ORIGINAL RESEARCH

Is Bioactive Glass an Effective Agent in Pulp-capping Treatments?: A Randomized Controlled Clinical Trial with One-year Follow-up

Merve Abaklı İnci[1], Emre Korkut[2]

Abstract

Aims: Indirect pulp-capping treatment is a procedure applied to teeth with deep and close-to-pulp caries lesions and without pulp degeneration symptoms. This study aimed to explore the use of a material containing bioactive glass for indirect pulp capping in primary and permanent teeth.

Materials and methods: The study included 145 patients, aged 4–15 years, without any systemic disease and 100 primary second molars and 100 permanent first molars in total. Four material groups were determined: calcium hydroxide (Dycal-DC group), glass ionomer (Biner LC–BC group), calcium silicate (TheraCal LC–TC group), and Bioactive glass-containing ACTIVA BioACTIVE-AC group. Clinical and radiographic evaluations were made 1, 3, 6, 9, and 12 months after the treatment. The data obtained were statistically analyzed using the Chi-square test.

Results: During the 12-month follow-up period, the DC and TC groups were more successful clinically (94%), while the DC and AC groups were found to be more successful radiographically (94%). However, no statistically significant difference was found between the groups ($p > 0.05$).

Conclusions: The results of this study supported the view that the success of indirect pulp-capping treatments was independent of the material used.

Clinical significance: This study demonstrated that a material containing bioactive glass, ACTIVA BioACTIVE-Base/Liner, can be used safely in indirect pulp-capping processes.

Keywords: Bioactive glasses, Biocompatible materials, Calcium hydroxide, Dental pulp, Pulp capping agents.

The Journal of Contemporary Dental Practice (2022): 10.5005/jp-journals-10024-3428

Introduction

The purpose of the treatment of teeth with deep carious lesions is to induce the formation of reparative dentin and minimize the risk of pulp perforation so as to preserve the vitality and health of the pulp. Maintaining pulp viability is of great importance for the roots to continue apexogenesis, especially in young permanent teeth.[1] Vital pulp treatment procedures include total or partial removal of caries tissue and coating the pulp with capping materials directly or indirectly.[2]

Indirect pulp-capping treatment is a procedure applied to the teeth with deep and near-pulp carious lesions and without any symptoms of pulp degeneration. In this procedure, the part of the caries tissue closest to the pulp is not removed and covered with a biocompatible material to avoid pulp perforation. The goal of the treatment is to preserve existing odontoblasts and promote the formation of reactive dentin in the dentin–pulp junction. For this purpose, many materials can be used for indirect pulp-capping treatments in primary and permanent teeth.[3] For many years, calcium hydroxide [$Ca(OH)_2$] has been recognized as the most important in pulp-capping treatments. However, the search for alternative materials continues due to some undesirable features of $Ca(OH)_2$, such as creation of tunnel defects in dentin bridges,[4] creation of microleakage, insufficient antibacterial activity, and dissolution under restoration.[5–8] Today, $Ca(OH)_2$ is replaced by new-generation materials that can show similar clinical results, examples include calcium silicate-containing cements and a resin-modified glass ionomer cement. All these materials have an active role in achieving high biocompatibility degrees, performing intrinsic osteoconductive activities, inducing regenerative activity, creating high-quality dentin bridges, and acquiring high sealing properties.[9]

TheraCal LC, a pulp-capping material containing calcium silicate, and Biner LC, a hydroxy calcium phosphate content, were both used in the study. Biocompatible materials called calcium phosphate cements are frequently utilized to treat bony deformities. They are utilized in dentistry to repair periodontal defects because of their potent osteoconductive properties. Additionally, numerous studies have shown that calcium phosphate cements can be utilized for pulp capping and promote the formation of reparative dentin.[10] A radiopaque, light-curing covering material called resin-modified calcium silicate was created for pulp-capping treatments. Calcium oxide, calcium silicate (type III Portland cement), strontium,

[1,2]Faculty of Dentistry, Department of Pediatric Dentistry, Necmettin Erbakan University, Konya, Turkey

Corresponding Author: Merve Abaklı İnci, Faculty of Dentistry, Department of Pediatric Dentistry, Necmettin Erbakan University, Konya, Turkey, Phone: +90 5065803056, e-mail: merveabakli@gmail.com

How to cite this article: İnci MA, Korkut E. Is Bioactive Glass an Effective Agent in Pulp-capping Treatments?: A Randomized Controlled Clinical Trial with One-year Follow-up. J Contemp Dent Pract 2022;23(11): 1128–1135.

Source of support: Nil

Conflict of interest: None

Informed consent: Patient parents'"informed volunteer consent form" was read, and their signed approvals were obtained.

