Zinc Oxide Inhibits Dental Discoloration Caused by White Mineral Trioxide Aggregate Angelus

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Abstract

Introduction: The aim of the study was to investigate the addition of variable amounts of zinc oxide to inhibit dental discoloration caused by mineral trioxide aggregate (MTA) Angelus. **Methods:** MTA Angelus and MTA with additions of 5%, 15%, and 45% zinc oxide (ZnO) in weight were tested. The set cements were characterized by using a combination of scanning electron microscopy, energy dispersive spectroscopy, and x-ray diffraction. Radiopacity and setting time were analyzed according to American National Standards Institute/American Dental Association (57/2012) and American Society for Testing and Materials (C266-08). Volume change was evaluated by using micro–computed tomography analysis. The pH and calcium ion release were measured after 3 hours, 24 hours, and 28 days. Dental discoloration in contact with the cements was measured after 24 hours, 28 days, and 90 days. Biocompatibility to subcutaneous implantation in rats was verified after 30 and 60 days. **Results:** Addition of ZnO did not alter significantly the radiopacity, setting time, volume change, pH, and biocompatibility compared with MTA Angelus ($P > .05$). Calcium ion release increased with addition of ZnO ($P < .05$). Proportions of 15% and 45% ZnO interfered in hydration. The 5% ZnO addition was sufficient to prevent the dental discoloration observed with MTA Angelus. **Conclusions:** The addition of 5%, 15%, or 45% zinc oxide to MTA Angelus inhibits dental discoloration without modifying the radiopacity, setting time, volume change, pH, and biocompatibility. *(J Endod 2017;43:1001–1007)*

Key Words

Biocompatibility, biomaterials, cement, endodontics, materials science, surface chemistry/properties

Significance

MTA is widely used for reparative procedures in dental practice. Dental discoloration caused by MTA limits its use for treatments in anterior teeth. The study demonstrates that the addition of zinc oxide in MTA formulation is able to prevent color alteration without significant interference with physical, chemical, and biological properties of the cement. Development of stable color formulation will allow the use of MTA with no restrictions in aesthetic zones, expanding clinical applications.

Mineral trioxide aggregate (MTA) is a tricalcium silicate–based cement used for reparative procedures in dentistry and endodontics (1). The procedures require a long period of contact of MTA in pulpal or apical tissues to promote repair (2). Ideally the use of any dental material does not result in tooth discoloration (3).

The first formulation of MTA was grey, which was not suitable for application in anterior teeth (4, 5). The limitation of this formulation stimulated the development of a tooth-colored material. However, white MTA causes dental discoloration *in vitro* and clinically (6–11). White MTA Angelus contains 20% of the radiopacifier bismuth oxide (12, 13). The discoloration has been attributed to the destabilization of bismuth oxide on contact with a strong oxidizing agent, ie, sodium hypochlorite or amino acids present in dentin collagen. In previous research on discoloration (14, 15) it has been shown that bismuth oxide in the presence of collagen and strong oxidizing agents changes from its oxide form. It has been postulated that because oxygen is given off and sodium chloride is formed on the surface of the black precipitate, then the bismuth is no longer in the oxide form but reacts, showing a phase change. Some alternatives are suggested to prevent discoloration of white MTA such as the substitution of the radiopacifier agent in MTA formula (16, 17). Zirconium oxide and calcium tungstate have been tested, but larger amounts are required to provide similar radiopacity to bismuth oxide; thus deterioration in physical and chemical properties of the cement would be expected (16, 18, 19).

The prevention of destabilization of bismuth oxide is the ultimate goal to mitigate the drawback of tooth discoloration. The aim of the current study was to investigate the inhibition of dental discoloration by adding 5%, 15%, or 45% zinc oxide to MTA Angelus. The physical, chemical, and biological properties were also studied.

Materials and Methods

The materials included MTA Angelus (white MTA; Angelus, Londrina, Paraná, Brazil) and MTA Angelus with 5.0%, 15%, and 45% zinc oxide (ZnO).

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The zinc oxide (Sigma-Aldrich, St Louis, MO) was added to the MTA Angelus and dosed by weight. All cements were mixed at a powder to liquid (distilled water) ratio of 0.3 (1 g powder to 0.3 mL liquid).

Characterization of Materials

Microscopy and Elemental Analysis. Cylindrical specimens 10 mm in diameter and 2 mm high were prepared and stored in Hank's balanced salt solution (HBSS) for 28 days at 37°C (19). The specimens were viewed under the scanning electron microscope (SEM) (Zeiss MERLIN Field Emission SEM; Carl Zeiss NTS GmbH, Oberkochen, Germany) at various magnifications in back-scatter electron mode, and energy dispersive spectroscopy (EDS) (Carl Zeiss NTS GmbH) was carried out.

