium chloride and hydrosoluble polymer	Pour 5 drops of liquid into the capsule, place the capsule on a mixing device and mix for 30 s	Septodont, Saint Maur des Fossés, France
TheraCal PT	Base: SG-Mix Cement, BisGMA, Barium Zirconate Catalyst: BisGMA, Triethylene Glycol Dimethacrylate, Barium Zirconate, Ytterbium Fluoride, Benzoyl Peroxide	Apply in 1 mm layers to the cavity. Then light-cure for 10 s	Bisco, Inc., Schaumburg, IL, USA
Cention N	Powder: calcium fluorosilicate glass, copolymer, barium-aluminium silicate glass, calcium-barium-aluminium fluorosilicate glass, barium glass, and ytterbium trifluoride Liquid: UDMA, aromatic-aliphatic UDMA, DCP, PEG-DMA, initiators, and mint flavour	Mix 1 measuring scoop of Powder and 1 drop of Liquid for about 45–60 s	Ivoclar Vivadent, Schaan, Liechtenstein
Stela Automix	Methacrylates (38 wt%) (63 vol%), Urethane Dimethacrylate, Glycerol Dimethacrylate, 10-MDP Fillers (61 wt%) (36 vol%), Barium-alumino-borosilicate glass, Fluoro-alumino-silicate glass, Ytterbium trifluoride, Silicon dioxide (hydrophobic fumed silica), Sodium Persulphate, Calcium aluminate Initiators (<1 wt%), Stabilisers (<1 wt%)	Using the automix syringe, extrude Stela into the cavity, filling the entire cavity in a single step	SDI Ltd, Bayswater, Victoria, Australia
Stela Primer	Methacrylates (including 10-MDP), MEK, water, initiators, stabilisers	1. Using a disposable brush applicator with solvent-resistant fibres (Points, SDI Limited), apply Stela Primer onto prepared cavity surfaces 2. Wait for 5 s 3. Dry for 2–3 s	SDI Ltd, Bayswater, Victoria, Australia
G-aenial Universal Injectable Composite	Matrix: (31%) in weight Bis-GMA, Bis-EMA, methacrylate monomer Fillers: (16 nm silica and 150 nm barium glass) make up (69 wt%). Ultra-fine particles combined with a silane coupling agent serve as a filler. Pigment, photoinitiator, barium glass, strontium glass, and silicon dioxide	Light-cure for 20 s	GC Corp., Tokyo, Japan
G-premio bond universal adhesive	Acetone, 2-Hydroxy-1,3 dimethacryloxypropane, methacryloyloxydecyl dihydrogen phosphate, Silane, dichlorodimethyl-, reaction products with silica, 2,2′-ethylenedioxydiethyl dimethacrylate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide, Butylated hydroxytoluene, aluminium oxide	1. Apply Bond with a rubbing motion 2. Dry with mild pressure air flow for 5 s 3. Light-cure for 10 s	GC Corp., Tokyo, Japan

MTA: Mineral Trioxide Aggregate; MDP: Methacryloyloxydecyl dihydrogen phosphate; GMA: glycidyl methacrylate; EMA: ethyl methacrylate; UDMA: urethane dimethacrylate; DCP: dicalcium phosphate; PEG-DMA: polyethylene glycol dimethacrylate; MEK: methyl ethyl ketone; wt: weight; vol: volume.

The dimensions of the cavities were verified using a digital caliper (Mitutoyo, Japan). MTA, Biodentine, and TheraCal PT were prepared according to the manufacturer's instructions and placed in the cavities of acrylic blocks, having 30 pieces of each pulp capping material. Mylar strip was placed over the newly applied pulp capping material to ensure a standard and flat surface. It was pressed against the acrylic block with a glass slide until the material reached its initial hardening. The excess biomaterials were removed from the surface to make it level with the acrylic block. The samples were kept for 24 hours at 37 °C and 100% humidity.

