Pulpal Responses to Direct Capping with Betamethasone/Gentamicin Cream and Mineral Trioxide Aggregate: Histologic and Micro–Computed Tomography Assessments

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Abstract

Introduction: This clinical trial was conducted to evaluate the response of human dental pulp to direct capping with betamethasone/gentamicin (BG) cream and mineral trioxide aggregate (MTA). We hypothesized that the results of direct pulp capping with a topical BG combination would be similar to or better than those with MTA. **Methods:** Thirty-six human first premolar teeth scheduled for orthodontic extraction were randomly divided into 4 groups: BG1 group (n = 9), BG cream with 2-week follow-up; BG2 group (n = 10), BG cream with 8-week follow-up; MTA1 group (n = 8), MTA with 2-week follow-up; and MTA2 group (n = 9), MTA with 8-week follow-up. Teeth were extracted and evaluated at respective time intervals. Micro–computed tomography scanning and histologic analyses were performed for all specimens. Pulp pathology (inflammation, pulp abscesses, and pulp necrosis) and reparative reaction (formation of dentin bridges) were recorded. **Results:** Both BG cream and MTA resulted in significantly better pulpal responses at 8 weeks than at 2 weeks. Dentin bridge formation was significantly thicker in the MTA group at 8 weeks than in any other group ($P < .05$). Inflammation was of the acute type in all groups; no statistically significant differences in the distribution of inflammatory cells were found among the groups. Pulpal abscesses and/or necrosis were observed more often in teeth capped with BG than with MTA. **Conclusions:** Direct pulp capping with both BG cream and MTA was associated with dentin bridge formation. MTA resulted in a significantly better pulpal response, with less inflammation and a thicker dentin bridge at 8 weeks. *(J Endod 2015;■:1–6)*

Key Words

Betamethasone/gentamicin cream, clinical trial, dentin bridge, direct pulp capping, mineral trioxide aggregate

Direct pulp capping is performed to protect pulp affected by caries, trauma, or other injuries to maintain its functional and biological activities (1). Vital pulp tissue is responsible for the formation of secondary dentin, reparative dentin, and peritubular dentin in response to different stimuli (2). In direct pulp capping, a protective layer of biomaterial is placed over the exposed pulp tissue. These biomaterials should be biocompatible and bioactive, and they should possess apatite-forming ability and provide a biological seal (3).

Calcium hydroxide has been a material of choice for pulp capping since 1930 because of its antibacterial activity, ability to release calcium and hydroxyl ions, and low potential for irritation of the traumatized pulp tissue (4, 5). However, it has major disadvantages including high solubility, dissolution in tissue fluids, and poor sealing ability (3, 4).

Calcium silicate–based materials such as mineral trioxide aggregate (MTA) have attained growing attention because compared with calcium hydroxide, they cause less pulp inflammation and form dentin bridges with significantly greater frequency and thickness (6, 7). Although clinical studies have also demonstrated that MTA results in good outcomes when used as an indirect or direct pulp-capping material (8, 9), it has a delayed setting time, poor handling characteristics, and an off-white color (1).

Pulpal trauma or exposure in conjunction with a pulp-capping procedure can induce inflammation in the pulpal tissue. Pulp-capping materials containing anti-inflammatory ingredients may prevent progression to irreversible pulpitis, thus protecting the vitality of the pulp. Topical corticosteroids such as betamethasone have known anti-inflammatory and vasoconstrictive properties (10). Direct application of corticosteroids reduces pulpal inflammation, and betamethasone has demonstrated better anti-inflammatory effects compared with hydrocortisone (11). After betamethasone was applied topically to the dentin of rat molars, the vascular phase of pulpal inflammation was shortened (12). Furthermore, the combination of betamethasone and gentamicin, an antibiotic, has beneficial antimicrobial and anti-inflammatory effects on soft tissues (13, 14). In a direct pulp-capping study in a rabbit model, the topical application of betamethasone and gentamicin cream significantly reduced histopathologic changes in dental pulps compared with those treated with calcium hydroxide (15). However, calcium hydroxide used in this study was hard-setting cement form that might have different pulpal response compared with other forms of calcium hydroxide.

The purpose of this study was to evaluate the response of human dental pulp to direct capping with betamethasone/gentamicin (BG) cream and MTA. We hypothesized that the results of direct pulp capping with a topical BG combination would be similar to or better than those with MTA.