© The Author(s). 2022 Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by-nc/4.0/), which permits unrestricted use, distribution, and non-commercial reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.

barium sulfate, barium zirconate, Bis-GMA, and polyethylene glycol dimethacrylate are all components of the material known as TheraCal LC. In critical pulp treatments, TheraCal LC can be utilized as a base material underlying composite, amalgam, and other materials. It has characteristics with biodentin and MTA, including the ability to stop bacterial leakage, reduce dentin sensitivity, and promote pulpal healing.[11]

New-generation materials with bioactive glass particles have been used in all areas of dentistry in recent years to increase the bioactivity and regeneration capacity of dental materials. The most characteristic feature of bioactive glasses for medical use is that their surface consists of a layer of bioactive hydroxycarbonate apatite (HCA) that provides bonding with tissues. Thanks to this HCA layer, bioactive glasses can be chemically bound to the surrounding hard and soft tissues.[12] It is thought that bioactive glasses can also be used in pulp-capping treatments because they stimulate hard tissue formation, can create dentin bridges that provide continuity, and have biocompatibility and antibacterial properties.[13–15]

ACTIVA BioACTIVE-Base/Liner material with bioactive glass has physical properties of composite materials, such as esthetics and durability. However, it has been introduced as a combination of glass ionomer-containing materials, such as calcium and phosphate, with fluoride ion-releasing and -recycling properties. Therefore, this study aimed to evaluate the clinical and radiographic success of bioactive glass-containing ACTIVA BioACTIVE-Base/Liner material in indirect pulp-capping treatments compared with other pulp-capping materials containing traditional calcium hydroxide, calcium silicate, and calcium hydroxyphosphate. The H0 hypothesis, which states that there is no statistically significant difference between other pulp-capping materials containing traditional calcium hydroxide, calcium silicate, and calcium phosphate materials, was tested using clinical and radiographic evaluation criteria for the ACTIVA BioACTIVE-Base/Liner material used in this study.

Materials and Methods

Patient Selection and Consent

The local ethics committee approved this randomized, controlled, and clinically planned study, which was carried out in accordance with the Helsinki Declaration (2016/009). The patients and their parents signed a consent form to participate in the study voluntarily. The study included 145 children who applied to the pediatric dentistry clinic between October 2016 and November 2016. Patients were followed until November 2017 with a 12-month follow-up period.

Inclusion Criteria

Clinical:

- Aged 4–15 years.
- No systemic diseases, such as diabetes, rheumatic disease, and congenital heart disease.
- Patient's cooperative level 3 or 4 according to the Frankl behavior scale.
- Restorable material loss observed.
- Pulp perforation not observed.
- No spontaneous pain.
- Percussion and palpation sensitivity not observed.

Radiographic:

- Normal lamina dura and periodontal interval view.
- No evidence of internal or external resorption.

Exclusion Criteria

Clinical:

- History of sharp, penetrating pulpal pain, indicating acute pulpal inflammation and necrosis; prolonged spontaneous pain at night.
- Pathological mobility.
- Negative response to vitality test.
- Presence of abscess/fistula.

Radiographic:

- Deep caries containing more than two-thirds of dentin thickness.
- Physiological resorptions exceeding one-third of the root.[1,16,17]

Pulp-capping Materials

While calculating the sample size, a power analysis was done using the G-Power Package program. The analysis with 80% power for each group indicated the need for at least 40 samples. Considering the problems that might arise, the number of samples was determined as 50 for each group. In 145 patients included in the study, 200 teeth comprising 100 permanent first molars and 100 primary second molars were randomly divided into four groups of 50: Dycal (DC group, Dentsply DeTrey Konstanz, Germany), Biner LC (BC group Meta BioMed, Chunbung, Korea), TheraCal LC (TC group, Bisco Inc., IL, USA), and ACTİVA BioACTIVE-Base/Liner (AC group Pulpdent, MA, USA) (Table 1). It was a single-blind, randomized controlled trial, thus, neither the participants in the study nor the second researcher knew to which group the study materials belonged. The material-group selections were randomized using the randomization.org website.

