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Fracture strength of bovine incisors after intra-radicular treatment with MTA in an experimental immature tooth model

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Abstract

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Aim To evaluate, using an experimental immature tooth model, the fracture resistance of bovine incisors submitted to different reinforcement treatments with mineral trioxide aggregate (MTA).

Methodology An immature tooth model was created by sectioning the coronal and apical portions of 40 bovine incisors 8 mm above and 12 mm below the cementoenamel junction. The root canals were irrigated with 1.0% sodium hypochlorite. They were enlarged both coronally and apically using number 703 carbide burs (ISO: 500–104-168-007-021) and their internal diameter was standardized to 2.1 mm. The specimens were assigned to four groups ($n = 10$): GI-control (without filling); GII-apical MTA plug + filling with gutta-percha and endodontic sealer; GIII-filling with MTA; GIV-apical MTA plug + filling with MTA + metallic post (Reforpost I). A polyether impression material was used to simulate the periodontal ligament. The specimens were submitted to a compressive load at a crosshead speed of 0.5 mm min^{-1} in a servo-hydraulic universal testing machine (MTS 810) applied at 45° to the long axis of the tooth until failure. Data were submitted to statistical analysis by the Kruskal–Wallis test at 5% significance level.

Results GIV presented the highest fracture resistance (32.7N) and differed significantly from the other groups ($P < 0.05$). No statistically difference was found between GII (16.6N) and GIII (23.4N) ($P > 0.05$). GIII had a significantly higher fracture resistance than GI ($P < 0.05$).

Conclusions The use of MTA + metallic post as an intra-radicular reinforcement treatment increased the resistance to fracture of weakened bovine teeth in an experimental immature tooth model.

Keywords: apexification, bovine teeth, fracture resistance, metallic post, mineral trioxide aggregate.

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Introduction

Dental trauma is most frequent in children aged 8–12 years and most commonly affects the maxillary central incisors possibly causing pulp necrosis (Andreasen & Andreasen 1994). In these cases, teeth with incomplete root development and periapical pathosis should undergo a treatment to induce apexification. The clinical management of pulpless, immature teeth is challenging because of the open, divergent apical morphology and weak, underdeveloped root dentine walls (Lawley *et al.* 2004).

Calcium hydroxide [$Ca(OH)_2$] is widely accepted as an inter-appointment intracanal medicament (Bystrom *et al.* 1985) during root canal treatment and its use in apexification procedures has been described (Frank 1966). When placed within the root canal system,

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$Ca(OH)_2$ has antimicrobial properties (Tamburic *et al.* 1993) and may inhibit the occurrence of inflammatory root resorption and induce apical closure in nonvital immature teeth. However, this therapy may extend from months to years before the desired effects are achieved (Dannenberg 1974, Sheehy & Roberts 1997). Furthermore, it has been suggested that changes in the physical properties of dentine by $Ca(OH)_2$ dressing may be responsible for an increase susceptibility to root fracture (Cvek 1992). According to White *et al.* (2002), a 5-week exposure to $Ca(OH)_2$ results in a 32% decrease in strength to bovine dentine. In sheep dentine treated with $Ca(OH)_2$, a marked decrease in fracture strength with increasing storage time was observed (Andreasen *et al.* 2002). Root filling with $Ca(OH)_2$ reduced the microtensile fracture resistance of teeth by almost 50% between 7 and 84 days (Rosenberg *et al.* 2006), and when immersed in a saturated solution of $Ca(OH)_2$ for 1 week, a reduction in the flexural strength of human dentine was demonstrated (Grigoratos *et al.* 2001).

