Evaluation of the shear bond strength of various adhesive systems to calcium silicate based pulp capping materials

Farklı adeziv sistemlerin kalsiyum silikat esaslı pulpa kaplama materyallerine makaslama bağlanma dayanımının değerlendirilmesi

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Abstract

Aim: This study aimed to evaluate the shear bond strength (SBS) values of different adhesive systems to calcium silicate and calcium hydroxide-based pulp capping materials.

Methods: Cylinder-shaped cavities (2x5 mm) were prepared in the middle of 120 acrylic blocks. Three pulp capping materials (Biodentine, TheraCal LC, Kerr Life) were placed into the cavities. Single Bond 2 (SB2), Clearfil SE Bond (CSB), Clearfil Universal Bond (CUB), Tokuyama Self-cured Universal Bond (TUB) were applied for each pulp capping material (n=10). After composite resin cylinders were prepared, SBS tests were carried out. Data and failure modes were analyzed using two-way ANOVA, Tamhane's T2 ($p\leq0.05$), and stereomicroscope, respectively.

Results: TheraCal LC showed the highest SBS values, and there was a statistically significant difference amongst pulp capping materials for all adhesives ($p\leq0.05$). The lowest results were found in the Life+TUB (0.79±0.14), and the highest was TheraCal LC+CSB (8.55±1.73). In Biodentine, all adhesive systems showed lower results than TheraCal LC groups, whereas there was a statistically significant difference between SB2 and TUB compared to the Life.

Conclusion: TheraCal LC, which has the highest bond strength value in different generation adhesive systems, can be preferred as a pulp capping agent for composite restorations.

Keywords: Biodentine; calcium hydroxide; calcium silicate ; dental adhesives; pulp capping

Öz

Amaç: Bu çalışma, kalsiyum silikat ve kalsiyum hidroksit esaslı pulpa kaplama materyallerine farklı adeziv sistemlerin makaslama bağlanma dayanımı (SBS) değerlerini incelemeyi amaçlamıştır.

Yöntemler: 120 adet akrilik bloğun ortasına silindir şeklinde kaviteler (2x5 mm) hazırlanmıştır. Kavitelere üç adet pulpa kaplama materyali (Biodentine, TheraCal LC, Kerr Life) yerleştirildi. Her bir pulpa kaplama materyali (n=10) için Single Bond 2 (SB2), Clearfil SE Bond (CSB), Clearfil Universal Bond (CUB), Tokuyama Self-cured Universal Bond (TUB) uygulandı. Kompozit rezin silindirler hazırlandıktan sonra makaslama testleri yapılmıştır. Veriler ve kırılma başarısızlıkları sırasıyla iki yönlü ANOVA, Tamhane's T2 ($p\leq0.05$) ve stereomikroskop kullanılarak analiz edildi.

Bulgular: TheraCal LC'de, en yüksek bağlanma değerleri görülmüş olup, tüm adezivler için pulpa kaplama materyalleri arasında istatistiksel olarak anlamlı bir fark bulunmuştur ($p\leq0.05$). En düşük sonuçlar Life+TUB (0,79±0,14), en yüksek sonuçlar ise TheraCal LC+CSB (8,55±1.73) grubuna aittir. Tüm adeziv sistemler için Biodentine grubu TheraCal LC gruplarına göre daha düşük sonuçlar gösterirken, Life ile karşılaştırıldığında SB2 ve TUB arasında istatistiksel olarak anlamlı bir fark izlenmiştir.

Sonuç: Farklı jenerasyon adeziv sistemlerde yüksek bağlanma dayanımı değerine sahip olan TheraCal LC, kompozit restorasyonlarda pulpa kapaklama ajanı olarak tercih edilebilir.

Anahtar Sözcükler: Biyomedikal ve dental materyaller; dental adezivler; kalsiyum silikat; kayma mukavemeti; pulpa kaplaması

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INTRODUCTION

Vital pulp capping is a regenerative procedure in which a drug or dental material is placed directly on the exposed pulp or dentin tissue close to the pulp to maintain its vitality. The restorative tertiary dentin formation initiation by the pulp cells was considered the ultimate goal of using a capping material (1,2). If extensive cavity preparations are required, usually due to deep carious lesions, fractures, or previous restorations, a liner should be applied to protect the pulp if the remaining dentin thickness is less than 1.5 mm (3). Although many materials are used in direct or indirect vital pulp treatments, calcium hydroxide (CH) is considered the universal standard (4).

CH has an antimicrobial effect and raises the pH of the oral environment. It stimulates the release of growth factors and matrix components of bioactive dentin and provides dentin regeneration in the area where the pulp is exposed (5). However, it also has disadvantages such as its toxic effect, dispersibility or degradability under restorations, and the dentin bridge underneath CH having a porous structure (6). These drawbacks have led researchers to search for more resistant and impermeable materials with better dentin bridge formation.

Although several calcium silicate-based products have been on the market recently, *Biodentine*, which was launched commercially in 2009, is the first bioactive and biocompatible 'all-in-one' "dentin replacement material". It is produced with active biosilicate technology, which eliminates metallic residues during the production phase. Therefore, the material causes a low level of inflammation, and also has been found to demonstrate less solubility compared to mineral trioxide aggregate (MTA), and higher structural strength providing better coverage (7,8).

TheraCal LC is a resin-modified calcium silicate-based, biocompatible material developed for direct and indirect pulp capping under restorative materials. It contains tri-calcium silicate particles, barium zirconate, and polyethylene-glycol dimethacrylate monomers. In previous studies, the healing effect of TheraCal LC has been reported as stimulating the formation of apatite and secondary dentine by Ca dissolution from its structure (9).

Cavity liner and pulp capping materials used in restorative dentistry are expected to show impermeability and resist chewing pressure or dislocation forces (10). Besides the biocompatibility and bioactivity of the pulp capping materials, adhesion between composite restorations and capping materials is also crucial for the long-term success of the restoration (11).