X-ray Diffraction Analysis. Disk-shaped specimens 15 mm in diameter and 2 mm high were prepared. They were immersed in HBSS for 28 days, after which they were retrieved, dried, and crushed to a fine powder by using a mortar and pestle. Phase analysis was performed with a Bruker D8 diffractometer (Bruker Corp, Billerica, MA) (19). Phase identification was accomplished by using search-match software that used International Centre for Diffraction Data (ICDD) database (Newtown Square, PA).

Radiopacity

Three cylindrical samples 10 mm in diameter and 1 mm in thickness of each cement type were prepared. The thickness was checked with a digital caliper (Mitutoyo Corp, Tokyo, Japan), and the samples were radiographed on occlusal films (D-speed; Kodak Company, Rochester, NY) with an aluminum step-wedge graduated from 2 to 16 mm. A radiographic unit (Gnatus XR 6010; Gnatus, Ribeirão Preto, SP, Brazil) was used with exposures set at 60 kVp, 10 mA, and 0.3 seconds and a focus-film distance of 30 cm. The radiographs were digitized and analyzed by using Digora 1.51 software (Soredex, Helsinki, Finland). The radiopacity was determined as previously described (16).

Setting Time

The setting time was determined according to the American Society for Testing and Materials specifications (C266-08), but the samples were made following the International Organization for Standardization (ISO) 6876/2001 standard. The cements were mixed and placed into stainless steel rings with a 10-mm internal diameter and 2 mm in height. Three stainless steel rings were filled with each material and stored in an incubator at 37°C ± 1°C and 95% ± 5% relative humidity. After 180 seconds of mixing the cements, a 113.4-gauge Gilmore needle was used on each specimen at 60-second intervals for determination of the initial setting time. From the moment that it was not possible to verify any mark on the specimen surface, the initial setting time was determined. The final setting time was measured with a 453.6-gauge Gilmore needle. Three specimens per group were prepared.

Volume Change

The test was performed by using volumetric micro–computed tomography measurements (20). Forty acrylic teeth (n = 10) with a standardized root-end cavity were used. The cavities were filled with the cements, and the samples were scanned by using a desktop x-ray microfocus computed tomography scanner (SkyScan 1174v2; SkyScan, Kontich, Belgium) (20). After scanning, the samples were individually immersed in flasks containing 15 mL ultrapure water and stored at 37°C for 28 days. After the period of immersion, the samples were dried and scanned. The volume change was determined in percentage by calculating the volume of cement that was lost during immersion.

pH and Calcium Ion Release in Solution

Forty acrylic teeth (n = 10) with a cavity of 3-mm depth were filled with the different materials and immersed individually in 10 mL deionized water and stored at 37°C. After 3 hours, 24 hours, and 28 days, the teeth were placed in new flasks containing an equal volume of new deionized water. The pH of the water in which the teeth had been kept was measured with a pH meter (model 371; Micronal, São Paulo, SP, Brazil) previously calibrated by using buffer solutions of pH 4, 7, and 14. After removal of the specimens, the container was placed in a shaker (model 251; Farmem, São Paulo, SP, Brazil) for 5 seconds before measuring. The temperature of the room during the reading was 25°C.

The water used for pH measurement was the same to measure the calcium ion release. For determination of calcium ion release, an atomic absorption spectrophotometer (AA6800; Schimadzu, Tokyo, Japan) equipped with a calcium-specific hollow cathode lamp was used following the operating conditions: lamp current, 3 mA; fuel, acetylene; support, oxygen; stoichiometry, reducing; wavelength, 422.7 nm; slit, 0.2 nm.

Measurement of Tooth Color

Sample Preparation. A total of 20 human teeth and 20 bovine teeth were used. For preparation of human teeth, the crowns were vertically sectioned with a 0.3-mm low-speed diamond saw (Isomet; Buehler, Lake Bluff, IL) at 200 rpm and continuous water cooling to prevent frictional heat. Buccal and lingual sections were obtained. Bovine teeth were sectioned in the crown in 10 × 10 mm enamel-dentin blocks. A cavity with a diameter corresponding to 3.0-mm diameter and 1.5-mm depth was prepared in the center of dentinal surface of human and bovine teeth with a high-speed diamond bur 4054 (Medical Burs Sorensen, São Paulo, SP, Brazil). The specimens were washed with distilled water, and then the samples were dried with gauze. The external limit of the cavities was conditioned with 37% phosphoric acid for 30 seconds, washed with distilled water for 1 minute, and dried with an air syringe. A layer of adhesive (Adper Single Bond 2; 3M ESPE, Sumaré, SP, Brazil) was applied to the conditioned external limit of the cavity and light-cured (Optilight LD Max; Gnatus) for 20 seconds to allow the sealing of the interface with resin. The cements were compacted into the prepared cavities at a depth of 1.5 mm. After the cements set, the cavities were sealed with a natural flow resin B2 (Nova DFL, Rio de Janeiro, RJ, Brazil). The polymerization was performed with an LED curing light (Optilight LD Max) for 60 seconds. The specimens were stored separated in dark flasks and were immersed in tap water at 37°C throughout the period of analysis.