The findings of these studies support the view that a long-term exposure to $Ca(OH)_2$ alters the physical properties of dentine. This may be a result of a change in the organic matrix (Andreasen *et al.* 2002). The pH increase observed after exposure to $Ca(OH)_2$ may reduce the organic support of the dentine matrix (Tronstad *et al.* 1980, Nerwich *et al.* 1993). The most promising alternative to long-term $Ca(OH)_2$ therapy for induction of apexification is the use of mineral trioxide aggregate (MTA) as an apical barrier (Shabahang *et al.* 1999, Witherspoon & Ham 2001, Felippe *et al.* 2006). The capacity of MTA to induce hard apical tissue formation in immature teeth has already been demonstrated (Shabahang *et al.* 1999, Felippe *et al.* 2006). Furthermore, the use of MTA as an apical barrier has shown clinical and radiographic success in humans (Giuliani *et al.* 2002). Despite the biological potential of using MTA to stimulate apical closure in immature teeth, the increase of root resistance to fracture remains a challenge. Some studies have suggested the use of bonding techniques to increase the fracture resistance of immature teeth (Saupe *et al.* 1996, Katebzadeh *et al.* 1998, Pene *et al.* 2001, Schatz *et al.* 2001, Goldberg *et al.* 2002, Carvalho *et al.* 2005). However, several factors might interfere with the adhesion of filling materials to root canal dentine walls, and the high-polymerization shrinkage of some adhesive materials may allow coronal leakage (Mannocci *et al.* 2001, Rogic-Barbic *et al.* 2006).

Bramante *et al.* (2006) used MTA and an intracanal post to reinforce a maxillary central incisor with an open apex and horizontal fracture in the coronal third of the root. According to the authors, this is an alternative treatment for teeth with horizontal root fractures, and is used to improve the retention of the intracanal post aiming at maintaining the tooth stability and preventing microleakage.

It is well known that MTA and Portland cement have similar structural properties and physicochemical behaviour (Funteas *et al.* 2003, Islam *et al.* 2006). In civil engineering, beams and pillars are supported and strengthened by metallic frames embedded within Portland cement. Based on this knowledge and taking into account that immature teeth are prone to fracture, especially at the cervical third (Cvek 1992), the use of MTA for reinforcement of immature teeth has been suggested (Andreasen *et al.* 2006). Nevertheless, it remains unclear whether a metallic post placed in a root filled with MTA provides structural reinforcement to a weakened immature tooth.

The purpose of this study was to evaluate, using an experimental immature tooth model, the fracture resistance of bovine incisors submitted to different reinforcement treatments with MTA.

Materials and methods

Forty recently extracted bovine incisors with similar dimensions were selected, stored and disinfected in 2.0% glutaraldehyde solution for 15 days. The teeth were examined under a ×4 magnifying glass to discard those with carious lesions, cracks or fractures. Buccolingual and mesiodistal radiographs were taken to demonstrate that the teeth had similar internal anatomy. For selection of the teeth, the mesiodistal and buccolingual diameters of the roots were determined by using a Boley Gauge (Buffalo Dental Manufacturing Co., Syosset, NY, USA) positioned at a point located 2.0 mm below the cementoenamel junction. The average values obtained were 6 mm for mesiodistal and 8 mm for buccolingual roots. To prevent dehydration, the teeth were stored in saline until use.

Specimen preparation

An experimental immature tooth model was established to simulate teeth with incomplete root development using the bovine incisors. The crowns and roots were sectioned 8.0 mm above and 12 mm below the cementoenamel junction, respectively, using a water-

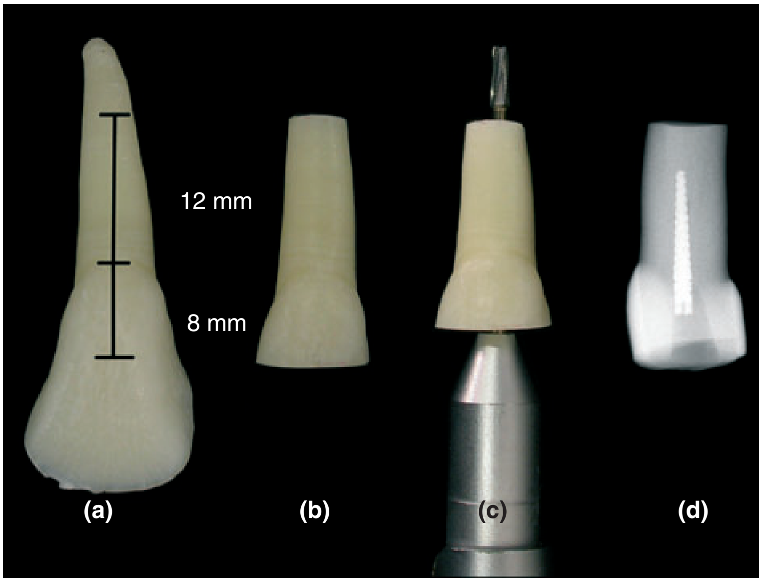

Figure 1 Model of incomplete apexification: (a) represents the sectioned parts of the bovine tooth; (b) the crown and root length; (c) crossing of the bur and (d) MTA + metallic post intra-canal reinforcement.