New-generation adhesives, known as universal adhesives, inherit the all-in-one philosophy of the 7th-generation systems with the addition of multimode applications such as self-etch, etch-and-rinse, or enamel selective-etch (12). These materials are frequently preferred today because they present a time-efficient procedure and require less technical sensitivity (13). It is also claimed that universal adhesives can be utilized for bonding to various substrates (zirconia, noble and non-precious metals, resin-based composites (RBC), and silica-based ceramics) (14). There are increasing numbers of studies in the literature regarding universal adhesive systems' bonding performance due to their popularity in recent years (15–17). However, Tokuyama Universal Bond is a two-component, "self-cured universal adhesive" (chemically polymerized without light irradiation), which has been stated to be fully compatible with light-cured, self-cured, and dual-cured composite materials by its manufacturer (18). There are a few studies investigating the bond strength of this novel adhesive system (19) in the literature. Furthermore, to the best of our knowledge, there have not been any publications employing different substrates, in this case, pulp-capping materials.

The present study aims to evaluate the adhesion of different adhesive systems to capping materials. The following hypotheses will be tested: the universal adhesive systems will perform similarly with other tested adhesive systems in terms of bonding to different pulp capping materials.

MATERIAL AND METHODS

Since no data is collected on humans or animals, ethics committee approval is not required as in similar studies.

Specimen Preparation

One hundred twenty acrylic resin blocks were prepared using quick-setting acrylic resin (0-80 self-cure acrylic resin, Imicryl, Konya, Turkey) with 1 cm x 1 cm x 7 mm (height, length, width) in dimensions. Cylin-

Table 1. Materials used in the study

Material	Manufacturer	Composition	Lot
Biodentine	Septodont, Saint Maur-des-Fosses, France	**Powder:** Tri-calcium silicate, di-calcium silicate, calcium carbonate, and oxide filler, iron oxide, zirconium oxide radiopacifier **Liquid:** Calcium chloride, hydrosoluble polymer, water **Application:** Mixing premeasured unit dose capsules in a high speed amalgamators for 30 sn. 5 drops of liquids: 1 capsule powder	B07907
TheraCal LC	Bisco; Schaumburg, IL, USA	CaO, calcium silicate particles, Sr glass, fumed silica, barium sulfate, barium zirconate, Bis-GMA, polyethylene glycol dimethacrylate **Application:** 1.Apply in incremental layers. (Layer is not to exceed 1 mm in depth) 2. Light cure each increment for 20 s.	1800003760 1900000716
Life	Kerr Italia S.r.l. Via Passanti, Scafati (SA)- Italy	**Base:** Calcium dihydroxide, N-ethyl-o (or p)-toluene sulphonamide, zinc oxide, calcium oxide **Catalyst:** Methyl salicylate, 2,2-dimethylpropane-1,3-diol	7088752 7110094
i-Gel	i-dental, Medicinos Linija UAB, Lithuania	37% phosphoric acid etching gel **Application:** For only Adper Single Bond 2 groups, after 15s application rinsed and dried with air-water spray.	161115
Adper Single Bond 2	3M ESPE	Bis-GMA, HEMA, dimethacrylate, copolymer of polyacrylic and polyitaconic acids, water, and alcohol **Application:** The bonding agent was applied then dried with air-water spray for 10 s.	N838403
Clearfil SE Bond	Kuraray Noritake Dental Inc., Kurashiki, Okayama, Japan	**Primer**: MDP, HEMA, hydrophilic dimethacrylate, dl-camphorquinone, N, N-diethanol-p-toluidine, and water **Bond**: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, dlcamphorquinone, N, N-diethanol-ptoluidine, and silanated colloidal silica **Application:** Primer was applied for the 20s, dried with mild air for 20s. Bond was applied for 10s and gently air-dried.	AW0272 AX0435
Clearfil Universal Bond	(Kuraray Noritake Dental Inc, Kurashiki, Okayama, Japan)	Bis-GMA, HEMA, MDP, gydrophilic aliphatic dimethacrylate; colloidal silica; dl-camphorquinone; silane coupling agent; zirconium oxide; accelerators; initiators; water; ethanol **Application:** The bonding agent was applied for 10 s then dried with medium air pressure for 5 s.	9P0031
Tokuyama Universal Bond	Tokuyama Dental Corporation, Tokyo, Japan	**Bond A:** Phosphoric acid monomer (New 3D-SR monomer), MTU-6, HEMA, Bis-GMA, TEGDMA, acetone **Bond B:** γ-MPTES, borate, peroxide, acetone, ısopropyl alcohol, water **Application**: One drop each of Bond A nad B were dispensed and mixed in a mixing well. After application, it was air-dried for 5s.	014E87
Harmonize	Kerr Corp., Orange CA, USA	BisGMA, BisEMA, TEGDMA, spherical silica (30 nm)-zirconia (5 nm) filler particles, barium glass particles	6689321

**Bis-GMA:* Bisphenol A, di (2-hydroxy propoxy) dimethacrylate, *TEGDMA:* Triethylene glycol dimethacrylate, *HEMA:* 2-Hydroxyethyl methacrylate, *MTU-6:* thiouracil monomer, γ-MPTES: γ-methacryloxypropyl triethoxy silane, *BisEMA:* Bisphenol-A polyethylene glycol diether dimetacrylate, MDP: 10-Methacryloyloxydecyl dihydrogen phosphate.