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Materials and Methods

This prospective randomized clinical trial was approved by the Ethical Committee of the University of Dammam, Dammam, Saudi Arabia (2011037). First premolar teeth scheduled to be extracted for orthodontic reasons were selected for this study. Teeth included were from patients between 15 and 25 years of age who had no medical or systemic conditions; teeth were also free of periodontal disease, caries, and previous restorations and had normal pulp chambers and closed apices. The pulp status was assessed with cold and electric pulp tests.

A total of 36 selected premolars were randomly divided by using a statistical randomized treatment table into 4 groups according to the materials used and the duration of follow-up: BG1 group (n = 9), BG cream with 2-week follow-up; BG2 group (n = 10), BG cream with 8-week follow-up; MTA1 group (n = 8), MTA with 2-week follow-up; and MTA2 group (n = 9), MTA with 8-week follow-up. All participants signed an informed consent form after the clinical procedure and risks involved had been thoroughly explained and all questions raised by the participants and/or their guardians had been answered.

Pulp Exposures

The pulp cavity procedures were carried out under local anesthesia and rubber dam isolation. Teeth were cleaned by using 2% chlorhexidine gluconate, and occlusal cavities were prepared with sterile half-round carbide burs by using a high-speed handpiece and sterile distilled water cooling. The prepared occlusal cavities were 3.0–3.5 mm in occlusal depth, 4.0–4.5 mm in mesiodistal width, and 3.0–3.5 mm in faciolingual width. Dimensions of the cavity were checked with a digital caliper in an attempt to standardize the cavity size. Pulp exposures were performed in the center of the pulp floor. One bur was used for each cavity. Complete hemostasis was achieved by applying gentle pressure to the exposed site with a sterile cotton pellet moistened with sterile saline. BG cream was applied as a pulp-capping material in groups 1 and 2, and MTA was applied as a pulp-capping material according to the manufacturer's instructions in groups 3 and 4 (Fig. 1). After application of the assigned material, cavities were sealed immediately with posterior glass ionomer. All participants were instructed to record postoperative pain by using a visual analogue scale on a form provided. Teeth were extracted after 2 weeks in groups 1 and 3 and after 8 weeks in groups 2 and 4. The apices of extracted teeth were removed under water cooling to facilitate formalin penetration. Teeth were fixed in 10% formalin for 24 hours.

Micro–Computed Tomography

All fixed teeth were scanned with a micro–computed tomography (micro-CT) machine (SkyScan1172 version 1.5; Bruker Micro-CT, Kontich, Belgium). Each sample was positioned in the middle of the specimen stage and scanned at 70 kV and 139 μA with a resolution of 8.99 μm, rotational step of 0.25°, and 360° rotation by using 0.5-mm aluminum and copper filters. Raw data were reconstructed with NRecon Software version 1.6.4.8 (Bruker Micro-CT) to obtain rough measurements of the thickness of the reparative hard tissue. Raw data were analyzed with CT analyzer (CTan) Software version 1.11.10. Two-dimensional slices were acquired in the axial plane to determine the first and last slices in the coronal-to-apical direction from which reparative hard tissues could be identified from the pulp. Data Viewer software version 1.4.4 was used to obtain 3 distinct views (coronal, sagittal, and transaxial) of each image in 2-dimensional form. This provided a precise and clear picture of each specimen and allowed measurement of the dentin bridges.

Histologic Sample Preparation

After the micro-CT scanning, fixed teeth were decalcified with 10% formic acid and sodium citrate. Teeth were split into 2 longitudinal sections at the level of pulp exposure, and each section was dehydrated in a series of ethanol solutions at ratios increasing from 45% to absolute. Samples were cleaned with xylene and embedded in paraffin. Sections 6 μm thick were prepared from each block. Ten serial sections were taken at the level of exposure.

