journal of dentistry 37 (2009) 652–657

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Review

The restoration of permanent immature anterior teeth, root filled using MTA: A review

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ARTICLE INFO

Article history:
Received 23 February 2009
Received in revised form
12 May 2009
Accepted 21 May 2009

Keywords:
Immature teeth
Composite resin
Endodontics
Root canal posts
Open apex

ABSTRACT

Objectives: Immature anterior teeth are at high risk of root fracture following root canal treatment. The literature was explored to determine the current status for post-endodontic restorative management of these teeth.

Data and sources: The authors explored multiple search engine databases to November 2008. Experiments included in the review involved simulated human or animal immature teeth with mineral trioxide aggregate as an apical plug. The experiments were designed to assess and compare the fracture strength of teeth restored with various materials. Studies that did not fulfil inclusion criteria were omitted from the review.

Study selection: Four *in vitro* studies fulfilled selection criteria and were systematically reviewed. All studies differed in sources of teeth, their simulated immature tooth model and mode of force application.

Clinical Implications: Current evidence, mostly from laboratory studies, suggests the use of composite resin materials placed deep into the coronal aspect of the root canal to impart superior fracture resistance. Further clinical research is needed to assess other reinforcing materials, which include a variety of post systems and luting agents.

1. Introduction

The clinical management of trauma is an integral part of general dental practice in many countries. The general protocol for fractured, non-vital anterior teeth involves root canal treatment followed by protective permanent restorations for the coronal structure followed by review. Special situations arise in young patients when the pulps of anterior teeth lose vitality with resultant arrested development of the roots. The open and sometimes divergent apical morphology and weak root dentine wall makes endodontic procedures challenging, and presents restorative problems. It is important to preserve these weakened teeth in young patients. More definitive treatment options, such as implant-supported crowns or fixed prostheses, may not be feasible until craniofacial growth is complete, which can be up to the age of 25 years.[1] Missing, fractured or aesthetically poor anterior teeth and restorations may have detrimental effects on nutrition as well as psychology and personality development.[2]

Several case reports have discussed methods for pulp space revascularization and apical tissue regeneration to continue root development and produce root-end closure.[3–5] However, it is common practice to use long-term calcium hydroxide dressings to promote formation of a hard apical barrier at the open apex of immature teeth to allow condensation of a gutta percha (GP) root filling.[6] Recent studies suggest using mineral trioxide aggregate (MTA) as an apical plug, which reduces the duration of the calcium hydroxide dressing and overall treatment.[7–9]

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doi:10.1016/j.jdent.2009.05.026

In teeth with open and divergent apical morphology, thin and weak dentine walls, a large pulp chamber and, in many cases, fractured coronal structure, there is a risk of cervical fracture during or following root canal treatment. A retrospective clinical study showed the rate of cervical fracture was dependent on the stage of root development. Most fractures were observed within 3 years of commencing long-term calcium hydroxide treatment. The frequency ranged from 77% in teeth with the least root development to 28% in teeth with the most developed roots.[10]

Several reasons have been put forward to explain the reduced fracture strength of teeth during and following endodontic treatment. The biomechanical behaviour of teeth changes after loss of coronal tooth tissue, pulp tissue and with the use of various canal disinfectants. Studies of physical properties have noted the reduced fracture resistance of pulpless teeth due to loss of tooth tissue from trauma, caries, restorations and overzealous root canal procedures.[11–13] Materials used for root canal disinfection and preparation also have negative effects on the physical properties of dentine. Sodium hypochlorite is a strong organic solvent and can reduce the microhardness of dentine by defragmentation of collagen.[14–16] Chelating agents soften dentine by removal of inorganic components.[17–19] Andreasen et al. (2002) in an *in vitro* experiment with sheep mandibular incisors with open apices demonstrated that long-term calcium hydroxide dressings had a significant negative effect on the strength of the root, but up to 4 weeks of calcium hydroxide did not adversely affect the fracture resistance.[20] Another *in vitro* experiment demonstrated that a previous traumatic event reduced the resistance to fracture of a tooth by up to 85%.[21] Cvek (1992) observed a significant correlation between cervical root fractures on endodontically treated immature teeth and cervical resorption defects, the resorption defects acting as loci of least resistance. The association was more pronounced in teeth with an advanced stage of root development.[10]