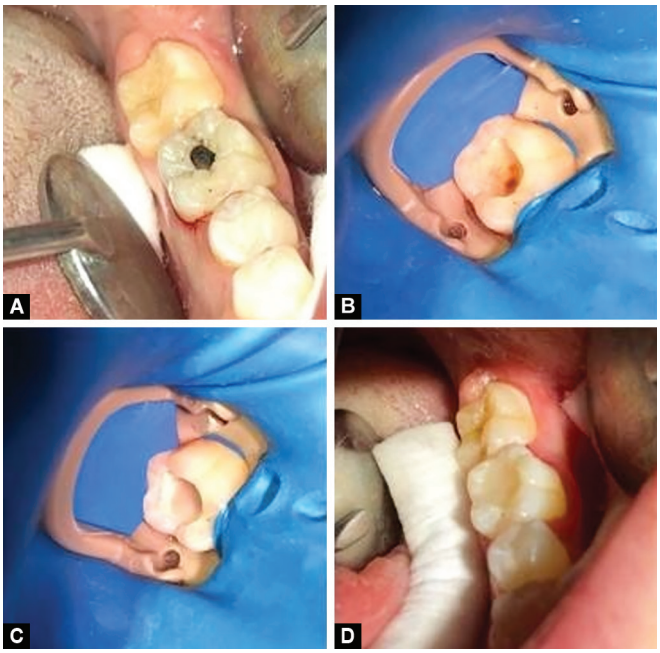
Clinical Procedure

After the caries cleaning and cavity preparation stages were completed, the pulp-capping materials were applied to the parts of the cavity floors closest to the pulp following the manufacturers' suggestions. On a mixing paper, the base and catalyst parts of the Dycal indirect pulp-capping material were combined in a 1:1 ratio for 10 seconds before being applied to the cavity floor using a cement fulvar. It was left to solidify for 1–3 minutes. Using disposable injection tips suitable with the tube, Biner LC indirect pulp-capping material, which is available in a 2-gram tube of liquid form, was applied to the cavity floor. A maximum of 2 mm of material must be applied, and polymerization takes 40 seconds. A maximum thickness of 1 mm of the fluid-like TheraCal LC indirect pulp-capping material was applied to the cavity floor using 22-gauge disposable injection tips that were designed to work with its tube. 1 mm applications were repeated until the required thickness was obtained after 20 seconds of polymerization. Two components of the Activa Bioactive indirect pulp-capping material are packed with 20-gauge automix injection tips. The incoming material is combined at a 1:1 ratio, applied to the cavity floor at a maximum thickness of 4 mm, and polymerized for 20 seconds with the aid of a disposable automix tip (Figs 1 and 2).

The finishing of restorations of the primary second molar teeth with indirect pulp-capping treatments was completed with compomer resin, and the finishing of restorations of the first permanent molar teeth was completed using direct composite resin. Clinical and radiographic evaluations were made 3, 6, and 12 months after treatment. Clinical evaluations included long-term success criteria of the restorations. The restorations were evaluated

Table 1: Indirect pulp-capping treatment materials used in the study and their chemical contents

Name of the product	*System*	*Chemical content*	*Application procedure*
Dycal	Self-cure	Base: 1,3-butylicylate esters of butylene glycol (<50%), calcium tungstate (<20%), zinc oxide (<15%), and others Catalyst: $Ca(OH)_2$ (<55%), zinc oxide (<15%), titanium dioxide (<10%), and others	Base and catalyst components are applied to the surface of the tooth after mixing in a 1:1 ratio for 10 s; Working time is 2–3 minutes.
Biner LC	Light-cure	Calcium hydroxyphosphate, urethane dimethacrylate (UDMA) (<35%), and barium aluminum silicate (<45%)	The material is applied to a maximum thickness of 2 mm and polymerized for 40 s.
TheraCal LC	Light-cure	Type III Portland cement (<60%), polyethylene glycol dimethacrylate (<50%), barium zirconate (<10%), resin-reinforced calcium silicate, and polymerizable methacrylate monomers	The applied material is polymerized for 20 s at a maximum thickness of 1 mm.
ACTIVA BioACTIVE-Base/Liner	Light-cure	Bioactive glass particles, mixture of diurethane and other methacrylates with modified polyacrylic acid (<53.2%), amorphous silica (<3%), and sodium fluoride (<0.9%)	The base and the catalyst mixed with the material automix tips are applied to a maximum thickness of 4 mm; it is polymerized for 20 s.



Figs 1A to D: Clinical images of tooth #36, which was treated with indirect-pulp capping with ACTIVA BioACTIVE material. (A) Initial clinical image; (B) Clinical image after partial caries removal procedure; (C) Clinical image after application of ACTIVA BioACTIVE material; (D) Clinical image after finishing restoration

according to the modified USPHS survival criteria at the end of the 12-month control period.[18]

Statistical Analysis

SPSS 19.0 package program (IBM SPSS, IL, USA) was used to analyze the data in the study. Descriptive statistical analysis (mean and standard deviation), as well as Chi-square and Fisher's exact test were used to compare qualitative data. The type-I error value was taken as 5% in the whole study, and a p value <0.05 was accepted as statistically significant.