Sections were stained with hematoxylin-eosin and Masson trichrome. After the sections were stained, coverslips were applied with

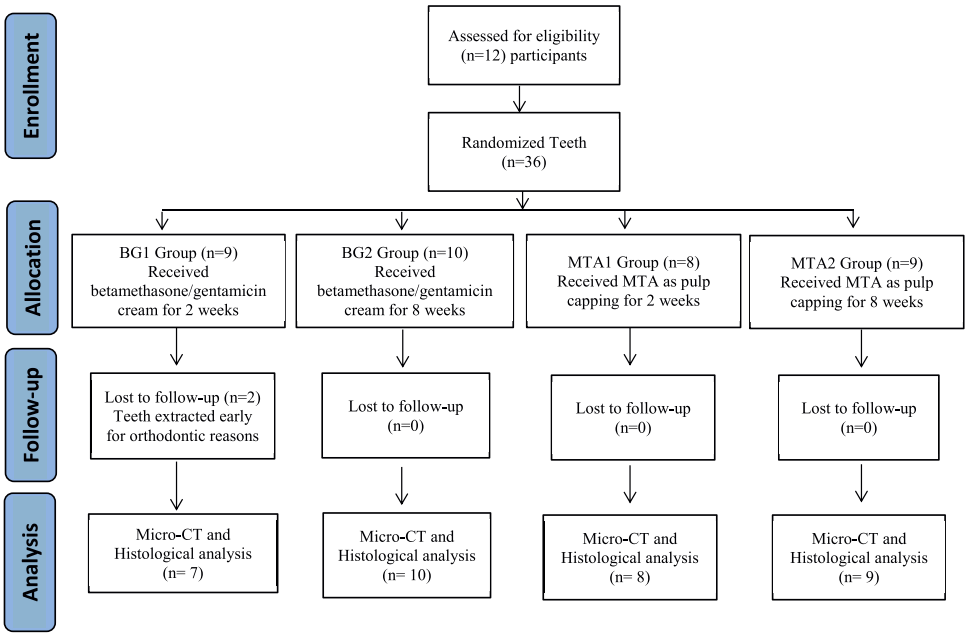

Figure 1. Flow diagram of the clinical trial process.

TABLE 1. Summary of Findings among All Cases of Groups

Groups	Materials	Time interval (wk)	Dentinal bridge (μm)	Abscess (%)	Type of inflammation
BG1	BG cream	2	7.19	14.3	Acute type with predominant neutrophils
BG2	BG cream	8	22.0	20	
MTA1	MTA	2	31.04	0	
MTA2	MTA	8	78.50	11	

mounting medium. Stained sections were evaluated under light microscopy by an observer blinded to the treatment according to a predesigned histopathologic protocol that included examination of the following: pulp pathology, including inflammation (type and intensity); pulp abscess and pulp necrosis; and reparative reaction of the pulp, including formation of dentin bridges. Thickness of dentin bridges was measured in micrometers at 3 random areas of each section by using Olympus cellSens Dimension V1.9 Software (Olympus, Tokyo, Japan). The mean of all measurements (3×10) was recorded and used for analysis. In the present study, we considered dentin bridge formation to be a sign of healing.

Data were analyzed by one-way analysis of variance and the Tukey-Kramer multiple comparison test at a significance level of $P < .05$.

Results

Out of 12 participants included in this randomized clinical trial, 10 were female, and 2 were male; their average age was 18 ± 1.5 years. Two teeth were excluded from the study because they were extracted for orthodontic reasons before completion of the study. Table 1 presents the summary of results for all groups, and Figure 2 shows a box plot of dentin bridge thicknesses in micrometers.

BG Cream

In BG1 group (BG cream after 2 weeks), histologic examination revealed evidence of a partial hard tissue barrier in 28.6% of the specimens; no hard tissue (dentin bridge) formation was apparent in 71.4% of the specimens. The average hard tissue thickness was 7.19 μm (Table 1).

In BG2 group (BG cream after 8 weeks), histologic examination revealed dentin bridge formation in 50% of the specimens. Bridge formation was complete in 10% of the specimens; hard tissue apposition at the exposure site was partial or incomplete in the others. The average thickness of reparative hard tissue was 22.0 μm (Fig. 3). Micro-CT images confirmed the histologic results for dentin bridge formation in both groups (Fig. 4).