The objective of the final restoration is to provide an effective coronal seal, reinforce or maintain the strength of the tooth against masticatory or external traumatic forces and to maintain the tooth in an aesthetic and functional relationship with the adjacent and opposing teeth. Effective coronal seals provided by sound restorations play a significant role in the outcome of endodontic treatment.[22] Dentine is a stronger core substance than some restorative materials,[23] and sound dentine provides a solid base for a restoration. The type of tooth, its location in the arch, existing or past pathology and restorative procedures, occlusion and finally quality and quantity of tooth structure determine the resistance to fracture.[24]

Currently, the trend is towards selection of MTA as the apical filling material for immature teeth.[25] Observational studies of MTA apexification have demonstrated comparable healing outcome to calcium hydroxide apexification.[9,26] Composite resin restorations (CR), resin reinforced glass ionomer cement (GIC), root canal posts—metallic/non-metallic, GP, monoblock root filling systems, MTA and various combinations have all been used to reinforce the thin walled canals of immature teeth. This review considers the current status regarding the selection of appropriate restorative materials for reinforcing weak immature anterior teeth following root canal treatment.

2. Methods

An extensive search was undertaken to identify all the clinical and laboratory-based studies (human and animal teeth) on the restoration of immature anterior teeth after root canal treatment. The Ovid Medline (R), Embase, Entrez and Scopus databases were searched using keywords individually and in combinations (November 2008). The key words were 'immature teeth', 'post restorations', 'composite resin', 'post-endodontic restorations', 'post and core restorations' and 'open apex'.

A preliminary analysis involved exploration of 26 studies, which fulfilled the inclusion and exclusion criteria (Table 1). The full texts of these papers were then screened. A 'backward search' was performed in the bibliography of the initially chosen articles to include any relevant paper not identified by the computerised search. A 'forward search' was carried out for citations made of the original shortlisted 26 studies.

3. Results

Many experiments did not use MTA as the apical filling material and were omitted from the review.[27–33] This left four papers to consider in detail.[34–37] A summary was produced of their study materials, methods and outcome (Table 2). Three groups conducted laboratory-based experiments to evaluate the reinforcing abilities of CR materials in thin walled root canals following apical filling with MTA.[34–36] The fourth paper examined the feasibility of MTA together with a metal post as a root strengthening concept.[37] All the experiments differed widely in their methods and materials, mainly the source of teeth, simulation of teeth, preparation of models and the direction of forces used to compare their abilities to strengthen the root.

The experiments measured the strength of teeth in terms of fracture resistance at their necks. None of the studies applied cyclic loads prior to placement in the Universal testing machine. In the three experiments evaluating CR, the direction of force was from lingual to labial, at the middle of the crown or at the cervical level. The force applied was at a 5 mm/min crosshead speed to measure the ultimate catastrophic force to fracture tooth and restoration at the cervical level. In the experiment with MTA and a metal post, the force was directed from the labial surface with a 0.5 mm/min crosshead speed.

Table 1 – Inclusion and exclusion criteria.

Inclusion criteria
(1) *In vivo* or *in vitro* studies
(2) The teeth subjected to test were anterior teeth (true or simulated/human or animal immature teeth)
(3) Outcome discussed in terms of reinforcing the physical properties of teeth
(4) MTA used for the apical root canal filling
Exclusion criteria
(1) Case reports
(2) Outcome measured different than the mentioned above
(3) Root canal filling material other than MTA

Table 2 – Summary of studies included in the review.

Authors	Type of study	Source of teeth	Tooth dimensions	Apical plug	Materials tested	Outcome—fracture resistance
Bortoluzzi et al.[37]	*In vitro*—post-endodontic restoration	Bovine incisors	Canal diameter—2.1 mm, dentine wall thickness at apex—0.1–0.2 mm	MTA	GP, MTA and MTA with metal post [GIC in access cavity]	MTA with metal post > MTA[a], MTA > empty canal[a]
Wilkinson et al.[36]	*In vitro*—post-endodontic restoration	Sheep mandibular incisors	Apical prep—#120 Light speed instrument	MTA	Resilon, GP, flowable CR, hybrid CR [CR in access cavity]	Hybrid CR > gutta percha[a], hybrid CR > flowable CR > Resilon[b], Resilon = GP = empty canal
Stuart et al.[35]	*In vitro*—post-endodontic restoration	Maxillary anteriors	Root canal diameter from orifice to apex—1.5 mm, root canal dentine thickness at CEJ—2.63 mm	MTA	Resilon, GP, flowable CR [CR in access cavity]	Flowable CR > GP, Resilon[b]
Lawley et al.[34]	*In vitro*—post-endodontic restoration	Maxillary incisors	Apical foramen diameter—1.24 mm	MTA	Flowable CR, GP [CR in access cavity]	Flowable CR > GP[a], GP = empty canal[b]