cooled diamond disc at low speed, thus providing specimens with total length of 20 mm. Pulp tissue was removed with size 60 Hedstrom files (Dentsply Maillefer, Ballaigues, Switzerland) and the root canals were irrigated with 1.0% sodium hypochlorite solution. The root canals were enlarged both coronally and apically using number 703 carbide burs (ISO: 500-104-168-007-021, JET carbide burs, Beavers Dental Products Ltd., Morrisburg, ON, Canada) and their internal diameter was standardized to 2.1 mm (Fig. 1). The thickness of the remaining dentinal walls (buccal, lingual, mesial and distal), measured at the root apex with a caliper (accurate to ±0.02 mm), ranged from 0.1 to 0.2 mm. During the procedures, the teeth were maintained in moist gauze and were irrigated with 1.0% sodium hypochlorite solution.

After preparation, the specimens were randomly divided into four groups ($n = 10$), according to the intra-radicular treatment performed.

GI-control (no root canal filling); GII-MTA powder was mixed with distilled water following the manufacturer's instructions (white MTA™, Angelus Indústria de Produtos Odontológicos Ltda., Londrina, PR, Brazil). The apical MTA plug was prepared according to Bramante *et al.* (2004). MTA was inserted into the root canal using a lentulo drill (Dentsply Maillefer) at 2.0 mm from the working length. MTA was condensed at the apical third of the root canal using a cotton pad moistened with distilled water wrapped around a size 70K-file (Dentsply Maillefer), which also served to clean the root canal walls. The thickness of the apical plug was 4 mm and the homogeneity of the root filling was confirmed radiographically. A cotton pad wrapped around an endodontic file was used for root canal drying. Thereafter, the remainder of the root canal was filled with gutta-percha (Dentsply-Herpo, Petrópolis, RJ, Brazil) and zinc oxide-eugenol sealer (Endofill; Dentsply, Rio de Janeiro, RJ, Brazil). New radiographs were taken to assess the quality of root canal filling;

GIII-filling with white MTA. MTA was mixed, inserted into the entire root canal and checked in the same manner as previously described.

GIV-placement of a 4.0-mm apical MTA plug as described for GII. Thereafter, MTA was delivered to the root canal in a wet consistency and then a metallic intra-radicular post (Reforpost I, Angelus Indústria de Produtos Odontológicos Ltda.) was inserted within the MTA mass. Post adaptation was checked radiographically. The posts were placed into the canals in such a way that their long axes were aligned with the long axis of the teeth and with no contact to the root canal walls (Fig. 1).

Coronal access carities were sealed with glass–ionomer cement (Vidrion R; SS White, Rio de Janeiro, RJ, Brazil) and the specimens were stored in a stove at 37 °C and 100% relative humidity for 48 h.

Periodontal ligament simulation

Periodontal ligament (PDL) simulation was performed by the method of Soares *et al.* (2005). The teeth were immersed in melted wax (Horus; Herpo Produtos Dentários, Petrópolis, RJ, Brazil) up to 2.0 mm below the cementoenamel junction. After cooling, a 0.2- to