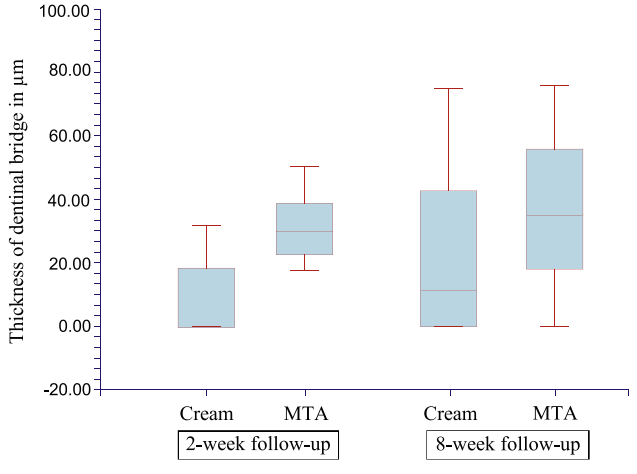

Figure 2. Box plot showing 25th percentile, median, and 75th percentile of the thickness of dentin bridge formed for all 4 groups. MTA after 8 weeks showed significantly thicker hard tissue barrier formation compared with all other groups.

Mild to moderate inflammatory cell infiltration was seen in all teeth in BG1 and BG2 groups. Inflammatory cell infiltration in all cases was of the acute type, with neutrophils predominating. Pulp abscesses developed in 1 tooth in BG1 group (14%) and in 2 teeth in BG2 group (20%) (Table 1). Dentin bridges did not appear in any teeth with pulp abscesses in which the tissue underwent necrotic changes.

MTA

In MTA1 group (MTA after 2 weeks), histologic examination revealed dentin bridge formation in 100% of the specimens. The average hard tissue thickness was 31.04 μm.

In MTA2 group (MTA after 8 weeks), dentin bridge formation at the exposure site was evident in 89% of the specimens. The average thickness of reparative hard tissue was 78.50 μm (Table 1). A complete dentin bridge with normal structure had formed in 67% of the specimens; a partial or incomplete hard tissue barrier had formed at the exposure site in the remaining 23%. Hard tissue that formed at the exposure site took the form of diffuse calcification in 4 samples treated with MTA (Fig. 3). Micro-CT images confirmed the histologic results for dentin bridge formation (Fig. 4).

Mild to moderate inflammatory cell infiltration was seen in 80% of the specimens in MTA1 and MTA2 groups. As with the teeth in the BG1 and BG2 groups, inflammatory cell infiltration in all cases was of the acute type, with neutrophils predominating. A pulp abscess developed in 1 tooth in MTA2 group (1%) (Table 1, Fig. 3). A dentin bridge did not appear in the tooth with the pulp abscess.

Statistical Comparison

The thickness of the dentin bridge differed significantly among the experimental groups ($P < .05$); the dentin bridge was thicker in group 4 than in groups 1, 2, or 3 ($P < .05$). The differences in dentin bridge thickness between groups 1 and 2 and between groups 3 and 4 were also statistically significant (both $P < .05$).

No statistically significant differences in the distribution of inflammatory cell infiltrates were found among the groups ($P > .05$). Mild pain lasting for 1–3 days was associated with 12% of the exposed teeth; severe pain lasting for 3 days was associated with 6% of the exposed teeth.

Discussion

Dentin bridge formation at the interface of pulp and capping material could be either a sign of healing or a reaction to irritation. This is a controversial issue because a dentin bridge does not prove that the pulp is healthy or protects it from bacterial challenges (1, 16). Most previous direct pulp-capping studies used animal models (rats, dogs, or baboons). Although the pulpal tissues of these species closely resemble those of humans, studies evaluating the responses of human pulpal tissue to direct pulp-capping materials are preferable. Therefore, the purpose of this study was to evaluate the response of pulp tissue to