Each of the 30 samples in all biomaterial groups was assigned a unique identification number for unbiased distribution. They were randomly divided into three subgroups (n = 10) using a sealed envelope system. An investigator unaware of material types drew the numbers to determine assignment of restorative materials. A cylindrical mold of polyethylene of 2 mm diameter and 2 mm height was used to place the restorative materials on pulp capping materials. No additional surface preparation or mechanical processing was performed on the hardened pulp capping before applying restorative materials. The restorative materials were prepared according to the manufacturer's instructions. Bonding protocols were performed as follows: Cention N was placed onto the molds without any adhesive because of its self-adhesive properties. G-Premio Bond was applied to the biomaterial surface for the composite resin group, and Stela Primer for the Stela Automix group before placing the restorative material. The adhesive layers were applied according to the protocol given in Table 1. The light curing was carried out at 1200 mV/cm^2 intensity (Elipar S10, 3M™ ESPE™, St. Paul, MN, USA).

2.2 SBS test

The specimens were immersed in distilled water and stored for 24 hours in an incubator at 37 °C and 100% relative humidity for the complete setting of materials. These standardized conditions were maintained throughout the pre-testing period. For the SBS test, specimens were secured in a holder mounted on testing machine table. The crosshead was parallel and aligned with the interface between restoration and pulp-capping materials. They were then cut by a knife-edge blade on universal testing machine (Lloyd LRX; Lloyd Instruments, Fareham, Hants, United Kingdom) at the crosshead speed of 1.0 mm/min. Fracture loads were recorded in Newtons (N), and converted to megapascals (MPa) by dividing it with sample's surface area.

2.3 Fracture analysis

Fracture test specimens were visualized under a stereomicroscope at 40× magnification. Fractures were classified as follows: (1) Cohesive fracture—Within the restorative material/pulp capping material; (2) Adhesive fracture—At the interface between pulp capping and restorative materials; and (3) Mixed fracture—A combination of adhesive and cohesive fractures.

2.4 Scanning electron microscopic analysis

Three representative specimens from each group were sputter-coated with a 12 nm gold–palladium layer using an SPI-Module Sputter Coater (Structure Probe Inc., West Chester, PA, USA). The specimens were analyzed under a scanning electron microscope (SEM) (EVO LS10, Zeiss, Oberkochen, BW, Germany) using secondary electron mode. Images were obtained at magnifications of 100×, 200×, and 400×. The specimens were examined to evaluate the interfacial characteristics between the two bonding surfaces at the fracture point.

2.5 Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 22 software (IBM Corp., Armonk, NY, USA). The normality of the data distribution was assessed using both Kolmogorov-Smirnov and Shapiro-Wilk tests, and all variables were found to be normally distributed. Homogeneity of variances was confirmed using Levene's test. A two-way analysis of variance (ANOVA) was conducted to evaluate the effects of pulp capping materials and restorative materials, as well as their interaction, on bond strength. *Post hoc* multiple comparisons were performed using Tukey's test. Statistical significance was set at $p < 0.05$.

3. Results

Two-way ANOVA showed that both the types of pulp capping and restorative materials had significant effect on SBS values ($p < 0.05$). However, there was a significant correlation between the two factors ($p < 0.05$). The means and standard deviations of SBS values for the groups are given in Table 2. TheraCal PT had stronger connection with the restorative materials than MTA and Biodentine ($p < 0.001$). The bond strength between Stela Automix, MTA, and Biodentine pulp capping materials was higher compared to other restorative materials when average SBS values of restorative materials were compared ($p < 0.001$). The TheraCal PT composite group had the highest, while MTA Cention N group had the lowest SBS values.

The distribution of fracture modes of the groups is shown in Fig. 1.

The predominant failure mode was cohesive failure in all pulp capping materials. No cohesive failure was observed in the restorative materials. SEM images of fracture modes are shown in Fig. 2. The Biodentine-composite resin group had the highest cohesive failure rate (90%), while the Biodentine-Stela Automix group had the highest adhesive failure rate (80%).

4. Discussion

The SBS values of three pulp capping (ProRoot MTA, Biodentine, TheraCal PT) and three restorative (Cention N, Stela Automix, G-aenial Universal Injectable composite) materials were compared in this *in vitro* study. Findings indicate that both the type of pulp capping and restorative materials significantly affect bond strength.

The interface formed between these materials is a key factor in vital pulp therapies. Bacteria may occur in the pulp if

TABLE 2. Means and standard deviations of SBS values for all experimental groups.