Spectrophotometry. The color measurements were performed immediately after filling and 90 days after filling. The color measurements were performed with a spectrophotometer (Vita Easyshade; VITA Zahnfabrik, Bad Sackingen, Germany) in the center of buccal side of the samples (15). The values of color change (ΔE) and lightness (L) were considered to evaluate the darkening of groups.

Stereomicroscopy. Representative samples of the materials were selected and horizontally sectioned in the center of the cavity by using a 0.3-mm diamond disk. Polished longitudinal sections of material and tooth sections were viewed under the stereomicroscope (Stemi 2000C; Carl Zeiss, Jena, Germany) at ×2 magnification. The images were acquired in Axiovision software (Carl Zeiss).

Biocompatibility

Sixteen adult male albino rats (*Rattus norvegicus*), weighing approximately 300 g, were selected (Ethical approval CEP 014-2014). The study followed Animal Research: Reporting *In Vivo* Experiments (ARRIVE) Guidelines. The mixed cements were inserted into sterile polyethylene tubes (10 mm in length and 1 mm in internal

diameter) and immediately implanted subcutaneously in the dorsal region of the rats (2 per animal). The animals were divided into 4 groups (n = 4) according to the cement type.

After the experimental periods, the animals were killed with a lethal dose of anesthetic (18). The evaluations were made at 30 and 60 days after the surgical procedures. Sections of 5-μm thickness were stained with hematoxylin-eosin. Histologic evaluations were made under a light microscope (Olympus, São Paulo, Brazil) at $\times$400 magnification by a pathologist. For a quantitative evaluation of the inflammatory infiltrate, 30 microscopic fields were analyzed (21): grade 0, without inflammatory cells; grade 1, sporadic presence of chronic inflammatory cells (<25 cells); grade 2, moderate infiltration of chronic inflammatory cells (25–125 cells); and grade 3, dense and severe infiltration of chronic inflammatory cells (>125 cells).

The measurements were repeated twice to ensure reproducibility. The median and range of the grades were calculated.

Statistical Analysis

Data were submitted to normality test of D'Agostino and Pearson. Statistical analysis was performed by using Kruskal-Wallis and Dunn test for radiopacity, setting time, volume change, pH, calcium ion release, and discoloration. The analysis of variance/Tukey tests were selected for analysis of biocompatibility ($P < .05$).

Results

Characterization

The scanning electron micrographs for all the cements are shown in Figure 1. MTA Angelus exhibited unhydrated cement particles coated by a layer of hydration product in the material structure. The bismuth oxide appeared whiter because of its higher atomic number. Peaks for bismuth and oxygen were shown on EDS analysis (Fig. 1). The x-ray diffraction analysis (XRD) scan of MTA Angelus exhibited a peak for calcium hydroxide (ICDD: 01-076-0571) at 18° 2θ. The presence of calcium hydroxide and reaction by-product gives an indication of the level of hydration of MTA Angelus in contact with HBSS for 28 days.

The addition of zinc oxide to the MTA Angelus was evident. The zinc oxide was composed of small particles when compared with the larger and angular particles of bismuth oxide (Fig. 1). The 5% addition showed evidence of cement particles with reaction rims, which had high calcium to silicon ratio (Fig. 1). Reaction by-product was present in the matrix. With increasing additions of zinc oxide, areas of flat crystals became evident in the material matrix. They were larger and more intense in the 45% ZnO group. EDS analysis showed peaks for calcium and oxygen (Fig. 1). The XRD scans showed the absence of calcium hydroxide peak at 18° 2θ. Although there was evidence of the presence of calcium hydroxide in the material matrix (Fig. 1) indicated by the crystal deposition and EDS analysis, the calcium hydroxide was not crystalline and thus not evident in the XRD scans. The tricalcium silicate peaks (ICDD: 00-031-0301) at 29 2θ, 32 2θ, and 34°2θ were still evident, thus indicating a lower degree of material hydration. For all materials containing zinc oxide there were peaks of zinc oxide at ~31° 2θ, 34° 2θ, and 36° 2θ in increasing intensities.