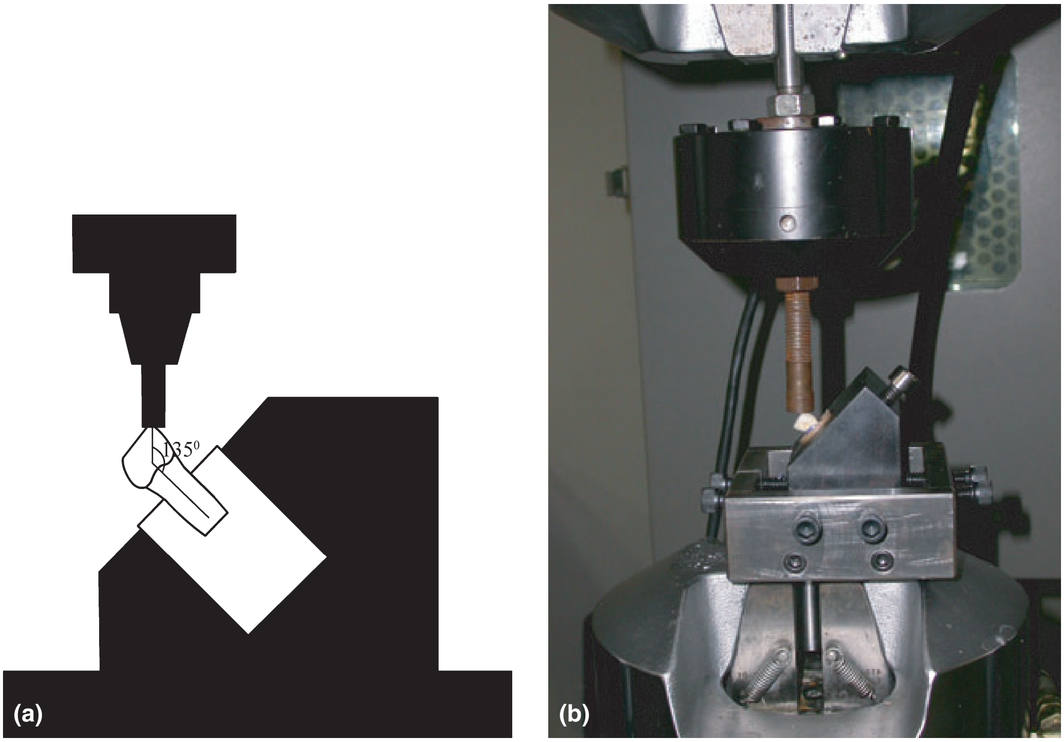

Figure 2 (a) Cylindrical device used for fixation and positioning of specimens subjected to fracture strength testing. Device positioned for load application at 135°. (b) Load being applied on the buccal surface.

0.3-mm thick wax layer was obtained by coating the roots. The teeth were embedded in polystyrene resin (Cristal, Piracicaba, SP, Brazil) using polyvinyl chloride (PVC) cylinders (21-mm diameter × 25-mm high). The resin was mixed according to the manufacturer's instructions and was inserted in the cylinder immediately after mixing. After resin polymerization, the teeth were removed from the PVC cylinders, and the wax was removed from root surface and resin cylinder 'sockets' using warm water for 2 s. The resin cylinders were filled with a polyether impression material (Impregum™ Soft; 3 M/ESPE, Seefeld, Germany) using a moulding syringe. The teeth were re-inserted into their respective cylinder 'sockets' and excess impression material was removed with a number 12 scalpel blade. Therefore, the polyether filled the space previously occupied by wax, thus providing a simulated 'PDL' with a thickness of 0.2–0.3 mm.

Fracture strength testing

All specimens were submitted to a compressive load at a crosshead speed of 0.5 mm min^{-1} (Soares *et al.* 2005) in a servo-hydraulic universal testing machine (MTS 810, MTS Systems Corporation, Eden Prairie, MN, USA) until fracture. For specimen adaptation to the assay apparatus, a cylindrical device was obtained as described by de Melo *et al.* (2005) (Fig. 2a). This cylinder design allowed fixing the specimens at 45° angle in such a way that the load was applied by the MTS 810 machine at 135° in relation to the long axis of the tooth (Fig. 2b). These procedures were used to simulate a traumatic blow on middle third of the dental crowns from a buccal direction.

The ultimate load required to fracture the specimens was recorded (n) and data were analysed statistically by the Kruskal–Wallis test at 5% significance level.

Results

Table 1 shows fracture strength results (n) for each group. GIV had the highest fracture resistance and differed significantly from the other groups ($P < 0.05$). No statistically significant difference was found between GII and GIII ($P > 0.05$). GIII had significantly higher fracture resistance than GI ($P < 0.05$) (Fig. 3).