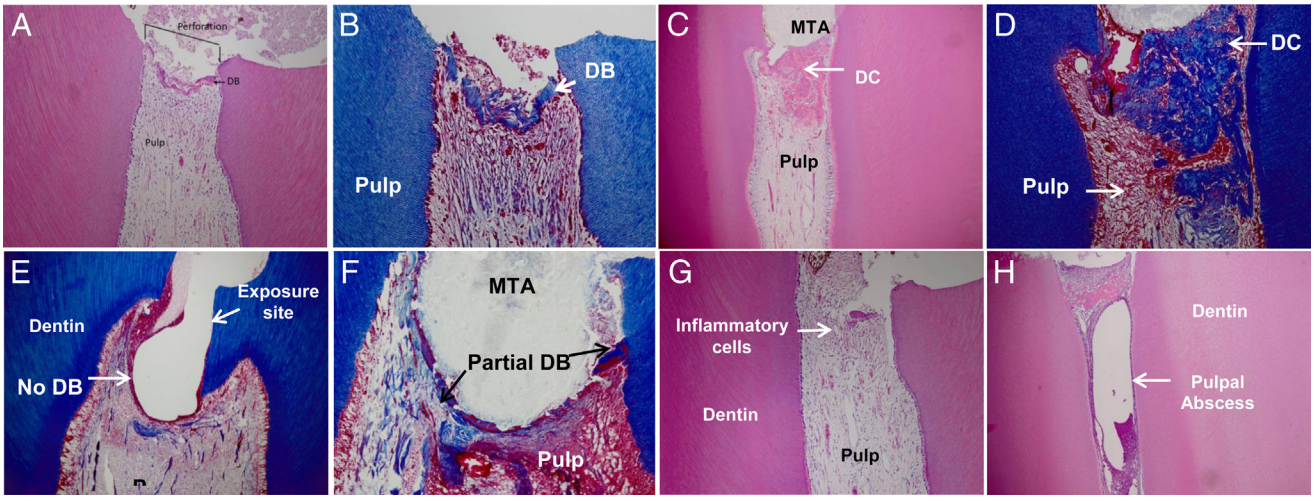

Figure 3. Photomicrographs of representative histologic sections from specimens in MTA and BG pulp-capping groups. (*A–D*) Specimens from MTA group. (*A*) Complete dentin bridge (DB) formation over the pulp at the perforation site (hematoxylin-eosin; original magnification, ×40). (*B*) Higher magnification of the specimen in (*A*) (Masson trichrome; original magnification, ×100). (*C*) Diffuse calcification (DC) over the pulp at the perforation site (hematoxylin-eosin; original magnification, ×40). (*D*) Higher magnification of specimen in (*C*) (Masson trichrome; original magnification ×100). (*E*) No DB formation at perforation site in specimen from BG group (Masson trichrome; original magnification ×100). (*F*) Partial DB formation at perforation site in specimen from MTA group (Masson trichrome; original magnification, ×200). (*G* and *H*) Specimens from BG group (hematoxylin-eosin; original magnification, ×100 and ×40; respectively). (*G*) Inflammatory cell infiltration of the pulp. (*H*) Pulpal abscess formation.

BG cream and MTA used as direct pulp-capping materials in human teeth.

Pulpal responses in this study were evaluated with both micro-CT and light microscopy. The micro-CT technique allowed for high-resolution scanning of extracted teeth to provide further information about the quality of the newly formed reparative hard tissue as compared with a previous study by Al-Hezaimi et al (17), where portions of animal jaws were scanned at low resolution. In addition, histologic sections were viewed under a light microscope, and software was used to measure the dimensions of newly formed hard tissue barriers to the micrometer.

Topical application of glucocorticoid-antibiotic combination has been infrequently used for the treatment of skin diseases and ear infections without unwanted drug interactions (18). BG cream has been proposed as a direct pulp-capping material because of its antimicrobial and anti-inflammatory effects (15). However, in our study, BG did not