Physical and Chemical Properties

The mean, standard deviation, and statistical analysis of radiopacity, setting time, and volume change are expressed in Table 1. The cements showed similar radiopacity (approximately 4 mm Al) ($P > .05$). For initial setting time, statistical difference was verified between MTA Angelus (31 $\pm$ 4 minutes) and 15% ZnO (18 $\pm$ 3 minutes) groups ($P < .05$). No statistical differences were verified in the other comparisons for initial and final setting time ($P > .05$). The volume change was similar for all cements tested (approximately 1% of volume loss) ($P > .05$).

The results of pH and calcium ion release are shown in Table 2. All the materials demonstrated an alkaline pH (7–8 range). At 3 hours and 24 hours, MTA Angelus (8.42 $\pm$ 0.26 and 8.02 $\pm$ 0.31, respectively) and 45% ZnO (8.06 $\pm$ 0.14 and 8.84 $\pm$ 0.78, respectively) presented higher pH values ($P < .05$). At 28 days, all cements presented similar pH

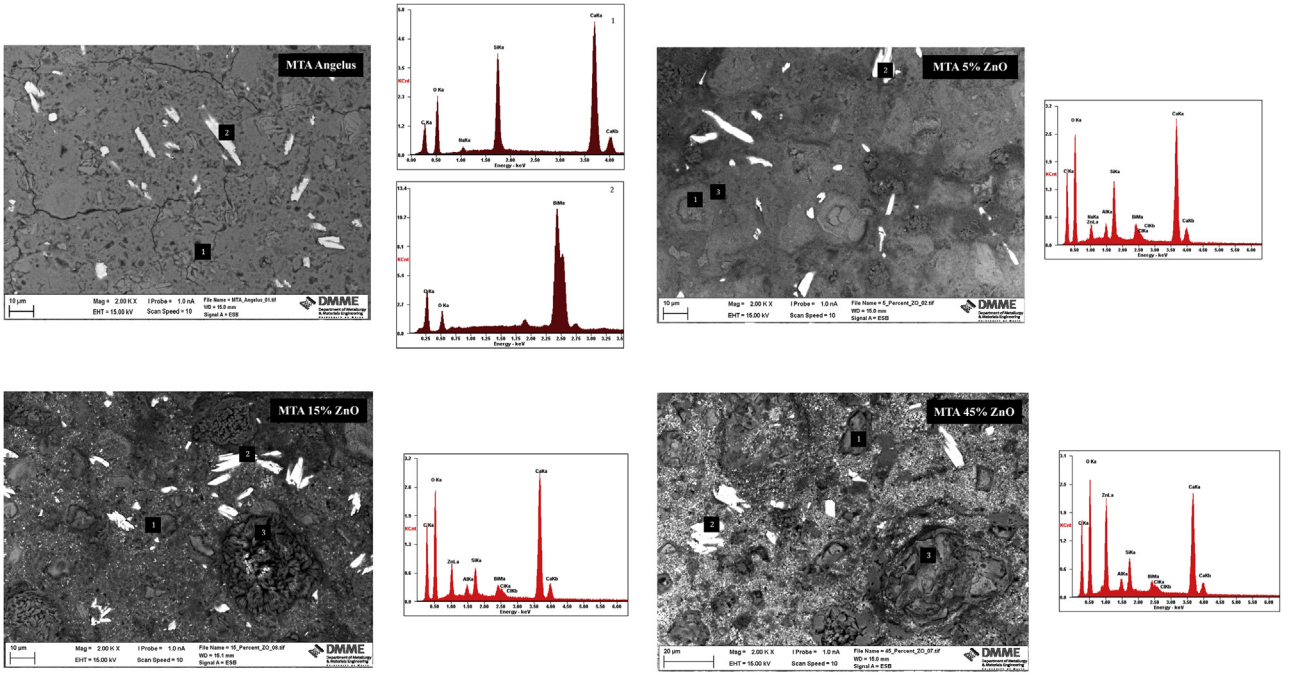

Figure 1. Scanning electron micrographs and EDS scans of MTA Angelus (1, cement matrix; 2, bismuth oxide particle; 3, cement particles) and modified MTA Angelus with additions of zinc oxide (ZnO) in increasing proportions.