Table 1 Maximum fracture forces (N) and Standard Deviation (SD) of the specimens

	Specimens										
Group	1	2	3	4	5	6	7	8	9	10	SD
GI	755.94	1085.93	615.99	634.70	551.02	666.97	643.97	802.22	912.93	509.62	175.95
GII	924.78	902.07	869.17	728.19	1015.37	799.06	723.60	1129.52	867.48	764.04	129.21
GIII	878.85	1129.52	932.04	1063.29	993.20	791.94	932.38	981.69	1129.51	876.66	111.48
GIV	1123.73	1063.73	991.16	1129.52	1420.18	944.95	1040.44	1500.13	1280.52	1155.40	182.04

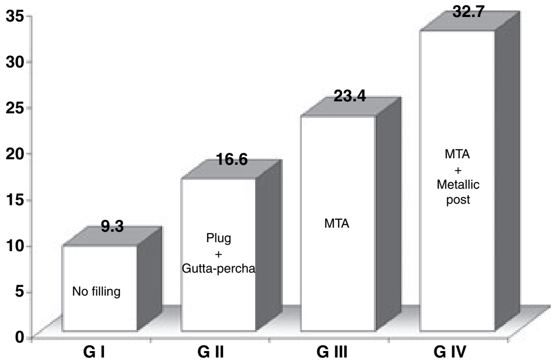

Figure 3 Fracture strength means (N) for each group.

Discussion

This study investigated a new concept for reinforcement of immature teeth using a technique similar to that used in civil engineering, in which a metallic post is covered by Portland cement to reinforce a structure. To test the validity of this concept, an experimental immature tooth model using bovine teeth was created. This model simulated teeth with underdeveloped roots that had relatively thin root canal walls and open apices.

Although bovine and human teeth have different features especially regarding their morphology, several studies have demonstrated similarities between those substrates. Sano *et al.* (1994) found similar results between human and bovine teeth regarding to the ultimate tensile strength (104 and 91 MPa, respectively) and the modulus of elasticity of dentine (13–15 MPa both). Moreover, other studies (Nakamichi *et al.* 1983, Saunders 1988, Ruse & Smith 1991, Schilke *et al.* 2000) have reported similar results between bovine and human dentine in bonding tests as well in the number and distribution of dentinal tubules. In addition, bovine incisors show less variation in anatomical morphology than human teeth. Therefore, bovine teeth provide a standard and reproducible anatomy that allows evaluation both parametrically and quantitatively of different treatment modalities for management of this challenging clinical situation.

When tooth resistance to fracture is evaluated *ex vivo*, simulation of the PDL plays an essential role in the fracture pattern. PDL is an important structure for distribution of stresses generated by load application to the teeth (Rees 2001). According to Soares *et al.* (2005), the root embedding method and the type of PDL simulation can affect the fracture modes. These authors observed that when roots were embedded in a rigid structure without simulating the PDL, the fracture patterns tended to occur at the limit of the resin cylinder. On the other hand, when roots were embedded in polystyrene resin and PDL was simulated by using polyether impression material, the fracture patterns changed to the root areas.

Although the PDL and the polyether impression material have different physical properties, they present similar behaviour when submitted to external stress, i.e. the response is nonlinear and viscous (Pini *et al.* 2002, Soares *et al.* 2005). In addition, several studies have used the same elastomeric material (Behr *et al.* 1999, Rosentritt *et al.* 2000, Soares *et al.* 2004) and polystyrene resin (Dias de Souza *et al.* 2001, 2002, Soares *et al.* 2004) used in the present study to simulate the clinical situation. Yoshida *et al.* (2001) have evaluated the PDL elastic properties and found that the elastic modulus varies according to the load applied and a range of 0.12–0.96 MPa was found to be the elastic modulus of the normal human PDL. Another study determined the elastic modulus of various elastomeric impression materials at the setting time and 30 min after start of mixing (Jamani *et al.* 1989). The elastic modulus of Impregnum F was found to be 0.35 MPa at the setting time and 0.70 MPa 30 min after setting, therefore very close to the elastic modulus of human PDL.