Table 2. The mean SBS values (MPa) of Biodentin, TheraCal LC and Life to different adhesive systems

	SB 2	CSB	CUB	TUB
Biodentin	$2.66 \pm 0.36^{a,x}$	$2.18 \pm 0.45^{a,xz}$	$1.44 \pm 0.27^{a,y}$	$1.61 \pm 0.28^{a,yz}$
TheraCal LC	$7.65 \pm 1.26^{b,x}$	$8.55 \pm 1.73^{b,x}$	$5.60 \pm 0.91^{b,y}$	$5.11 \pm .50^{b,y}$
Life	$1.46 \pm 0.19^{c,x}$	$1.80 \pm 0.18^{a,x}$	$1.14 \pm 0.16^{a,y}$	$0.79 \pm 0.14^{c,z}$

Two-way ANOVA, Tamhane's T2 test ($p \leq 0.05$)

[abc] The different letters in vertical column indicate significant difference between capping materials.

[xvyz] The different letters in horizontal column indicate significant difference between adhesive systems.

(SB2: Single Bond 2, CSB: Clearfil SE Bond, CUB: Clearfil Universal Bond, TUB: Tokuyama Universal Bond)

SBS: Shear Bond Strength

drical cavities with a diameter of 5 mm and a depth of 2 mm were created in the middle of the acrylic blocks divided into three groups according to the pulp capping materials (figure 1). Biodentine was mixed, and a single dose of liquid and powder was mixed for the 30 s at 4000 rpm in an amalgamator (Capsmix-X, Atlas Health Care Technologies, Izmir, Turkey). Equal amounts of base and catalyst were extruded and mixed with a spatula for 10 s for the two-component CH-based capping material (Life) preparation. These materials were placed into cavities with a flat and round end filling instrument and flattened with a glass slab. TheraCal LC, packaged as syringes with disposable tips, was applied directly to the cavities in two layers (1 mm-thickness) with each layer lightly cured (BlueLEX GT-1200, Monitex Industrial Co. Ltd, Taiwan) for 20 s. Hence, the capping materials completely covered the cavities in accordance with the manufacturers' instructions.

Then, a two step etch and rinse Single Bond 2, a two step self-etch Clearfil SE Bond, a one-bottle Clearfil Universal Bond, and a self-cured Tokuyama Universal Bond were applied to each pulp capping material, providing n=10 per group (Figure 1). In the Single Bond 2 subgroup, the capping material's surface underwent etching with acid phosphoric gel for 15 seconds, followed by a 10-second water rinse and gently drying. The application procedure of three adhesive systems is described in Table 1, following the manufacturers' instructions. A nanohybrid universal RBC (Harmonize, Kerr Corp., Orange CA, USA) was incremented in two-layers utilizing cylindrical molds, 3 mm diameter and 4 mm height. As mentioned above, the LED light-curing device used the adhesive system (except for TUB) and RBC polymerization for 10 s and 20 s, respectively. The samples were stored in distilled water for 24h at 37°C in an incubator.

Shear Bond Strength (SBS) Testing and Failure Mode Analysis

Shear bond strength tests were carried out with a universal testing device (Shimadzu) with a 1 mm/min cross-head speed. SBS results were determined by Trapezium X software as N/mm^2; then, failure modes were classified via stereomicroscope (Olympus SZX 10, Olympus Life Science Europa GmbH, Hamburg, Germany) images into four categories: adhesive, cohesive in capping material, cohesive in composite, and mixed failure (Figures 2 to 4).

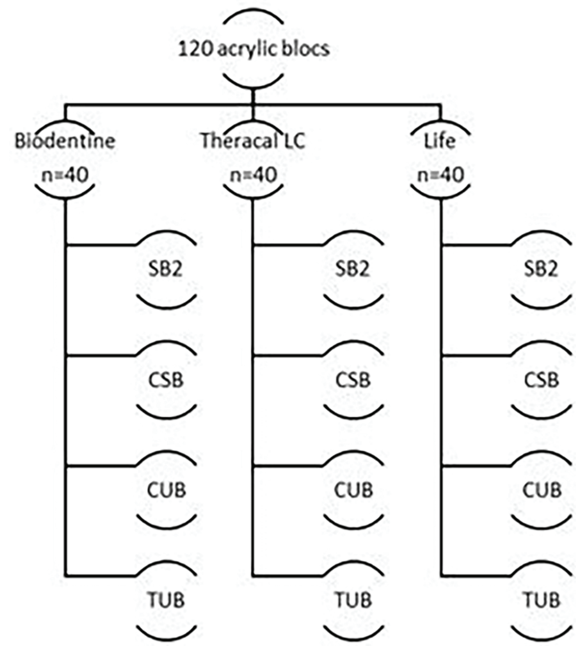

Figure 1. Study design (SB2: Single Bond 2, CSB: Clearfil SE Bond, CUB: Clearfil Universal Bond, TUB: Tokuyama Universal Bond)

Statistical Analysis

Two-way ANOVA analysis was conducted to establish the significance level in the interaction between adhesive and pulp capping material and multiple comparison tests were performed with Tamhane's T2. The analyses were performed using the IBM SPSS Statistics for Windows program version 20.0 (Corp, Armonk.) P-value ≤0.05 was considered statistically significant. Failure mode categories were analyzed descriptively.