Results

The study comprised 84 (57.9%) female and 61 (42.1%) male patients, aged 4–15 years. When the patients were examined according to the period of dentition, 8.3% were found to be in the period of primary dentition, 77.9% in mixed dentition, and 13.8% in permanent dentition. In all study groups, primary and permanent teeth were subjected to indirect pulp-capping treatment in equal numbers. When the teeth included in the study were examined according to their localizations, 59% were found in the lower jaw and 41% in the upper jaw.

The relationship of the clinical and radiographic success rates of indirect pulp-capping treatments observed for 12 months with age, sex, tooth type, localization, and dentition period was evaluated using the Chi-square and Fisher's exact tests. The analysis revealed no statistically significant relationship between clinical and radiographic success rates and age, sex, tooth type, localization, and dentition period variables ($p = 0.594$; $p = 0.683$; $p = 0.554$; $p = 0.778$; $p = 0.707$).

The Chi-square test was used to compare the clinical and radiographic success rates of the materials used in indirect pulp-capping treatments at the end of the 12-month follow-up period.

Figs 2A and B: ACTIVA BioACTIVE material was used for the indirect pulp capping treatment on tooth #36 as seen in radiographic images. (A) The first radiographic image; (B) Radiographic image following treatment

Table 2: Evaluation of the clinical success rates of the capping materials used in the study during the follow-up period

Clinical success	*DC (n = 50) n (%)*	*BC (n = 50) n (%)*	*TC (n = 50) n (%)*	*AC (n = 50) n (%)*	*Chi-square value*	*p*
Beginning	50 (100)	50 (100)	50 (100)	50 (100)	4.735	1.000
1 month	50 (100)	49 (98)	50 (100)	49 (98)		
3 months	50 (100)	48 (96)	50 (100)	49 (98)		
6 months	50 (100)	48 (96)	49 (98)	47 (94)		
9 months	47 (94)	46 (92)	47 (94)	46 (92)		
12 months	47 (94)	46 (92)	47 (94)	46 (92)		

Table 3: Evaluation of the radiographic success rates of the capping materials used in the study during the follow-up period

Radiographical success	*DC (n = 50) n (%)*	*BC (n = 50) n (%)*	*TC (n = 50) n (%)*	*AC (n = 50) n (%)*	*Chi-square value*	*p*
Beginning	50 (100)	50 (100)	50 (100)	50 (100)	4.115	1.000
1 month	50 (100)	49 (98)	50 (100)	49 (98)		
3 months	50 (100)	48 (96)	50 (100)	49 (98)		
6 months	50 (100)	48 (96)	48 (96)	47 (94)		
9 months	47 (94)	46 (92)	46 (92)	47 (94)		
12 months	47 (94)	46 (92)	46 (92)	47 (94)		

The analysis showed no statistically significant difference between the material groups (Tables 2 and 3). At the end of a 12-month follow-up period, ACTIVA material proved statistically similar to clinical and radiographic success in both primary and permanent teeth when compared with other pulp-capping materials.

When the causes of failures observed for all material groups were examined during the 12-month follow-up period, it was observed that most failures occurred due to spontaneous pain, but with no statistically significant difference between the materials ($p = 0.998$). The clinical evaluations revealed spontaneous pain and fistula formation in one permanent molar tooth in the AC material group in the 6th month. The radiographic evaluations revealed periapical radiolucency and enlarged lamina dura. In the 9th month, spontaneous pain was detected in the AC material group in one primary molar tooth. In the 9th month, DC material group, spontaneous pain, percussion sensitivity, and external root resorption were observed in one primary molar tooth. In the follow-up performed in the 9th month, furcal radiolucency was detected in one primary molar tooth in the TC material group, and the tooth was deemed to be radiographically unsuccessful. Table 4 and Figure 3 show the teeth that were considered clinically or radiographically successful, unsuccessful, or out of follow-up during the entire follow-up period.

The evaluation of the clinical successes of the compomer and composite restorations using the modified USPHS criteria at the end of the 12-month follow-up period showed no statistically significant difference between the groups ($p = 0.179$; $p = 0.081$).