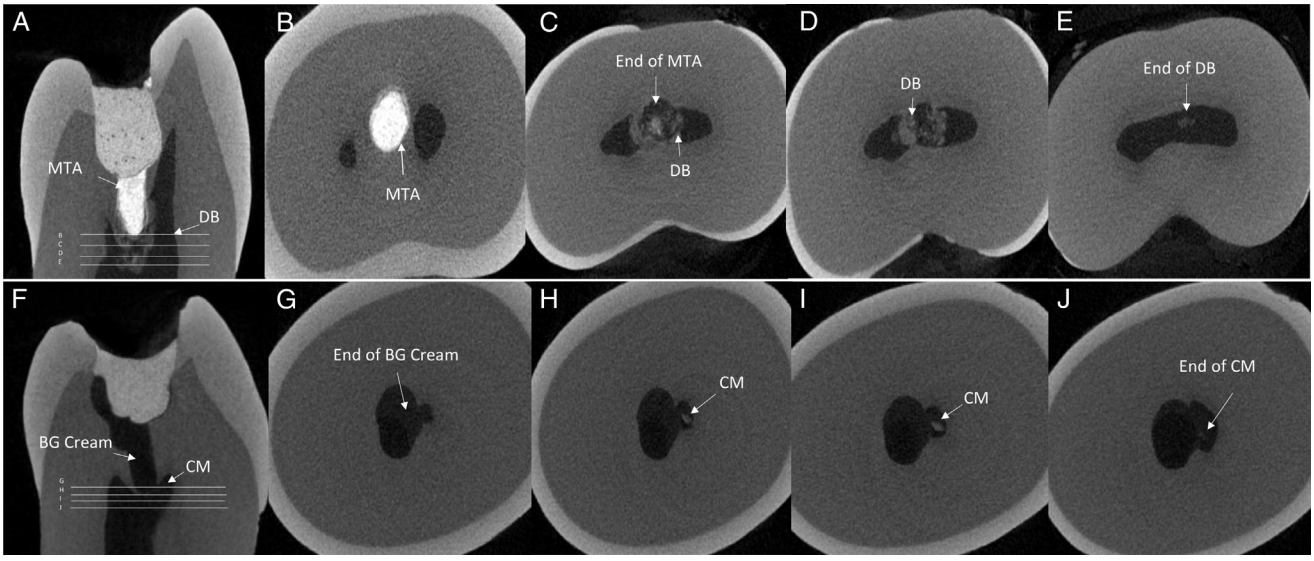

Figure 4. Representative micro-CT images from specimens in MTA and BG pulp-capping groups. (*A–E*) Specimens from MTA group. (*A*) Section in the coronal plane showing the perforation (exposure) site, MTA, and dentin bridge (DB) formation. (*B*) Section in axial plane at level of perforation showing the presence of MTA. (*C*) Section in axial plane 0.1 mm from (*B*) showing the edge of MTA and DB. (*D*) Section in axial plane taken 0.2 mm from (*B*) showing DB. (*E*) Section taken 0.3 mm from (*B*) showing edge of DB. (*F–J*) Specimens from BG group. (*F*) Section in coronal plane showing perforation (exposure) site, BG, and the presence of a thin calcified mass (CM). (*G*) Section in axial plane at level of perforation showing edge of BG. (*H*) Section in axial plane 0.1 mm from (*G*) showing leading edge of irregular CM. (*I*) Section in axial plane taken 0.2 mm from (*G*) showing irregular CM. (*J*) Section taken 0.3 mm from (*B*) showing no CM or DB.

produce results comparable with or better than those of MTA. Therefore, the hypothesis was rejected.

In the present study, BG cream resulted in dentin bridge formation in only 29% and 50% of specimens after 2 and 8 weeks, respectively. Although the dentin bridge was significantly thicker after 8 weeks than after 2 weeks, it was only partially formed at both observation times. In a previous study on rabbits, direct pulp capping with BG cream under calcium hydroxide significantly reduced the histologic changes indicating an inflammatory response, as compared with calcium hydroxide alone (15). However, to our knowledge, no other published studies have evaluated the efficacy of BG cream as a direct pulp-capping material in humans.

We evaluated pulpal responses at 8 weeks because this time interval was used in a number of previous studies (19–22). We also evaluated pulpal responses at an earlier time because the initiation of hard tissue formation has been reported to start as early as 2 weeks (19, 23).

A variety of direct pulp-capping materials can reportedly initiate dentin bridge formation at the exposure site. Previous studies that used animal (15, 24) and human (25) models reported that direct pulp capping with MTA initiated tertiary dentin formation more effectively than capping with other materials. These findings are in agreement with those of the present study, in which MTA performed significantly better than BG cream.

Direct pulp capping with MTA results in the formation of fibrodentin and reparative dentin at the pulpal surface (19). After initial contact, a superficial crystalline layer is formed on the exposed pulp surface, followed by formation of a lining of columnar odontoblast-like cells. After MTA hardens, it forms calcium oxide that may react with tissue fluids to form calcium hydroxide (20). The mechanism of action of MTA may thus be similar to that of calcium hydroxide (19). However, MTA is more effective than calcium hydroxide because it promotes the differentiation of pulpal cells into odontoblast-like cells by upregulating the expression of transcription factors such as RUNX2 and odontoblastic genes such as osteocalcin and dentin sialoprotein, resulting in dentin bridge formation (26). Hard tissue may form adjacent to MTA because of its high alkalinity (27), sealing ability (28, 29), and biocompatibility (30). In the present study, hard tissue formation was observed in all teeth capped with MTA after 2 weeks, with mild to moderate inflammation. In comparison, only 28.6% of the teeth capped with BG cream showed evidence of partial hard tissue formation. The findings are in agreement with previous studies that also demonstrated hard tissue formation 2 weeks after capping with MTA (19, 23).