RESULTS

Shear Bond Strength

The two-way ANOVA revealed statistically significant differences in the SBS performance of adhesive systems, with a p-value≤0.05 considered. Table 2 displays the mean SBS values and standard deviations of capping materials to various adhesives. It is apparent that TheraCal LC exhibited the highest SBS values (8.55±1.73 MPa), while the Life group demonstrated the lowest SBS values (0.79±0.14 MPa). Although Biodentin's SBS

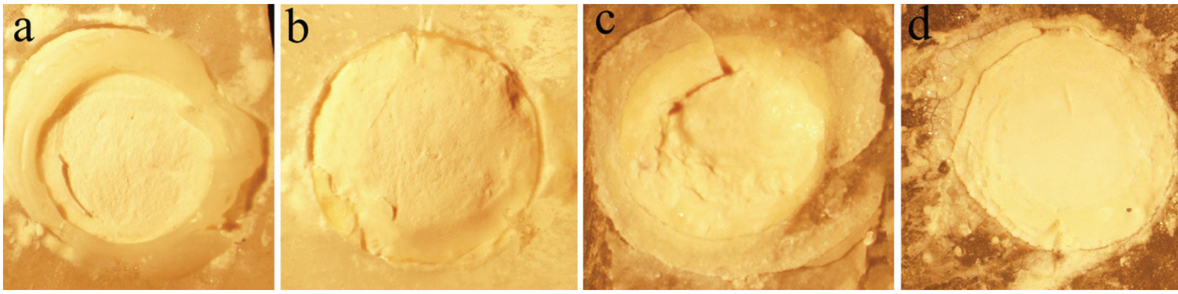

Figure 2. Biodentine's stereomicroscope images of bond failure modes

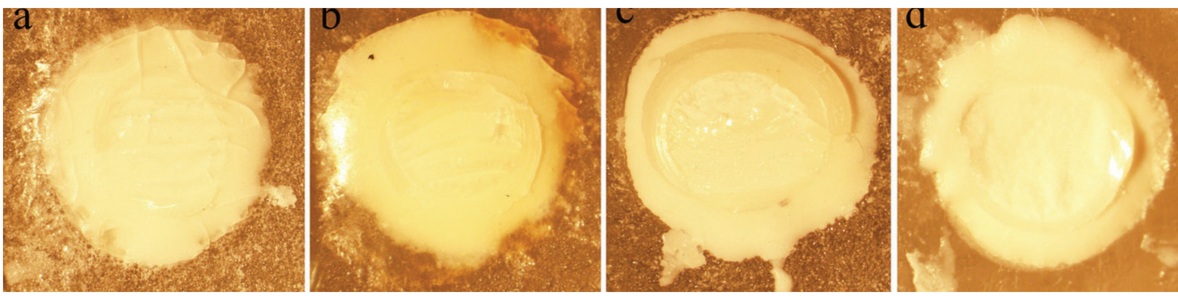

Figure 3. TheraCal LC's stereomicroscope images of bond failure modes a)Adhesive failure; the specimen was from the SB2: Single Bond 2 group, b) Adhesive failure; the specimen was from CSB: Clearfil SE Bond group, c) Mixed failure; the specimen was from the CUB: Clearfil Universal Bond group, d) Cohesive failure; the specimen was from the TUB:Tokuyama Universal Bond group

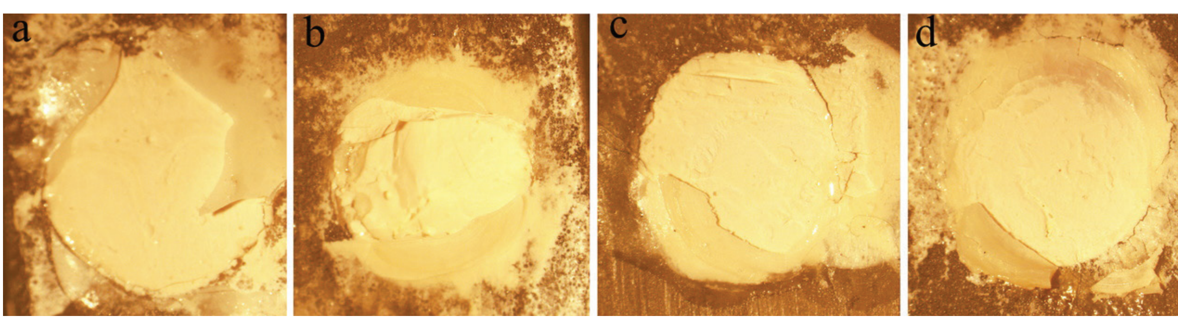

Figure 4. Life's stereomicroscope images of bond failure modes a) Mixed failure; the specimen was from the SB2: Single Bond 2 group, b) Mixed failure; the specimen was from CSB: Clearfil SE Bond group, c) Cohesive failure; the specimen was from the CUB: Clearfil Universal Bond group, d) Adhesive failure; the specimen was from the TUB: Tokuyama Universal Bond group

values were low for each adhesive group, they showed a statistically significant difference for SB2 and TUB adhesives compared to Life ($p \leq 0.05$). The SBS values of SB2 and CSB adhesive groups were high, while those of universal adhesives were low for each capping material (Figure 5). Table 2 illustrates a significant difference between SB2 and CSB bond strength values in the Life group, unlike other capping materials.

Failure mode analysis

Overall, the most recurrent or frequent failure modes of all groups were cohesive, mixed, and adhesive (Figure 6). Overall failure types of TUB in decreasing order were as follows: cohesive, adhesive, and mixed. Mixed failure was not observed in Biodentin-TUB and TheraCal-TUB groups, whereas adhesive failure was not observed in the Life-TUB group. Cohesive failure was detected as 90% in the TheraCal-TUB group.

In Biodentine groups, adhesive failure was not detected for SB2 and CUB groups, and it had the highest percentage (60%) in the TUB group, wherein mixed failure was not observed. Cohesive failure was the most recurrent type overall, with 70%, 60%, 50%, and 30% in CSB, CUB, SB2, and TUB groups, respectively. For