Discussion

The study's goal was to evaluate the clinical and radiological success of ACTIVA BioACTIVE-Base/Liner pulp-capping material, which has recently been developed and has gained attention for its biocompatibility and ability to promote the creation of hard tissue. The study comprised Dycal, which contains calcium

Table 4: All data obtained during the entire follow-up period

145 patient, 100 primary second molars, and 100 permanent first molars				
	Dycal	*Biner LC*	*TheraCal LC*	*ACTIVA BioACTIVE*
1 month	50 teeth clinically successful 50 teeth radiographically successful	49 teeth clinically successful 49 teeth radiographically successful 1 permanent first molar unfollow	50 teeth clinically successful 50 teeth radiographically successful	49 teeth clinically successful 49 teeth radiographically successful 1 primary second molar unfollow
3 months	50 teeth clinically successful 50 teeth radiographically successful	49 teeth clinically successful 49 teeth radiographically successful 1 permanent first molar unfollow	50 teeth clinically successful 50 teeth radiographically successful	49 teeth clinically successful 49 teeth radiographically successful 1 primary second molar unfollow
6 months	50 teeth clinically successful 50 teeth radiographically successful	48 teeth clinically successful 48 teeth radiographically successful 2 permanent first molar unfollow	49 teeth clinically successful 49 teeth radiographically successful 1 primary second molar unfollow	47 teeth clinically successful 47 teeth radiographically successful 1 permanent first molar clinically unsuccessful 1 permanent first molar radiographically unsuccessful 2 primary second molar unfollow
9 months	47 teeth clinically successful 47 teeth radiographically successful 1 primary second molar clinically unsuccessful 1 primary second molar radiographically unsuccessful 2 permanent first molar unfollow	46 teeth clinically successful 46 teeth radiographically successful 3 permanent first molar unfollow 1 primary second molar unfollow	47 teeth clinically successful 46 teeth radiographically successful 1 primary second molar radiographically unsuccessful 3 primary second molar unfollow	46 teeth clinically successful 47 teeth radiographically successful 1 permanent first molar clinically unsuccessful 1 primary second molar clinically unsuccessful 1 permanent first molar radiographically unsuccessful 2 primary second molar unfollow
12 months	47 teeth clinically successful 47 teeth radiographically successful 1 primary second molar clinically unsuccessful 1 primary second molar radiographically unsuccessful 2 permanent first molar unfollow	46 teeth clinically successful 46 teeth radiographically successful 3 permanent first molar unfollow 1 primary second molar unfollow	47 teeth clinically successful 46 teeth radiographically successful 1 primary second molar radiographically unsuccessful 3 primary second molar unfollow	46 teeth clinically successful 47 teeth radiographically successful 1 permanent first molar clinically unsuccessful 1 primary second molar clinically unsuccessful 1 permanent first molar radiographically unsuccessful 2 primary second molar unfollow

hydroxide, TheraCal LC, which contains calcium silicate, and Biner LC, which contains calcium phosphate, all of which are frequently used in pulp-capping treatments. In terms of all clinical and radiographic criteria, the H0 hypothesis that there would be no statistically significant difference between ACTIVA BioACTIVE-Base/Liner material and other pulp-capping materials was accepted.

Many materials have been used in pulp-capping treatments throughout history. Many capping materials that can be used as alternatives to calcium hydroxide have been tried in the last 20 years due to some negative properties of calcium hydroxide-containing capping materials. Qureshi et al., in a 2014 article, listed the following properties that an ideal pulp-capping treatment material should have: it should promote tertiary (reparative) dentin formation, preserve pulp vitality, release fluoride to prevent secondary caries formation, attach to dentin, attach to restorative materials, and inhibit bacterial leakage.[19] The search for an alternative pulp-capping material that possesses all of these characteristics is still ongoing. For this purpose, clinical and radiographic properties of Dycal, Biner LC, TheraCal LC, the most commonly used pulp capping materials today, and ACTIVA BioACTIVE, a relatively new material, were compared.

For the preservation of pulp vitality in young permanent teeth with deep dentin caries, the continuation of root development is of high importance for odontoblasts to provide dentin bridge formation and maintain pulp function.[20] Indirect pulp-capping treatments are often preferred because they are more invasive in the treatment of young permanent teeth.[21]

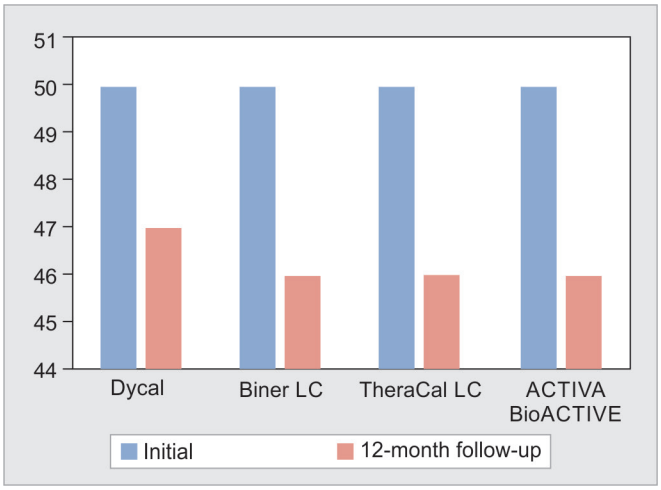


Fig. 3: All groups' initial and final values at the end of 12 months

In indirect pulp-capping treatments applied to primary teeth, correct case selection is important and marginal sealing should be provided during the treatment.[22] In addition, many previous studies showed that the success rate of indirect pulp-capping treatments was higher than that of other vital pulp treatments.[23] In this study, indirect pulp-capping treatment was applied to deeply dentin carious primary and young permanent teeth with appropriate indications, since it was a more conservative treatment method and the success rate was higher than that of alternative vital pulp treatment methods.