The difference in dentin bridge formation at 2 and 8 weeks in the 2 MTA groups was statistically significant. At 8 weeks, the hard tissue formation at the exposure site was thicker, with less inflammation. However, a thinner hard tissue barrier was also observed in all specimens at 2 weeks. Pulp capping with MTA may have initiated the formation of hard tissue at 2 weeks. This tissue would gradually be lined by odontoblast-like cells and become calcified in a tubular pattern, forming a thicker dentin bridge. Our findings confirmed the similar results reported in previous studies of pulp capping with MTA (19, 23). We found diffuse calcification in pulpal tissue not adjacent to the capping material in 4 teeth in the MTA group. We could not explain the reason for this; the mechanism may be similar to that of pulp stone formation.

MTA performed significantly better than BG cream. The poor performance of BG cream could be related to its consistency as well as to the differences in chemical composition. Because BG is a cream, it dissolves in tissue fluids and does not provide a solid surface, whereas MTA sets to a hard structure even in the presence of moisture, providing a solid base and sealing ability. High solubility and fast dissolution are also drawbacks for conventional calcium hydroxide in reparative dentinogenesis (3). Both MTA and BG caused mild to moderate acute pulpal inflammation with predominantly neutrophilic infiltrates in all groups. Although a previous study reported that betamethasone cream was an effective and biocompatible direct pulp-capping material in an animal model (15), we found pulpal necrosis and abscesses in 3 teeth capped with BG but in only 1 tooth capped with MTA.

The results of the present study confirmed the efficacy of MTA for direct pulp capping, as reported previously (17, 19). However, few reports of the use of BG cream have been published in endodontics journals. Further studies are needed to evaluate the effects of biocompatible scaffolding materials such as bioceramics on the performance of BG cream for direct pulp capping.

This study was performed on healthy teeth with normal pulpal tissue and does not predict the results of these materials in inflamed pulps. Most previous pulp-capping studies were also performed on healthy teeth of animals (17, 31) or humans (19); the results should be translated carefully for clinical situations. Further studies are required to evaluate the responses of inflamed pulps to direct capping materials.

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The authors deny any conflicts of interest related to this study.

References

1. Asgary S, Eghbal MJ, Parirokh M, et al. A comparative study of histologic response to different pulp capping materials and a novel endodontic cement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:609–14.
2. Al-Hiyasat AS, Barrieshi-Nusair KM, Al-Omari MA. The radiographic outcomes of direct pulp-capping procedures performed by dental students: a retrospective study. J Am Dent Assoc 2006;137:1699–705.
3. Gandolfi MG, Spagnuolo G, Siboni F, et al. Calcium silicate/calcium phosphate biphasic cements for vital pulp therapy: chemical-physical properties and human pulp cells response. Clin Oral Investig 2015;19:2075–89.
4. Nowicka A, Wilk G, Lipski M, et al. Tomographic evaluation of reparative dentin formation after direct pulp capping with Ca(OH)2, MTA, Biodentine, and dentin bonding system in human teeth. J Endod 2015;41:1234–40.
5. Tziafas D, Belibasakis G, Veis A, Papadimitriou S. Dentin regeneration in vital pulp therapy: design principles. Adv Dent Res 2001;15:96–100.
6. Aeinehchi M, Eslami B, Ghanbariha M, Saffar AS. Mineral trioxide aggregate (MTA) and calcium hydroxide as pulp-capping agents in human teeth: a preliminary report. Int Endod J 2003;36:225–31.
7. Ford TR, Torabinejad M, Abedi HR, et al. Using mineral trioxide aggregate as a pulp-capping material. J Am Dent Assoc 1996;127:1491–4.
8. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review—part III: clinical applications, drawbacks, and mechanism of action. J Endod 2010;36:400–13.
9. Okiji T, Yoshiba K. Reparative dentinogenesis induced by mineral trioxide aggregate: a review from the biological and physicochemical points of view. Int J Dent 2009; 2009:1–12.
10. Dyderski S, Grześkowiak E, Szałek E, Mrzygłód A. Pharmaceutical availability of betamethasone dipropionate and gentamicin sulfate from cream and ointment. Acta Pol Pharm 2002;59:99–103.
11. Fachin EV, Zaki AE. Histology and lysosomal cytochemistry of the postsurgically inflamed dental pulp after topical application of steroids: I—histological study. J Endod 1991;17:457–60.
12. Fachin EV, Scarparo RK, Pezzi AP, et al. Effect of betamethasone on the pulp after topical application to the dentin of rat teeth: vascular aspects of the inflammation. J Appl Oral Sci 2009;17:335–9.
13. Aslan O, Teberik K, Yucel M, et al. Effect of topical Diprogenta on the reduction of bacterial flora on the human conjunctiva. Eur J Ophthalmol 2008;18:512–6.