SBS (MPa)	Stela Automix Mean ± SD	Cention N Mean ± SD	Composite Mean ± SD	*p*-values
MTA	$10.48 \pm 1.92^{A,a}$	$6.02 \pm 1.40^{A,b}$	$6.42 \pm 1.09^{A,b}$	<0.001*
TheraCal PT	$21.63 \pm 2.74^{B,a}$	$22.06 \pm 2.75^{B,a}$	$24.56 \pm 2.89^{B,a}$	0.057
Biodentine	$10.24 \pm 1.17^{A,a}$	$7.68 \pm 1.84^{A,b}$	$6.73 \pm 1.63^{A,b}$	<0.001*
p	<0.001*	<0.001*	<0.001*	

*Two-way ANOVA test *p < 0.05. Different superscript capital letters (A,B) in each column and lowercase letters (a,b) in each row indicate statistically significant differences. SD: Standard Deviation; MTA: Mineral Trioxide Aggregate.*

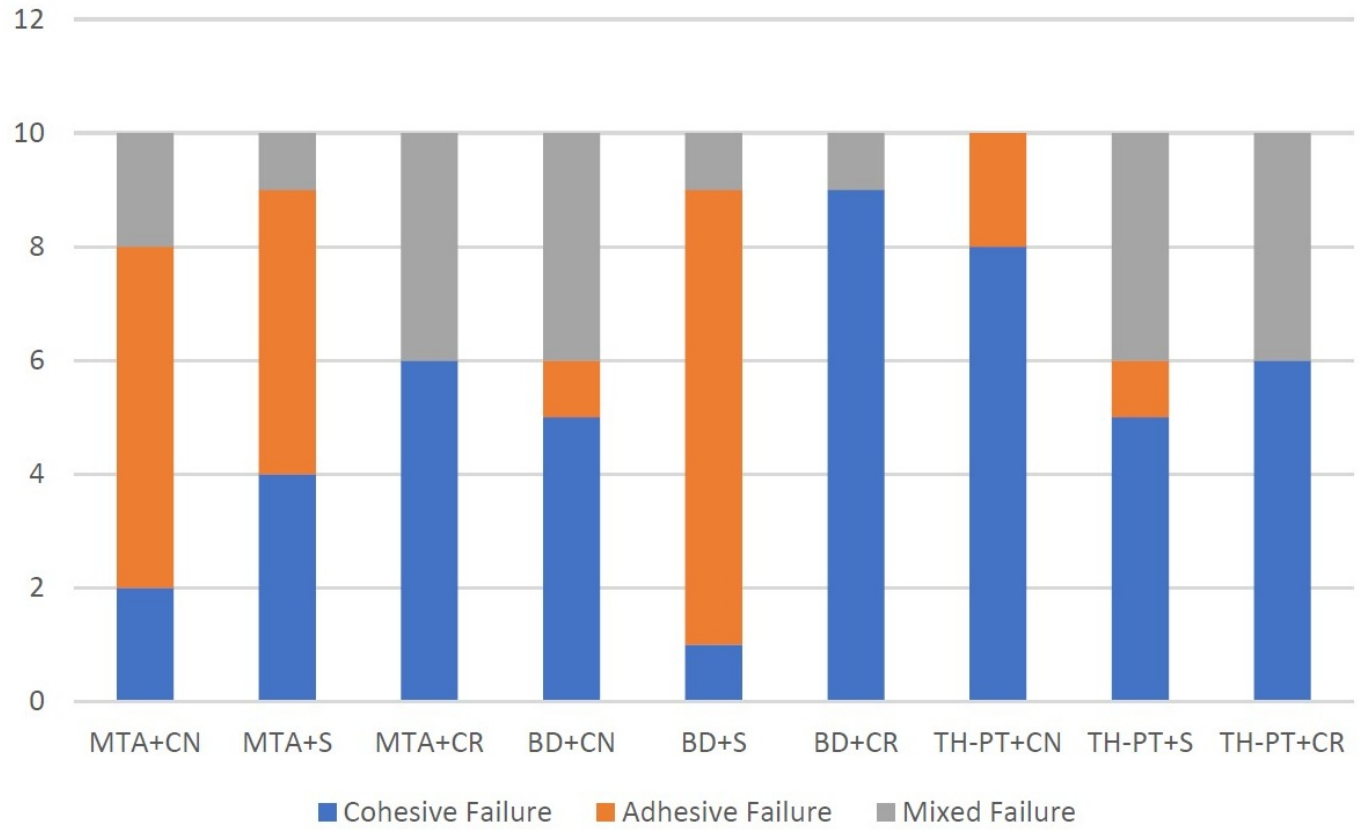

FIGURE 1. Distribution of failure modes within groups. CN: Cention N; S: Stela Automix; CR: Composite resin; BD: Biodentine; TH-PT: TheraCal PT; MTA: Mineral Trioxide Aggregate.

an adequate seal is not achieved. It may negatively affect treatment success. The bond strength of calcium silicate-based cements to restorative materials is thus an important clinical parameter [29].

A strong, rapid bond between the pulp capping material and the restoration is crucial. Consequently, the restoration must withstand the polymerization shrinkage stresses of the composite resins and functional mechanical loading occurring shortly after treatment [1]. TheraCal PT, as a resin-modified calcium silicate, has advantages in restoration protocols due to its light-curing mechanism and higher initial bond strength [16]. MTA and Biodentine are the gold standards regarding bioactivity; however, their long-term curing kinetics can lead to a less stable interface in the early stages of restoration placement [6].

Bond strength testing is used to assess the adhesive properties of restorative materials. These tests analyze the *in vitro* performance of materials [30]. Accordingly, the SBS test was used in this study to evaluate the adhesive properties of pulp capping to restorative materials.

A self-etch adhesive (G-Premio Bond Universal Adhesive) was applied in the groups where composite served as the restorative material. Several studies in the literature have shown that acid etching increases the bond strength of ProRoot MTA to resin materials [28, 31, 32]. The acid application alters the surface characteristics of MTA, which leads to erosion of the crystal structure and partial loss of matrix. Consequently, it creates a favorable surface for bonding. The relatively low bond strength between ProRoot MTA and composite in our study can be due to the absence of an acid-etching procedure. However, some studies have reported that acid application can also damage the MTA surface [33, 34].

The acid etching with phosphoric acid increases the bond strength of Biodentine with composite resins [28, 35]. How-