In a study comparing the clinical and radiographic success rates of indirect pulp-capping treatments with mineral trioxide aggregate (MTA) and $Ca(OH)_2$ materials in primary teeth, 40 teeth were treated. Pain, percussion sensitivity, and mobility were examined in the clinical success evaluations of the teeth, whose permanent restorations were completed in the second session. Internal–external root resorption, periapical radiolucency, intrapulpal calcification, periodontal ligament interval, and dentin thickness criteria were examined in the radiographic success evaluations. At the end of the 6-month follow-up period, the dentin thickness increased significantly in both MTA and Dycal study groups. The study concluded that MTA was a clinically and radiographically more successful material for indirect pulp-capping treatments performed in primary molar teeth.[24] Many different follow-up and success parameters were used in the studies evaluating the radiographic successes of pulp-capping treatments. Some studies used parameters such as intrapulpal calcification and dentin thickness, while others used parameters such as internal–external root resorption and periapical radiolucency. In this study, in accordance with similar studies in the literature, radiographic success and failure were determined by evaluating the normal lamina dura and periodontal interval view, internal–external root resorption, and periapical–furcal radiolucency. Dentin thickness was not evaluated due to the short follow-up period.

In a follow-up study on primary and permanent teeth with indirect pulp-capping treatment, TheraCal LC material was compared with ProRoot MTA and Dycal, however, no statistically significant difference was found in the clinical success rates of the materials. At the end of the study, it was reported that the success of the treatment was independent of the indirect pulp-capping material applied, and was mostly related to sealed finish restoration, as indicated in this study. In the present study, permanent restorations were examined according to the modified USPHS criteria; no statistically significant difference was found.[25] Indirect pulp-capping materials do not have a direct effect on the success of restorations because of many other factors affecting the success of restoration (remaining dentin thickness, distance to the pulp closure, patient's diet and brushing habits, and amount of saliva). This study found no relationship between the clinical achievements of restorative materials and the clinical achievements of pulp-capping materials.

In a study comparing a pulp-capping material based on bioactive glass-containing resin with Dycal and TheraCal LC materials, Bioactive glass-containing pulp-capping material showed biomineralization properties on human pulp stem cells similar to those of TheraCal LC and Dycal.[26] In another study, Long et al. evaluated the success of direct pulp-capping treatments on rats and revealed that the sol–gel derivative bioactive glass-containing material produced a similar inflammatory response as that of MTA and intensely induced dentin bridge formation.[27] An *in vitro* study examining the effects of a new-generation bioactive glass-containing pulp-capping material on dental pulp cells emphasized that the antibacterial and anti-inflammatory properties of the material could be applied to vital pulp treatments. It has also been reported to increase odontogenic activity on dental pulp cells.[28] Another study found that bioactive glass material can provide a suitable environment for human dental pulp cells to differentiate during odontogenesis and has an effect on inducing the formation of dental pulp–dentin complexes. As a result of these factors, it has been suggested that it could be a useful application agent in the field of dental pulp damage repair and regeneration.[29] The effects of MTA, Biodentine, and ACTIVA BioACTIVE-Base/Liner materials on subcutaneous connective tissue were investigated in a 2020 rat study. At the assessments done 7, 30, and 60 days following the implantation process, the presence of inflammation, predominant cell type, calcification, and fibrous connective tissue thickness were noted by histological testing. At the conclusion of the study, there was no noticeable difference in any material's edema, inflammation, fibrous capsule, or necrosis at any period. At day 30, MTA and Biodentine® displayed statistically higher calcification than ACTIVA BioACTIVE-Base/Liner. On the surfaces near the connective tissue, ACTIVA BioACTIVE-Base/Liner material also considerably encourages dystrophic calcification, it should be highlighted. Therefore, they reported that ACTIVA BioACTIVE-Base/Liner material can be used safely in pulp-capping treatments.[30] ACTIVA BioACTIVE material was chosen as the main material in our study due to its ability to induce hard tissue formation, contribute to the formation of dentin bridges, and biocompatibility. At the end of a 1-year follow-up period, it demonstrated clinical and radiographic results comparable to other pulp-capping materials, and it was considered a material that can be used safely.