14. Friberg O, Svedjeholm R, Söderquist B, et al. Local gentamicin reduces sternal wound infections after cardiac surgery: a randomized controlled trial. Ann Thorac Surg 2005;79:153–61.
15. Aljandan B, AlHassan H, Saghah A, et al. The effectiveness of using different pulpcapping agents on the healing response of the pulp. Indian J Dent Res 2012;23:633–7.
16. Schröder U. Effects of calcium hydroxide-containing pulp-capping agents on pulp cell migration, proliferation, and differentiation. J Dent Res 1985;64:541–7.
17. Al-Hezaimi K, Salameh Z, Al-Fouzan K, et al. Histomorphometric and microcomputed tomography analysis of pulpal response to three different pulp capping materials. J Endod 2011;37:507–12.
18. Raab W. Experimental investigations on interactions between gentamicin and betamethasone dipropionate. Australas J Dermatol 1973;14:83–90.
19. Zarrabi MH, Javidi M, Jafarian AH, Joushan B. Histologic assessment of human pulp response to capping with mineral trioxide aggregate and a novel endodontic cement. J Endod 2010;36:1778–81.
20. Asgary S, Parirokh M, Eghbal MJ, Ghoddusi J. SEM evaluation of pulp reaction to different pulp capping materials in dog's teeth. Iran Endod J 2006;1:117–23.
21. Briso AL, Rahal V, Mestrener SR, Dezan Junior E. Biological response of pulps submitted to different capping materials. Braz Oral Res 2006;20:219–25.
22. Koliniotou-Koumpia E, Tziafas D. Pulpal responses following direct pulp capping of healthy dog teeth with dentine adhesive systems. J Dent 2005;33:639–47.
23. Tziafas D, Pantelidou O, Alvanou A, et al. The dentinogenic effect of mineral trioxide aggregate (MTA) in short-term capping experiments. Int Endod J 2002;35:245–54.
24. Shayegan A, Petein M, Vanden Abbeele A. The use of beta-tricalcium phosphate, white MTA, white Portland cement and calcium hydroxide for direct pulp capping of primary pig teeth. Dent Traumatol 2009;25:413–9.
25. Mente J, Geletneky B, Ohle M, et al. Mineral trioxide aggregate or calcium hydroxide direct pulp capping: an analysis of the clinical treatment outcome. J Endod 2010;36:806–13.
26. Paranjpe A, Zhang H, Johnson JD. Effects of mineral trioxide aggregate on human dental pulp cells after pulp-capping procedures. J Endod 2010;36:1042–7.
27. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod 1995;21:349–53.
28. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. J Endod 1993;19:591–5.
29. Asgary S, Eghbal MJ, Parirokh M, et al. Comparison of mineral trioxide aggregate's composition with Portland cements and a new endodontic cement. J Endod 2009;35:243–50.
30. Mitchell PJ, Pitt Ford TR, Torabinejad M, McDonald F. Osteoblast biocompatibility of mineral trioxide aggregate. Biomaterials 1999;20:167–73.
31. Dominguez MS, Witherspoon DE, Gutmann JL, Opperman LA. Histological and scanning electron microscopy assessment of various vital pulp-therapy materials. J Endod 2003;29:324–33.