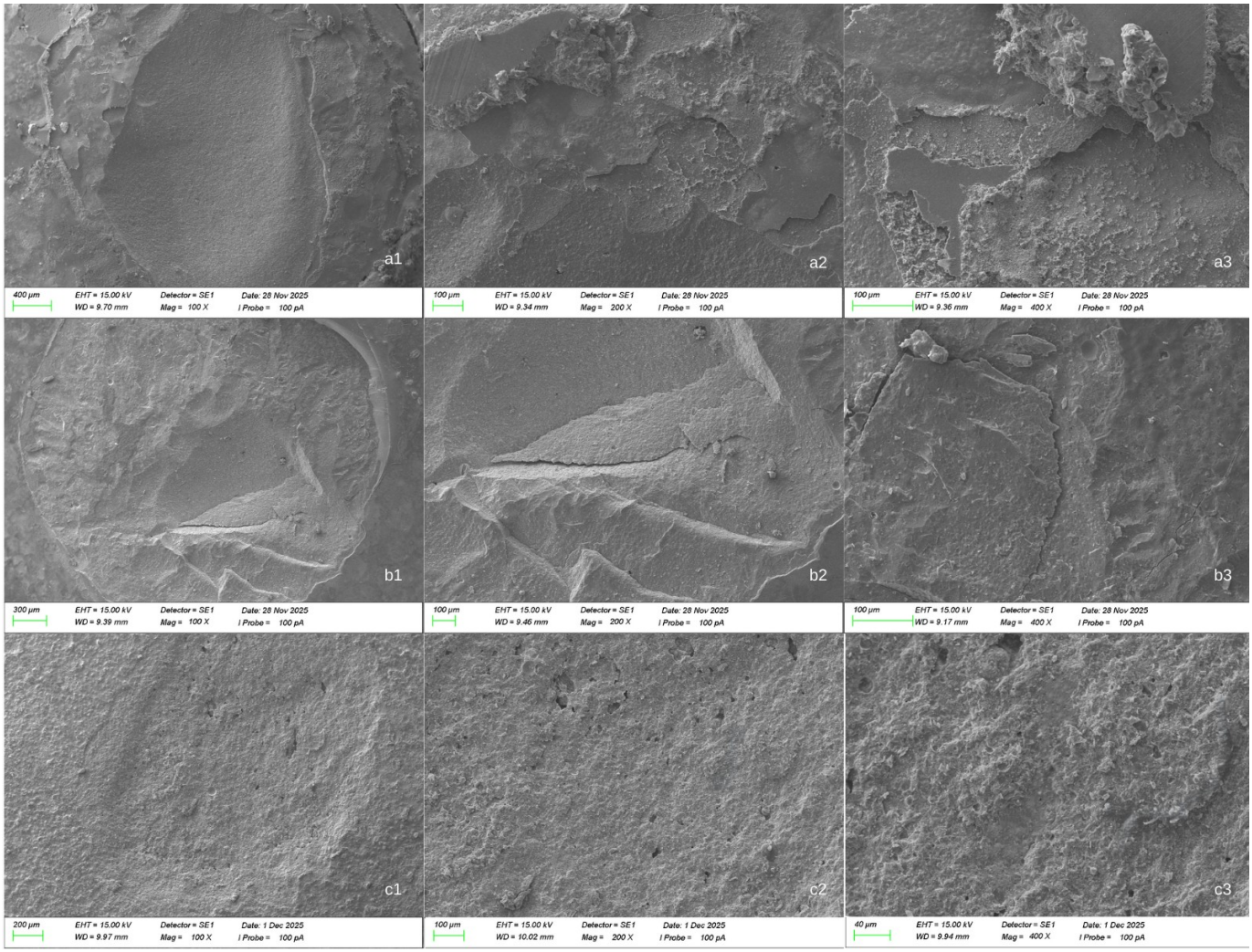

FIGURE 2. SEM images of the fracture modes. Images indicated with the letter "a" represent mix fracture between Biodentine and Cention N. a1 indicates 100× magnification, a2 indicates 200× magnification, a3 indicates 400× magnification. Images indicated with the letter "b" represent cohesive fracture between TheraCal PT and composite. b1 indicates 100× magnification, b2 indicates 200× magnification, b3 indicates 400× magnification. Images indicated with the letter "c" represent adhesive fracture between MTA and Stela Automix. c1 indicates 100× magnification, c2 indicates 200× magnification, c3 indicates 400× magnification. EHT: Electron High Tension; WD: Working Distance; SE1: Secondary Electron Detector 1; Mag: Magnification.

ever, adhesive application modes (etch, rinse, and self-etch) do not significantly alter the bond strength [23, 31]. Acid application may also compromise the structural and chemical integrity of Biodentine, which can lead to microleakage [36, 37]. The self-etch adhesive systems in clinical practice are preferred to reduce the leakage risk. The study here also used a self-etch adhesive system to ensure standardization.

Results show that TheraCal PT has greater SBS compared with MTA and Biodentine. The limited reported studies on TheraCal PT confirm its stronger bonds compared with MTA [22, 38, 39]. This can be attributed to the hydrophilic methacrylate monomer of TheraCal PT, which promotes chemical adhesion and strong contact with the bonding agent [32, 40]. In contrast, bonding to composites occurs through micromechanical interlocking in resin-free materials such as MTA, Dycal, and Biodentine [32, 41]. The superior adherence of TheraCal PT to restorative materials compared to MTA and Biodentine in our study is based on this chemical difference. The null hypothesis of our study is thus rejected considering these findings.

The SBS value between TheraCal PT and composite in this study is consistent with the outcomes of previous studies [22, 38, 39]. The bond strength between ProRoot MTA and composite (6.42 MPa) is lower than that of TheraCal PT. Previous studies have reported SBS values of MTA-composite as 4.52 to 8.9 MPa [32, 42, 43]. Results vary because of the factors such as adhesive type, pH, solvent composition, filler content, and MTA setting time [41, 44, 45].