Studies on resin-based pulp-capping materials with bioactive glass content are quite limited. However, experimental bioactive glass-containing products have been used in most of the studies. Besides a limited number of *in vitro* studies evaluating the use of resin-based materials in indirect pulp-capping treatments, no studies were found evaluating the use of bioactive glass-containing pulp-capping material *in vivo*. Hence, in the present study, ACTIVA BioACTIVE-Base/Liner, which is a pulp-capping material with Bioactive glass, and Biner LC, TheraCal LC, and Dycal materials were evaluated clinically and radiographically. Compared with

other pulp-capping materials, Activa Bioactive base/liner material was not affected by variables such as age, sex, tooth type, tooth localization, and dentition period. It was found to be successful clinically and radiographically.

One of the few studies that used ACTIVA BioACTIVE-Base/Liner material was this one. The entirety of our study's materials cannot be compared to any other study in the literature. However, because Dycal is still the most commonly used pulp-capping material in the majority of countries, it was included in the study. However, unlike the other materials in the study, it does not contain resin. One of our limitations is that resin is not present in all study groups. Furthermore, one of the study's limitations was the inclusion of several patient groups. Studies with split mouth and similar material study groups can produce more distinct results. In this method, the variables resulting from patient-specific variations are excluded, such as oral and dental health, nutritional status, caries risk level, etc.

When all the results are evaluated, as in many other studies of a similar nature, the findings of this study provide support to the idea that the material utilized has no impact on the effectiveness of indirect pulp-capping treatments. However, one of the alternative materials that can be utilized in pulp-capping procedures safely is ACTIVA BioACTIVE-Base/Liner material. Future *in vivo* and *in vitro* studies, in our opinion, will corroborate this theory. We believe that as the number of clinical studies conducted with the material increases, so will its use. Furthermore, as the cost of the material decreases and physicians' access to the material improves, more up-to-date results will be obtained.

Conclusions

At the end of the 12-month follow-up period, a study was conducted to compare the clinical and radiographic success rates of the materials used in indirect pulp-capping treatments. No statistically significant difference was found between the material groups. The findings of this study support the notion that the success of indirect pulp-capping treatments is unrelated to the material used. Effective isolation and hermetic restoration were critical success factors. However, the results of the study demonstrated that a material-containing bioactive glass, ACTIVA BioACTIVE-Base/Liner, can be used safely in indirect pulp capping.

Orcid

Merve Abaklı İnci https://orcid.org/0000-0003-2979-0336
Emre Korkut https://orcid.org/0000-0001-6976-3071