TABLE 1. Mean and Standard Deviation of Physical Tests (Radiopacity, Initial and Final Setting Time, and Volume Change) and Color Analysis (Color Change of Human and Bovine Teeth and Lightness)

Group	Radiopacity (mm Al)	Initial setting time (min)	Final setting time (min)	Volume change (%)	Color change (ΔE) human teeth	Color change (ΔE) bovine teeth	Lightness (L at 28 d) human teeth	Lightness (L at 28 d) bovine teeth
MTA	$4.4^{a} \pm 0.7$	$31^{a} \pm 4$	$67^{a} \pm 1$	$1.18^{a} \pm 0.60$	$134.6^{a} \pm 42.8$	$106.8^{a} \pm 109.2$	$72.22^{a} \pm 8.24$	$80.64^{a} \pm 4.45$
5% ZnO	$4.2^{a} \pm 1.3$	$21^{a} \pm 0$	$60^{a} \pm 10$	$0.92^{a} \pm 0.78$	$15.64^{b} \pm 23.22$	$44.37^{b} \pm 13.43$	$81.48^{ab} \pm 6.32$	$94.02^{b} \pm 2.02$
15% ZnO	$4.0^{a} \pm 1.2$	$18^{b} \pm 3$	$66^{a} \pm 3$	$0.82^{a} \pm 0.57$	$12.55^{b} \pm 17.2$	$76.09^{b} \pm 13.26$	$83.54^{ab} \pm 4.11$	$94.26^{b} \pm 1.27$
45% ZnO	$3.9^{a} \pm 1.3$	$25^{a} \pm 3$	$80^{a} \pm 14$	$1.01^{a} \pm 0.54$	$22.62^{b} \pm 9.81$	$47.11^{b} \pm 27.93$	$85.76^{b} \pm 1.81$	$87.54^{ab} \pm 4.96$

Different lowercase letters in each column indicate statistically significant differences ($P < .05$).

(around 8) ($P > .05$). For calcium ion release, the cement 5% ZnO (5.23 ± 1.08) showed significantly high values in comparison with MTA Angelus (3.08 ± 1.83) at 3 hours ($P < .05$). At 24 hours, all cements containing zinc oxide presented elevated calcium release ($P < .05$). At 28 days, the cements 5% ZnO (15.07 ± 6.78) and 45% ZnO (11.91 ± 2.96) showed statistically high release in comparison with MTA Angelus (8.90 ± 1.26) ($P < .05$).

Tooth Color

Mean, standard deviation, and statistical differences of the color change (ΔE) and lightness (L) for human and bovine teeth are shown in Table 1. Representative samples sectioned of each group are shown in Figure 2. MTA Angelus showed statistically significant difference for color change in comparison with the other test cements in human and bovine teeth ($P < .05$). MTA presented the lower L values in comparison with the other test cements in both human and bovine teeth. The discoloration of MTA Angelus teeth was evident for both human and bovine models (Fig. 2). The addition of 5% ZnO to MTA Angelus was effective to inhibit dental discoloration (Fig. 2).

Biocompatibility

Median, minimum, and maximum values of inflammatory infiltrate are expressed in Table 3. Representative sections of groups in each period of analysis are shown in Figure 3. Microscopic analysis of specimens of each group revealed neoformation of connective tissue around the implanted tube in contact with cements. Predominance of lymphocyte cells was observed in the initial periods, with decrease to the final period of analysis. In this period, the tissue showed capsular aspect. No statistical differences were verified in median and range among cements in all periods ($P > .05$).

Discussion

The addition of zinc oxide to MTA Angelus inhibited discoloration of dental structures. Zinc oxide (ZnO) is an inorganic solid compound widely used as an additive in dermatologic products (22–25). Zinc oxide is also present in dental practice, ie, intermediate restorative materials or root canal sealers, and has never been implicated with dental discoloration (22, 24, 25). It is postulated that the zinc molecules interact with the bismuth oxide, stabilizing it from phase changes when in the presence of strong oxidizing agents (11, 15).

Various amounts of zinc oxide were added to investigate its effects on the material properties. MTA particles react with water to initiate the hydration and thus setting. The increase in the amount of zinc oxide resulted in more unreacted particles in cement matrix. The setting time was not influenced by the increase of zinc oxide amounts to MTA Angelus because this test provides the hardening and not the extent of hydration.

MTA Angelus containing all proportions of zinc oxide tested presented similar radiopacity, which were higher than 3 mm Al (recommended by American National Standards Institute/American Dental Association no. 57/2012) ($P > .05$). The results were similar to those previously reported for MTA Angelus (approximately 4 mm Al) (17). The solubility in accordance with the American National Standards Institute/American Dental Association no. 57/2012 or ISO 6876:2012 is based on weights of samples (26). The method proposed by Cavenago et al (20) uses volumetric analysis with microtomography to measure volume change. This methodology allows testing samples more approximately to clinical conditions. Instead of samples with 10-mm diameter, root-end cavities are prepared in acrylic teeth, reducing the surface of contact with water (20). All cements presented volume loss, which was lower than that verified in the study of Cavenago et al (1.83% mean).