In our study, the difference is not statistically significant although the SBS of Biodentine (6.73 ± 1.63 MPa) is higher compared with ProRoot MTA. Tulumbaci *et al.* [46], have compared the SBS of ProRoot MTA and Biodentine with restorative materials. The bond strength of ProRoot MTA to composite resin (18.69 ± 10.26 MPa) is higher than that of Biodentine (9.34 ± 4.08 MPa). The SBS for Biodentine in that study is higher than that of our results. It can be attributed

to the fact that Tulumbaci *et al*. [46] allowed 72 hours for Biodentine setting, whereas our study involves only 24 hours. According to Kaup *et al*. [47], SBS of Biodentine increases between 2 days and 1 week. The complete maturity takes 2 weeks to a month, whereas Bachoo *et al*. [48] have reported that Biodentine's first setting reaction takes ~12 minutes. The binding strength between materials can thus be influenced by Biodentine setting time.

There is no significant difference between the bond strength of Cention and composite resin with MTA, Biodentine, and TheraCal PT in our study. However, Stela Automix has stronger affinity to MTA and Biodentine. The Stela Automix primer contains 10-MDP (10-Methacryloyloxydecyl dihydrogen phosphate) monomer, which chemically binds to calcium ions of calcium silicate-based materials. The covalent bonds between phosphate groups and calcium ions enhance hydrolytic stability and bond durability over time [49, 50]. Both micromechanical and chemical adhesions are thus achieved. They explain the high SBS values in the Stela Automix group in our study.

The interaction between pulp capping and restorative materials can influence failure modes. Cohesive failures may occur frequently when chemical interactions between pulp capping and restorative materials weaken the internal structure of pulp capping material. The bonding is satisfactory when fracture occurs cohesively within the material rather than at the adhesive interface [51]. Cohesive failures in our study are predominantly observed in TheraCal PT groups, which have higher bond strengths. Adhesive failure is not observed in the groups where composite is used as the restorative material. The superior bond strength between TheraCal PT and composite from a clinical perspective suggests that this combination can provide better interface integrity, reduced microleakage, and increased success rate of permanent restorations compared to pulp capping materials.

The water-based cements such as Biodentine and MTA require complete hydration to achieve optimal properties. Resin-modified silicates like TheraCal indicate incomplete hydration. The resin monomer matrix in these materials acts as a physical barrier to partially restrict the water interaction necessary for complete reaction of calcium silicate particles. It represents a clinical trade-off; despite this, the resin component enables TheraCal PT to bind effectively with contemporary adhesives. These resin-modified systems prioritize immediate interfacial stability and faster restorative workflow. They may initially offer lower biomineralization compared to pure tricalcium silicate cements [52].

The primary limitation of the present study includes *in vitro* assessment of bonding between two materials instead of under clinical conditions or on dentin substrates. The acrylic provides a standardized surface for comparing material interactions; however, it does not fully replicate the biological complexity of the tooth-material interface in a clinical setting. Nonetheless, these *in vitro* investigations may provide useful reference for *in vivo* studies assessing the binding strength of materials. Another limitation involves the absence of an artificial aging protocol such as thermal cycling. The results herein provide valuable data on the immediate bonding of pulp capping materials, while long-term aging is required to simulate complex thermal and mechanical stresses of the oral cavity. Furthermore, samples are stored in distilled water at 100% humidity instead of artificial saliva. Distilled water is a standard medium for initial bond strength tests; however, the non-use of artificial saliva is a limitation as it cannot replicate the oral environment. Although TheraCal PT has shown high bonding values but more comprehensive studies on the physicochemical properties, ion release behavior, curing kinetics, and biocompatibility are recommended.

5. Conclusions

Within the limitations of this *in vitro* study, TheraCal PT demonstrated higher shear bond strength with all tested restorative materials compared with MTA and Biodentine. The 10-MDP monomer in the adhesive system of contemporary restorative material, Stela Automix showed strong adhesion, particularly on calcium-rich surfaces such as MTA and Biodentine. This can be attributed to its ability to form chemical bonds with calcium ions on hydroxyapatite surface. Further clinical studies are essential to confirm these results.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

MA—designed the research study, wrote the manuscript. SK and KK—performed the research, analyzed the data. ŞTK—provided help and advice for designing the study, helped with proofreading and editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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