References

1. American Academy of Pediatric Dentistry (AAPD) Guideline on pulp therapy for primary and immature permanent teeth 2014;37(6): 244–252.
2. Akhlaghi N, Khademi A. Outcomes of vital pulp therapy in permanent teeth with different medicaments based on review of the literature. Dent Res J 2015;12(5):406–417. DOI: 10.4103/1735-3327.166187.
3. Fagundes TC, Barata TJ, Prakki A, et al. Indirect pulp treatment in a permanent molar: Case report of 4-year follow-up. J Appl Oral Sci 2009;17(1):70–74. DOI: 10.1590/s1678-77572009000100014.
4. Cox CF, Sübay RK, Ostro E, et al. Tunnel defects in dentin bridges: Their formation following direct pulp capping. Oper Dent 1996;21(1):4–11. PMID: 8957909.
5. Murray PE, Hafez AA, Smith AJ, et al. Bacterial microleakage and pulp inflammation associated with various restorative materials. Dent Mater 2002;18(6):470–478. DOI: 10.1016/s0109-5641(01)00072-0.
6. Hilton T. Keys to clinical success with pulp capping: A review of the literature. Oper Dent 2009;34(5):615–625. DOI: 10.2341/09-132-0.
7. Gökcek M, Bodrumlu EH. Vital pulpa tedavilerinde güncel yaklaşımlar. Atatürk Üniv Diş Hek Fak Derg 2016;14:118–129.
8. Komabayashi T, Zhu Q, Eberhart R, et al. Current status of direct pulp-capping materials for permanent teeth. Dent Mater J 2016;35(1):1–12. DOI: 10.4012/dmj.2015-013.
9. Kunert M, Lukomska-Szymanska M. Bio-inductive materials in direct and indirect pulp capping – A review article. Materials (Basel) 2020;13(5):1204. DOI: 10.3390/ma13051204.
10. Lee J-B, Park S-J, Kim H-H, et al. Physical properties and biological/odontogenic effects of an experimentally developed fast-setting α-tricalcium phosphate-based pulp capping material. BMC Oral Health 2014;14:87. DOI: 10.1186/1472-6831-14-87.
11. Colon P. Interactions between a calcium silicate cement (Biodentine) and its environment. J Dent Res 2010;89.
12. Brunner TJ, Stark WJ, Boccaccini AR. Nanoscale bioactive silicate glasses in biomedical applications. Wiley-VCH GmbH & Co KGaA 2009, pp. 203–220.
13. Stanley HR, Clark AE, Pameijer CH, et al. Pulp capping with a modified bioglass formula (#A68-modified). Am J Dent 2001;14(4):227–232. PMID: 11699742.
14. Farooq I, Imran Z, Farooq U, et al. Bioactive glass: A material for future. World J Dent 2012;3(2):199–201. DOI: 10.5005/jp-journals-10015-1156.
15. Cannio M, Bellucci D, Roether JA, et al. Bioactive glass applications: A literature review of human clinical trials. Materials (Basel) 2021;14(18):5440. DOI: 10.3390/ma14185440.
16. Frankl SN, Shiere FR, Fogels HR. Should the parent remain with the child in the dental operatory? J Dent Child 1962;29:150–163.
17. Falster CA, Araujo FB, Straffon LH, et al. Indirect pulp treatment: In vivo outcomes of an adhesive resin system vs calcium hydroxide for protection of the dentin-pulp complex. Pediatr Dent 2002;24(3): 241–248. PMID: 12064499.
18. Cvar JF, Ryge G. Reprint of criteria for the clinical evaluation of dental restorative materials. 1971. Clin Oral Invest 2005;9(4):215–232. DOI: 10.1007/s00784-005-0018-z.
19. Qureshi A, Soujanya E, Nandakumar SN, et al. Recent advances in pulp capping materials: An overview. J Clin Diagn Res 2014;8(1):316–321. DOI: 10.7860/JCDR/2014/7719.3980.
20. Brizuela C, Ormeno A, Cabrera C, et al. Direct pulp capping with calcium hydroxide, mineral trioxide aggregate and biodentine in permanent young teeth with caries: A randomizal clinical trial. J Endod 2017;43(11):1776–1780. DOI: 10.1016/j.joen.2017.06.031.
21. Garrocho-Rangel A, Quintana-Guevara K, Vazquez-Viera R, et al. Bioactive tricalcium silicate-based dentin substitute as an indirect pulp capping material for primary teeth: A 12-month follow-up. Pediatr Dent 2017;39(5):377–382. PMID: 29070160.
22. Rosenberg L, Atar M, Daronch M, et al. Prospective study of indirect pulp treatment in primary molars using resin-modified glass ionomer and 2% chlorhexidine gluconate: A 12-month follow-up. Pediatr Dent 2013;35(1):13–17. PMID: 23635886.
23. Al-Zayer M, Straffon LH, Feigal RJ, et al. Indirect pulp treatment of primary posterior teeth: A retrospective study. Pediatr Dent 2003;25(1):29–36. PMID: 12627699.
24. George V, Janardhanan SK, Varma B, et al. Clinical and radiographic evaluation of indirect pulp treatment with MTA and calcium hydroxide in primary teeth (in-vivo study). J Ind Soc Ped Prev Dent 2015;33(2):104–110. DOI: 10.4103/0970-4388.155118.
25. Gürcan AT, Seymen F. Clinical and radiographic evaluation of indirect pulp capping with three different materials: A 2-year follow-up study. Eur J Paediatr Dent 2019;20(2):105–110. DOI: 10.23804/ejpd.2019.20.02.04.

26. Jun S-K, Lee J-H, Lee H-H. The biomineralization of a bioactive glass-incorporated light-curable pulp capping material using human dental pulp stem cells. Biomed Res Int 2017:2017:2495282. DOI: 10.1155/2017/2495282.
27. Long Y, Liu S, Zhu L, et al. Evaluation of pulp response to novel bioactive glass pulp capping materials. J Endod 2017;43(10): 1647–1650. DOI: 10.1016/j.joen.2017.03.011.
28. Ningxin Z, Xanthippi C, Lihong G, et al. Biological properties of modified bioactive glass on dental pulp cells. J Dent 2019;83:18–26. DOI: 10.1016/j.jdent.2019.01.017.
29. Zhu L, Li J, Dong Y. Effect of mesoporous bioactive glass on odontogenic differentiation of human dental pulp stem cells. PeerJ 2021;23(9):e12421. DOI: 10.7717/peerj.12421.
30. Karabulut B, Dönmez N, Göret CC, et al. Reactions of subcutaneous connective tissue to mineral trioxide aggregate, Biodentine®, and a newly developed BioACTIVE base/liner. Scanning 2020;2020:6570159. DOI: 10.1155/2020/6570159.