The alkaline pH and release of calcium ions allow tissue repair and induction of mineralized barrier (13,27–29). The test cements presented alkaline pH with an increase from initial (3 hours) to final period (28 days) (30). High pH levels are frequently found in the initial periods before complete setting, decreasing or maintaining stable in the subsequent periods (27, 31, 32). In relation to calcium release, for all groups an increase from initial to final analysis was verified. MTA Angelus containing additions of zinc oxide showed high calcium ion release in comparison with the unaltered formula in all periods.

The interaction between MTA Angelus and human or bovine tooth was previously demonstrated (10, 15). In the study, the spectrophotometer analysis indicated that all cements promoted color alteration for both models of study, which was more intense for MTA Angelus. Bovine teeth presented more intense color change, which can be attributed to the higher number of dentinal tubules in comparison with human teeth (33). The data of L indicated low values for MTA Angelus, suggesting darkening of teeth filled with MTA Angelus, which

TABLE 2. Mean and Standard Deviation of pH (ppm) and Calcium Ion Release (mg L^{-1}) Values in the Periods of Analysis

Group	pH (ppm)			Calcium ion release (mg L^{-1})		
	3 h	24 h	28 d	3 h	24 h	28 d
MTA	$8.42^{a} \pm 0.26$	$8.02^{ab} \pm 0.31$	$8.73^{a} \pm 0.45$	$3.08^{a} \pm 1.83$	$5.26^{a} \pm 1.35$	$8.90^{a} \pm 1.26$
5% ZnO	$7.45^{b} \pm 0.11$	$7.97^{ab} \pm 0.18$	$8.98^{a} \pm 0.57$	$5.23^{b} \pm 1.08$	$8.64^{b} \pm 2.06$	$15.07^{b} \pm 6.78$
15% ZnO	$7.50^{b} \pm 0.08$	$7.65^{a} \pm 0.62$	$8.54^{a} \pm 0.49$	$4.57^{ab} \pm 1.06$	$7.96^{b} \pm 1.23$	$11.12^{ab} \pm 1.58$
45% ZnO	$8.06^{a} \pm 0.14$	$8.42^{b} \pm 0.44$	$8.84^{a} \pm 0.78$	$4.01^{ab} \pm 0.95$	$8.60^{b} \pm 1.72$	$11.91^{b} \pm 2.96$

Different lowercase letters in each column indicate statistical differences among groups ($P < .05$).