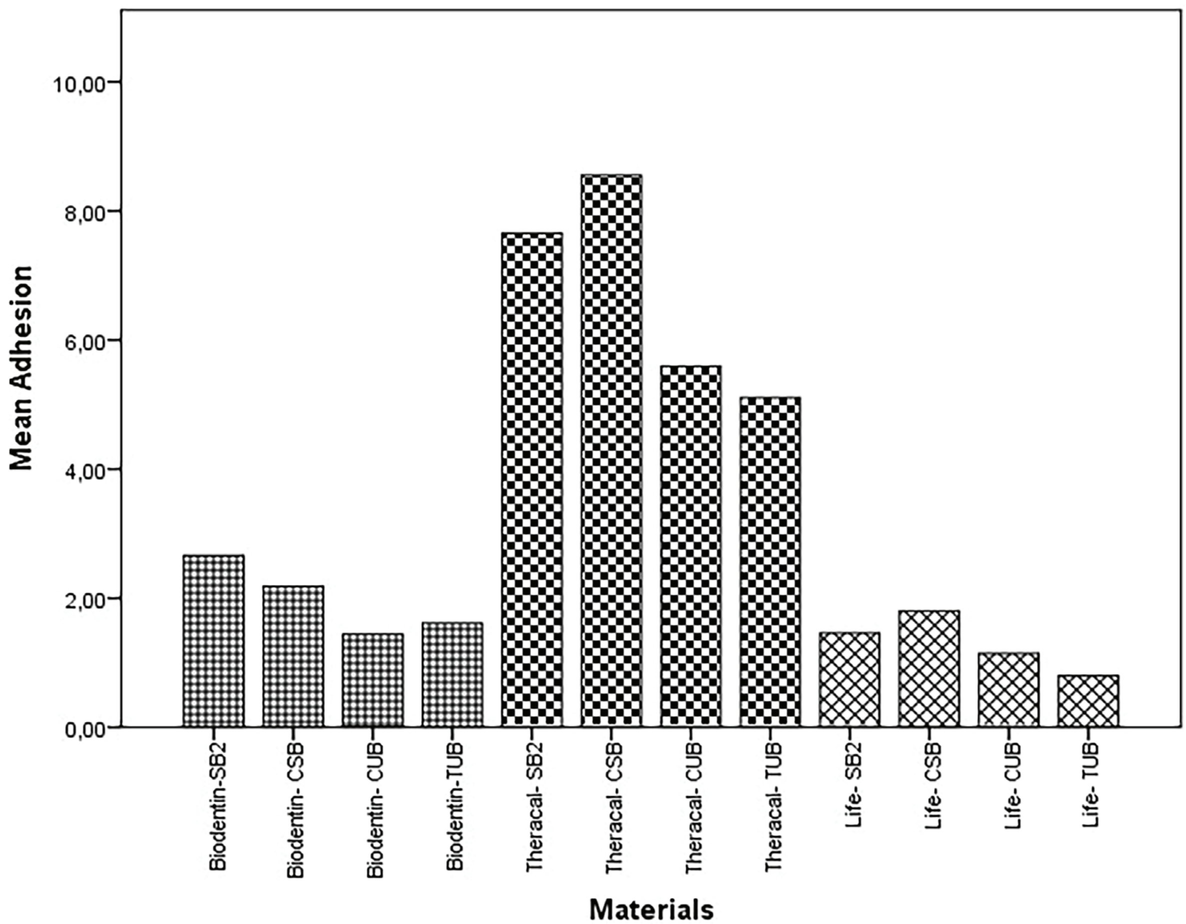

Figure 5. Mean adhesion in different experimental groups
SB2: Single Bond 2, CSB: Clearfil SE Bond, CUB: Clearfil Universal Bond, TUB: Tokuyama Universal Bond

TheraCal groups, cohesive failure was not identified for the SB2 group although it had the highest percentage in the other groups, with 90%, 60%, and 40% in TUB, CUB, and CSB, respectively. Mixed failure was not seen in the TUB group, and it was the least common failure type in SB2, CSB, and CUB groups, with 20%, 10%, and 10%, respectively. Adhesive failure was not observed in any of the Life groups. Cohesive and mixed failures were the same (60% mixed, 40% cohesive) except for the Life-TUB group (Figure 6). Representative stereomicroscope images are presented in Figures 2-4.

DISCUSSION AND CONCLUSION

For a successful vital pulp treatment, the pulp-capping material is expected to act as a sound barrier for preventing bacterial leakage and induce the formation of a dentine bridge between the pulp and the restorative material (20). Appropriate adhesive material selection in composite restorations is a crucial factor to be considered in the success of vital pulp treatments. Today, although there are various materials with different effects for pulp capping, calcium hydroxide is frequently preferred due to the formation of repaired dentin and its antibacterial effect. However, due to calcium hydroxide's disadvantages, such as high solubility and causing necrotic tissue, new and alternative substances were needed in vital pulp treatments (21,22). In the present study, calcium silicate containing Biodentin and TheraCal LC capping materials were preferred as an alternative to calcium hydroxide.

The surface properties of the capping materials, which have different physical and chemical properties, directly affect their bonding with the adhesive resins because this adhesion occurs due to the physicochemi-