To reproduce the clinical situation and to provide a more accurate assessment of bovine root fracture strength in an immature tooth model, the methodology of the present study included tooth embedding in polystyrene resin and PDL simulation using a polyether impression material (Impregum^{TM} Soft).

Although the use of MTA as a root canal filling material in cases of immature teeth has shown excellent results from both biological and mechanical standpoints, delivery and adaptation of this material to the intracanal space remain a challenge in clinical practice. Several studies have indicated the use of ultrasound to enhance the adaptation of MTA to the apical portion of the canals (Witherspoon & Ham 2001, Hachmeister *et al.* 2002, Lawley *et al.* 2004).

As the goal of this study was not to investigate the most appropriate MTA delivery technique, root canal filling was performed according to the method described by Bramante *et al.* (2004), which is a simple and reliable technique and allows controlling apical extrusion. In addition, radiographs were taken to ensure that the canal space was completely filled and that plug thickness was 4.0 mm. In GIV, MTA was delivered to the root canals in an aqueous consistency to allow the insertion of the metallic posts within the MTA mass. The posts were placed in a single and rapid movement. In all groups, the specimens were submitted to fracture testing only if the compaction of the filling was confirmed radiographically.

A low crosshead speed was used in this study (0.5 mm min^{-1}) to assess the fracture resistance and not the impact strength. High-speed assays tend to equalize low values from which on the crack formation begins, as well as the crack propagation towards the fracture area.

In the present study, roots reinforced with a metallic post/MTA had fracture strength almost four times higher than that of the roots in the control group and twice that of the roots that received an apical MTA plug and were filled with gutta-percha and sealer. It was also significantly better than the use of MTA as a stand-alone filling material. These results do not agree with those of Andreasen *et al.* (2006), who did not find a significant increase in fracture strength when immature sheep teeth filled with MTA were compared with control teeth (without filling). These divergent results may be attributed to the fact that those authors embedded the teeth in plaster of Paris and did not simulate the PDL. As mentioned above, the root embedding technique and PDL simulation can interfere with the resistance to fracture and the fracture patterns (Soares *et al.* 2005).

The fact that immature teeth are more prone to fracture than mature teeth represents a serious clinical problem and a challenge for all clinicians. A technique in which it is possible to do both apical filling and root reinforcement using the same material within the same visit and under good isolation would be very welcome as a treatment option for these cases.

Studies have suggested that resistance to fracture of immature teeth would be increased with use of bonding techniques (Saupe *et al.* 1996, Katebzadeh *et al.* 1998, Pene *et al.* 2001, Schatz *et al.* 2001, Goldberg *et al.* 2002, Carvalho *et al.* 2005). The findings of a recent study (Carvalho *et al.* 2005), in which bovine incisors were used in a simulated immature nonvital tooth model, similar to that of the present study, showed that roots reinforced with light-cured composite resin or zirconium fibre posts presented fracture strength approximately twice higher than that of the control specimens. Similar outcomes were found by Lawley *et al.* (2004). Although the present study did not evaluate the resistance to fracture of roots restored with bonding systems, it was observed that the roots reinforced with MTA and metallic posts had fracture strength four times higher than that of the control roots. Furthermore, the fracture pattern in the present study showed interesting outcomes. Even though it was not the scope of this study, a large number of root fractures were observed in GI, GII and GIII. However, in GIV, the pattern changed to coronal fractures. When the fracture involved the cervical third of the root, it was noted that the post/MTA 'pillar' withstood the loading efforts and did not break.

A relevant point is that in the longer term, corrosion problems might develop at the post/MTA interface in the same way that occurs with reinforced concrete. Therefore, it is essential to use a post with high resistance to oxidation (stainless steel) (McDonald *et al.* 1995).

This intra-radicular reinforcement technique might be indicated in cases where the post is not essential for retention of a posterior restoration, but is important to strengthen the root. Vargas *et al.* (2004) demonstrated that the retentive strength of MTA was only approximately half that of other luting agents for endodontic posts. The findings of the present study support the idea that, in the near future, the use of MTA and metallic posts might be the technique of choice to deal with such a special clinical situation.

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