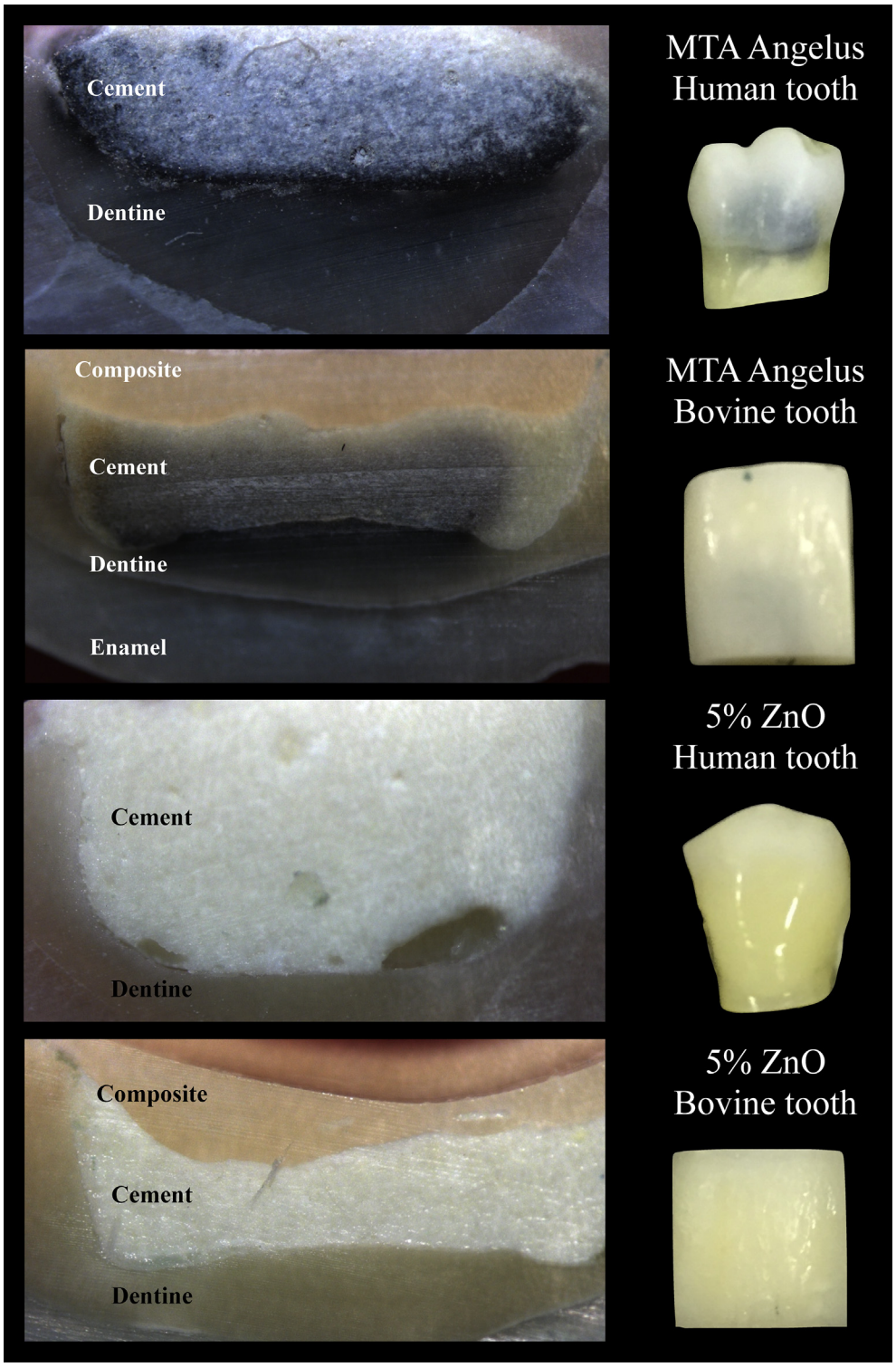

Figure 2. Representative samples of human and bovine teeth filled by using MTA Angelus and MTA containing 5% ZnO. Staining is evident in MTA Angelus group with color alteration of material and dentin. Groups in which ZnO was added did not show color alteration. Original magnification of stereomicroscope images, ×2.

was not verified for the other groups. The discoloration of teeth was evident for MTA Angelus, with black areas close to the interface cement/dentin and marked dentin staining. The color alteration was also verified in buccal surface of the samples, suggesting that in clinical conditions MTA Angelus would promote darkening (6, 7). On the contrary, the small amount of zinc oxide tested (5%) was sufficient to prevent tooth color alteration, indicating the efficacy of this substance to inhibit discoloration of MTA Angelus. Future studies evaluating even small proportions of these substances would indicate the minimal proportion required to prevent color alteration.

Contrary to a previous investigation, the samples were not submitted to contact with sodium hypochlorite (15). This substance has a

TABLE 3. Median, Minimum, and Maximum Values of Inflammatory Infiltrate at 30 and 60 Days of Analysis

Group	30 d	60 d
MTA	2.0[a] (1.0–2.0)	2.0[a] (1.0–3.0)
5% ZnO	1.5[a] (1.0–2.0)	1.5[a] (1.0–2.0)
15% ZnO	2.0[a] (1.0–2.0)	1.0[a] (1.0–2.0)
45% ZnO	1.5[a] (1.0–3.0)	1.0[a] (1.0–2.0)

Different lowercase letters in each column indicate statistical differences among groups ($P < .05$).

negative effect on color of white MTA, resulting in darkening (14). Thus, the exposure to sodium hypochlorite remnants in dentin was avoided to demonstrate the interaction of dentin and the cement.

Subcutaneous implantation has been used to evaluate tissue response of dental materials (34, 35). The results found showed that the proportions of zinc oxide did not interfere in inflammatory response of MTA in all periods of analysis studied. The microscopic analysis revealed that the inflammatory infiltrate was more intense in the groups in which high proportions of the test substances were