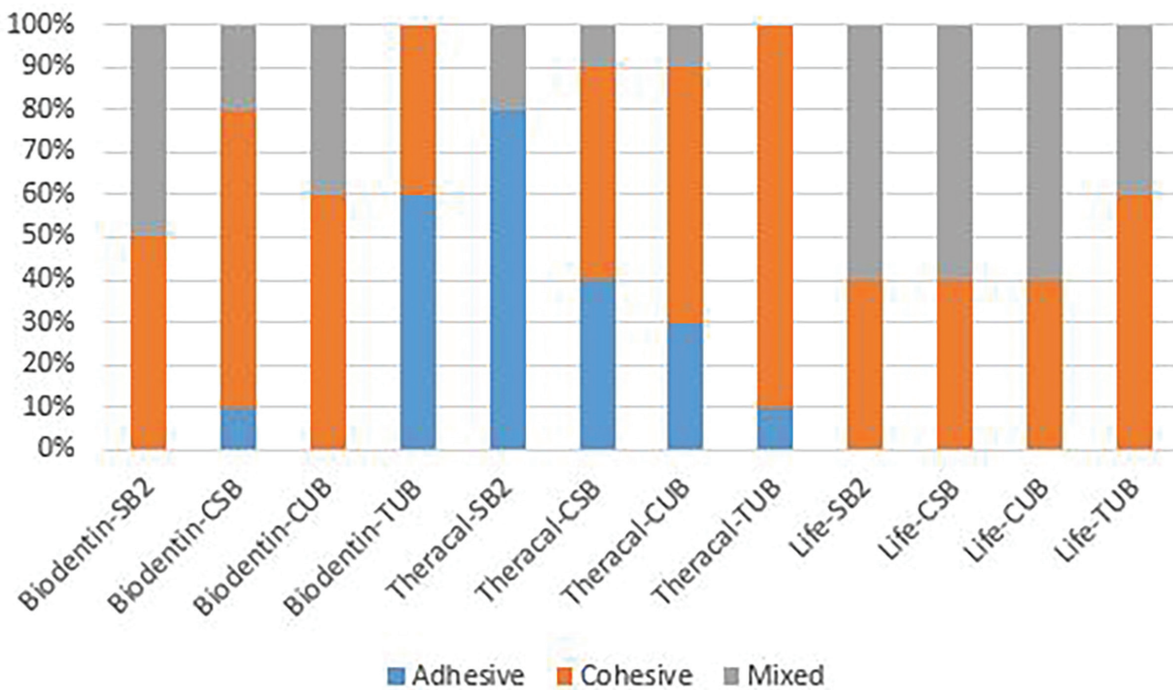

Figure 6. Shear bond strength failure mode distributions by percentages according to the test groups
SB2: Single Bond 2, CSB: Clearfil SE Bond, CUB: Clearfil Universal Bond, TUB: Tokuyama Universal Bond

cal interaction of two different materials along the interface (23). In pulp-capping treatments, the adhesive system we will prefer before composite restoration directly affects the treatment's success. Strong composite-capping material bonding is essential for the longevity of the restoration and maintenance of pulp vitality (24). Many studies are conducted to reduce the application time of current universal adhesives (25). Tokuyama Universal Bond (TUB; Tokuyama Dental, Tokyo, Japan) is one of the newest universal adhesives that allows a faster application by eliminating the light polymerization step and chemically polymerizes by mixing two liquid structures. Since there are limited studies in the literature evaluating this adhesive's success in terms of shear bond strength, TUB was compared with other adhesives in the present study.

TUB has shown low bond strength values, although it is claimed to provide a reliable adhesion with 3D-SR monomer and BoSE technology using a borate initiator. In their study, Katsumata et al. compared the microtensile bond strengths of TUB and Single Bond Universal to dentin and found no statistically significant difference in terms of microtensile bond strengths, thus, supporting the results of the present study (26). While the highest SBS value of TUB was observed in the TheraCal LC group, the lowest SBS value was observed in the Life group, and the first null hypothesis was rejected because statistically significant differences were observed among all capping material groups. It is possible to see conflicting results in studies examining the bond strength of different adhesives to capping materials. Colak et al. reported that the total-etch group's SBS values are similar to the SBS values of the one-step Clearfil S3 Bond group; in the study conducted by Odabaşı et al., the highest bond strength value was obtained with a two-step self-etch adhesive system, CSB (27,28). The null hypothesis was rejected based on the current study's findings, which demonstrated that SB2 and CSB adhesive systems provide high performance compared to one-step universal adhesives (Table 2). This result was in agreement with those of the previous studies, which found that the bond strengths of two-step self-etch adhesives were higher than those of one-step self-etch adhesives (12,29). These differences may be explained by different monomer content, acidity levels, operators, and time intervals.

Similar SBS values between CSE and SB2 adhesives may be due to the porous nature of the Biodentine surface, which may have counteracted differences between adhesive techniques. In addition, the acidity of the adhesives may be buffered by the alkalinity of Biodentine, which reduces the effect (24). Biodentin is marketed as a bioactive dentin-like, biocompatible capping material, with a shorter curing time (12 min) than other silicate-containing cement (30). As mentioned in the literature review, it has been reported that the etching of Biodentine causes damage to its microstructure and increased leakage at the Biodentin-composite interface. Therefore, if composite resin restoration will be placed after the Biodentine application, it is recommended to use self-etch after waiting for a while (24,31). Although the manufacturer states that the waiting time of 12 min after mixing of the Biodentine is sufficient for the application, it is recommended to increase the waiting time to ensure acceptable adhesion with the restorative material. Although there are limited studies in the literature on the bonding strength of Biodentine to resin materials, there are many studies on its application at different time intervals. Odabaş et al. (12 min and 24 h) and Hashem et al. (0.5, 20 min, 24 h, two weeks, one month, and six months) assessed the SBS of a composite to Biodentine in different time intervals and found higher SBS values in the 24 h groups (24,27). Bachoo et al. reported that the initial setting time of Biodentine takes approximately 12 min, but the full maturation of the material takes two weeks. Consequently, the hardening reaction of Biodentine can affect the bonding strength between Biodentine and restorative materials (32). In this study, the low SBS values of the Biodentine group may be attributed to our preference for the minimum waiting time after mixing.

Calcium hydroxide liner does not adhere to dentin or resin-based adhesive systems, providing a poor seal. The bonding between Dycal and the adhesive system and between the dycal and dentin tissue was evaluated under scanning electron microscopy (SEM). Significant gaps were observed between Dycal and dentine and between Dycal and the adhesive (33,34). In the present study, the lower SBS of Life can be explained by its high solubility and its tendency to release fewer calcium ions than calcium silicate-based materials.