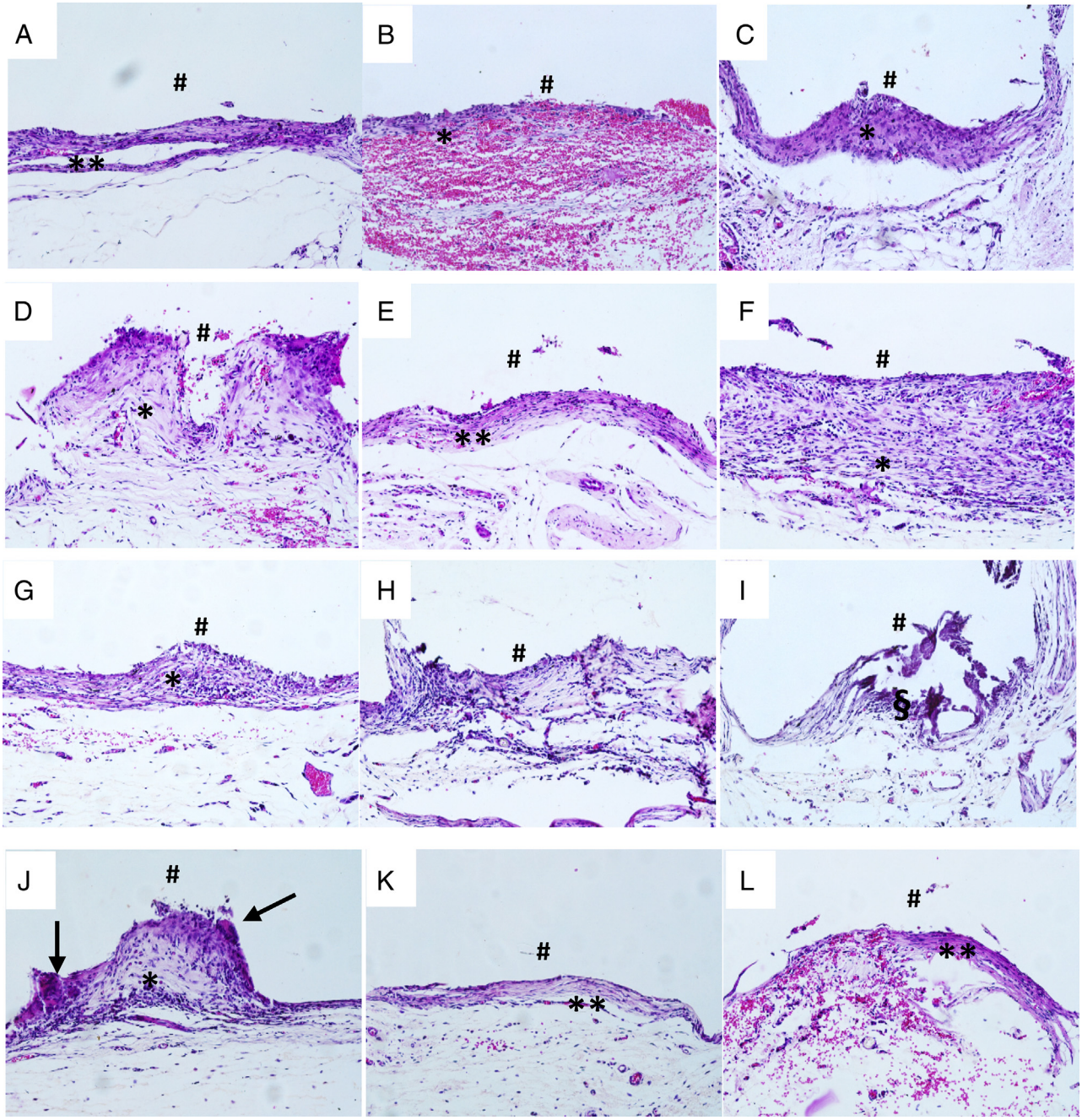

Figure 3. (*A–F*) Microscopic representative specimens at 30 days of analysis. (*A–C*) MTA Angelus, (*D*) 5% ZnO, (*E*) 15% ZnO, and (*F*) 45% ZnO. Close to the material (#) was visualized areas with inflammatory tissue (*) infiltrated by leukocytes and areas with fibrous connective tissue in a capsule aspect (**) with slight infiltrate. (*G–L*) Microscopic representative specimens at 60 days of analysis. (*G–I*) MTA Angelus, (*J*) 5% ZnO, (*K*) 15% ZnO, and (*L*) 45% ZnO. Close to the material (#) was visualized areas with inflammatory tissue (*) infiltrated by leukocytes. In some groups there was formation of fibrous capsule (**) with the presence of leukocytes. In some specimens, areas with necrosis (§) and giant cells (*black arrow*) were verified. (Hematoxylin-eosin; original magnification, ×20).

implanted. Thus, the amount of 5% ZnO would be preferable for biological properties, and even lower amount can be tested in future studies for development of a novel commercial formula of MTA. Further testing is necessary to fully understand the mechanisms by which the zinc oxide mitigates the dental discoloration caused by bismuth oxide in MTA.

Conclusions

The addition of 5%, 15%, or 45% zinc oxide to MTA Angelus inhibits dental discoloration without changing radiopacity, setting time, volume change, pH, and biocompatibility. Calcium ion release of MTA Angelus increased with addition of zinc oxide.

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

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