There are many studies in the literature on tricalcium silicate, resin-containing, and light-curing TheraCal. It has been recommended for pulp capping due to its short application time, low solubility, and release of more Ca ions than calcium hydroxide-based liner (9,35,36). For all adhesive systems tested here, TheraCal LC presented higher SBS values compared to Biodentine and Life (Figure 5). The high SBS values of TheraCal LC can be attributed to the chemical adhesion between the dimethacrylate monomers it contains and the adhesive resins. Cengiz et al. examined the bond strength of tricalcium silicate-based materials to different restorative materials and observed the highest bond strength for all restorative materials in TheraCal LC groups (36). Consistent with this result, Karadas et al. examined the bonding strength of different adhesives to TheraCal LC and MTA, and reported that the highest SBS values were in TheraCal LC groups (37). However, another clinical study demonstrated that TheraCal and Calcium Hydroxide showed similar survival rates at the 6-month follow-up period (38). Considering these studies, it may be concluded that TheraCal LC can be used as an alternative material to calcium hydroxide and Biodentine for pulp capping.

In the present study, while adhesive and cohesive failure were seen together in the TheraCal LC group, in both Life and Biodentine, the fracture modes were mostly cohesive. As a result of the high number of adhesive failures between the TheraCal LC and the composite restoration, it can be stated that there is no strong bonding strength between them. The higher number of cohesive fractures in Biodentin and Life compared to TheraCal LC may be explained by the lower compressive strength of Biodentine and Life capping materials (Figures 2-4). Similar to these results, Cengiz and Ulusoy determined the highest number of adhesive failures in TheraCal LC and Biodentin groups in their study and observed cohesive failure in the Biodentin group (36). Tulumbacı et al. observed mostly adhesive failure between Biodentin-composite resin, and did not report cohesive failure; thus, their findings do not appear to be consistent with the current study (39). However, in another study, the adhesive failure did not occur, and the samples showed cohesive or mixed failure in the MTA, CEM, and Biodentine layers (40). While the failure modes were predominantly cohesive in TheraCal LC in Deepa et al.'s study, Schmidt et al. mostly determined the mixed failure type for Biodentin in their study (41,42). There is no consensus in the literature regarding fracture failure type between the materials. A possible explanation for these different results may be the setting times of capping materials and differences in adhesive systems.

One limitation of this study was the utilization of only one type of resin composite. Evaluating various restorative materials and adhesive systems would provide more comprehensive findings. Additionally, the short-term measurement of bond strength was another limitation. It would be advantageous in future studies to assess shear bond strength following the aging of samples and thermal cycling to simulate the oral environment.

TheraCal LC exhibited the highest bond strength values when bonded to composite resin among all adhesive systems. Biodentine and Life demonstrated significantly lower bond strength values compared to TheraCal LC. Additionally, the type of adhesive system utilized affected the bond strength of the capping materials. One-step universal adhesives demonstrated the lowest bond strength values for all three capping materials. Further research is required to gain a better understanding of the bonding mechanism between adhesive systems and capping materials. Due to its simple application and high capacity for bond strength to resin composite, TheraCal LC can be preferred for pulp capping.

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Conflict-of-interest and financial disclosure

The authors declare that they have no conflict of interest to disclose. The authors also declare that they did not receive any financial support for the study.

REFERENCES

1. Cohenca N, Paranjpe A, Berg J.Vital Pulp Therapy. Dent Clin North Am. 2013;57(1):59–73.
2. Hilton TJ. Keys to Clinical Success with Pulp Capping: A Review of the Literature. Oper Dent. 2009;34(5):615–25.
3. Caneppele T, Bresciani E, Da Silva Ávila D, Barcellos D, Pucci C. Effect of Lining Materials on Shear Bond Strength for Composite Restorations In Vitro. Int J Periodontics Restorative Dent. 2017;37(1):137–43.
4. Hilton TJ, Ferracane JL, Mancl L, et al. Comparison of CaOH with MTA for Direct Pulp Capping. J Dent Res. 2013;92(7):16–22.
5. Graham L, Cooper PR, Cassidy N, Nor JE, Sloan AJ, Smith AJ. The effect of calcium hydroxide on solubilisation of bio-active dentine matrix components. Biomaterials. 2006;27(14):2865-73.
6. Ghoddusi J, Forghani M, Parisay I.New approaches in vital pulp therapy in permanent teeth. Iran Endod J. 2013;9(1):15–22.
7. Arora DV. Bioactive dentin replacement. IOSR J Dent Med Sci. 2013;12(4):51–7.
8. Poggio C.Biocompatibility of a new pulp capping cement. Ann Stomatol (Roma). 2014;5(2):69–76.
9. Gandolfi MG, Siboni F, Prati C.Chemical-physical properties of TheraCal, a novel light-curable MTA-like material for pulp capping. Int Endod J. 2012;45(6):571–9.
10. Atmeh AR, Chong EZ, Richard G, Festy F, Watson TF. Dentin-cement interfacial interaction: Calcium silicates and polyalkenoates. J Dent Res. 2012;91(5):454–9.
11. Aksoy S, Ünal M.Shear bond strength of universal adhesive systems to a bioactive dentin substitute (Biodentine®) at different time intervals. Stomatol Dis Sci. 2017;1:116–22.
12. Da Rosa WLDO, Piva E, Da Silva AF. Bond strength of universal adhesives: A systematic review and meta-analysis. J Dent. 2015;43(7):765–76
13. Hanabusa M, Mine A, Kuboki T, et al. Bonding effectiveness of a new “multi-mode” adhesive to enamel and dentine. J Dent. 2012;40(6):475–84.
14. Alex G. Universal adhesives: the next evolution in adhesive dentistry?. Compend Contin Educ Dent. 2015;36(1):15-40.
15. Oz FD, Kutuk ZB, Balkan E, Ozturk C, Gurgan S.Bond strength of three different universal adhesives after different thermal cycling protocols. J Adhes Sci Technol. 2018;32(24):2741–52.
16. Ataol E, Ertan A, Cehreli ZC. Sealing effectiveness of fissure sealants bonded with universal adhesive systems: influence of different etching modes. J Adhes Sci Technol. 2017;31(14):1626–34.
17. Eyüboğlu TF, Olcay K, Özcan M.Effects of chemical and physico-chemical surface conditioning methods on the adhesion of resin composite to different mineral trioxide aggregate based cements. J Adhes Sci Technol. 2019;33(16):1836–45.
18. Technical Report Ver. 1.2, Tokuyama Dental Corp, 2017.02.21.

19. Akturk E, Bektas OO, Ozkanoglu S, Akin EGG. Do ozonated water and boric acid affect the bond strength to dentin in different adhesive systems? Niger J Clin Pract. 2019;22(12):1758–64.
20. Modena KC, Casas-Apayco LC, Atta MT, et al. Cytotoxicity and biocompatibility of direct and indirect pulp capping materials. J Appl Oral Sci. 2009;17(6):544-54.
21. Queiroz AM, Assed S, Leonardo MR, Nelson-Filho P, Silva LA. MTA and calcium hydroxide for pulp capping. J Appl Oral Sci. 2005;13(2):126-30.
22. Cantekin K. Bond strength of different restorative materials to light-curable mineral trioxide aggregate. J Clin Pediatr Dent. 2015;39(2):143–8.
23. Guo YJ, Du TF, Li HB, et al. Physical properties and hydration behavior of a fast-setting bioceramic endodontic material. BMC Oral Health. 2016;16:23.
24. Hashem DF, Foxton R, Manoharan A, Watson TF, Banerjee A.The physical characteristics of resin composite-calcium silicate interface as part of a layered/laminate adhesive restoration. Dent Mater. 2014;30(3):343–9.
25. Saito T, Takamizawa T, Ishii R, Tsujimoto A, Hirokane E, Barkmeier WW, et al. Influence of Application Time on Dentin Bond Performance in Different Etching Modes of Universal Adhesives. Oper Dent. 2020;45(2):183–95.
26. Katsumata A, Saikaew P, Ting S, Katsumata T, Hoshika T, Hidehiko Sano YN. Microtensile Bond Strength Bonded to Dentin of a Newly Universal Adhesive. J Oral Tissue Eng. 2017;15(1):18–24.
27. Odabaş ME, Bani M, Tirali RE. Shear bond strengths of different adhesive systems to biodentine. ScientificWorldJournal. 2013;2013:626103.
28. Colak H, Tokay U, Uzgur R, Uzgur Z, Ercan E, Hamidi MM.The effect of different adhesives and setting times on bond strength between biodentine and composite. J Appl Biomater Funct Mater. 2016;14(2):e217–22.
29. Cuevas-Suárez CE, da Rosa WL de O, Lund RG, da Silva AF, Piva E.Bonding performance of universal adhesives: An updated systematic review and meta-analysis. J Adhes Dent. 2019;21(1):7–26.
30. Dawood AE, Parashos P, Wong RHK, Reynolds EC, Manton DJ. Calcium silicate-based cements: composition, properties, and clinical applications. J Investig Clin Dent. 2017;8(2):10.1111/jicd.12195.
31. Camilleri J.Investigation of Biodentine as dentine replacement material. J Dent. 2013;41(7):600–10.
32. Bachoo IK, Seymour D, Brunton P. A biocompatible and bioactive replacement for dentine: is this a reality? The properties and uses of a novel calcium-based cement. Br Dent J. 2013;214(2):E5.
33. John NK, Manoj K V, Joseph B, Kuruvilla A, Faizal N, Babu BS. A comparative evaluation of the internal adaptation of various lining materials to dentin under light cure composite restorations: A scanning electron microscope study. J Int Oral Heal. 2017;9(1):6–11.
34. Dionysopoulos D, Koliniotou-Koumpia E.SEM Evaluation of Internal Adaptation of Bases and Liners under Composite Restorations. Dent J. 2014;2(2):52–64.
35. Gandolfi MG, Taddei P, Siboni F, Modena E, De Stefano ED, Prati C.Biomimetic remineralization of human dentin using promising innovative calcium-silicate hybrid “smart” materials. Dent Mater. 2011;27(11):1055–69.
36. Cengiz E, Ulusoy N. Microshear bond strength of tricalcium silicate-based cements to different restorative materials. J Adhes Dent. 2016;18(3):231–7.
37. Karadas M, Cantekin K, Gumus H, Ateş SM, Duymuş ZY. Evaluation of the bond strength of different adhesive agents to a resin-modified calcium silicate material (TheraCal LC). Scanning. 2016;38(5):403–11.
38. Cengiz E, Yilmaz HG. Efficacy of erbium, chromium-doped: yttrium, scandium, gallium, and garnet laser irradiation combined with resin-based tricalcium silicate and calcium hydroxide on direct pulp capping: A randomized clinical trial. J Endod. 2016;42(3):351–5.
39. Tulumbaci F, Almaz M, Arikan V, Mutluay M.Shear bond strength of different restorative materials to mineral trioxide aggregate and Biodentine. J Conserv Dent. 2017;20(5):292–6.
40. Altunsoy M, Tanriver M, Ok E, Kucukyilmaz E.Shear bond strength of a self-adhering flowable composite and a flowable base composite to mineral trioxide aggregate, calcium-enriched mixture cement, and biodentine. J Endod. 2015;41(10):1691–5.
41. Deepa VL, Dhamaraju B, Bollu IP, Balaji TS. Shear bond strength evaluation of resin composite bonded to three different liners: TheraCal LC, Biodentine, and resin-modified glass ionomer cement using universal adhesive: An in vitro study. J Conserv Dent. 2016;19(2):166–70.
42. Schmidt A, Schäfer E, Dammaschke T.Shear Bond Strength of Lining Materials to Calcium-silicate Cements at Different Time Intervals. J Adhes Dent. 2017;19(2):129–35.