MTA, mineral trioxide aggregate; CR, composite resin; GP, gutta percha; CEJ, cementum–enamel junction; GIC, glass ionomer cement.
[a] Outcome is statistically significant.
[b] Outcome is statistically NOT significant.

A further difference in the experimental models was the preparation of a simulated periodontal ligament (PDL) space around the roots. Two experiments on the reinforcing abilities of CR in the root canal and access cavity did not simulate a PDL[34,36] and one did.[35] The MTA and post study featured a simulated PDL.

Three experiments compared the fracture strength of teeth following placement of hybrid or flowable CR, Resilon, GP or an empty canal. All noted the superior mean fracture load for the teeth filled with CR materials over GP, Resilon or empty canals.[34–36] Although the teeth filled with Resilon were inferior in fracture strength compared to CR this was not statistically significant.[35] The fracture resistance of the GP filled canals were no different from Resilon or an empty, wide canal. In the experiment where a metal post was used to reinforce MTA the teeth had twice the strength compared to GP, and were significantly stronger than MTA alone.[37]

None of the four studies evaluated the use of non-metallic posts and resin-based luting cements.

4. Discussion

Four experiments fulfilled selection criteria. While other studies included the word immature in the title, the experimental teeth were not apically enlarged sufficiently to mimic open apices and did not use MTA as a root filling material. Studies with an apical plug of MTA were selected as many endodontists use it in immature teeth. Outcome studies have revealed satisfactory results using the method.[9,26,38]

4.1. *Validity of the sample and study models*

In mature teeth, variations in mineral density due to the number and diameter of dentinal tubules lead to differences in dentine microhardness at different locations.[19] Dentine microhardness is inversely related to tubule density.[39] During dentinogenesis, the odontoblasts move towards the centre of the dental papilla leading to higher tubular density on the pulpal surface of dentine than towards mantle dentine in mature teeth.[40] Accordingly, in pulpless immature teeth, as root dentinogenesis is halted, depending upon the stage of root development, the thin root wall has incompletely developed peritubular and intertubular dentine with higher tubular density towards the cementum. When mature teeth are enlarged to simulate immature teeth, the outer part of their roots would demonstrate lower tubular density and more intertubular dentine. Teeth for these experiments may therefore mimic immature teeth in shape but not in tissue composition or physical properties.

In the present review, simulated teeth where the apical 2–3 mm was resected, and an apical foramen constructed of greater than 1.2 mm, were used, as they have some resemblance to immature teeth. Dimensions differed in the four experiments examined; it is not possible to produce standardised *in vitro* models of incompletely developed anterior teeth.[34–37] Cvek (1992) classified open apex teeth into four groups according to level of root maturity (less than half, half, 2/3rd and more than 2/3rd).[10] The apical foramen enlargements of the simulated teeth in the experiments reviewed were well within the range of the clinical scenario.

It is common practice to use animal teeth to study selected properties of dentitions. Human and bovine tooth enamel and superficial dentine are comparable in adhesion tests.[41] Schilke et al. (1999) found no difference in human permanent dentine and bovine coronal dentine (both buccal and pulpal) when testing shear bond strength of dentine adhesives and hybrid composite restorative materials.[42] Similarly, Saleh and Taymour (2003) considered bovine enamel a reliable substitute to human material for composite resin adhesion.[43] Both types of dentine have similar tensile strength and modulus of elasticity.[44]

PDL space simulation has been considered significant in the outcomes of *in vitro* experiments. Polyether impression material, polystyrene resins or self-curing rubber have been used to simulate a PDL space.[37,45,46] It could be speculated that, in the experiments by Stuart et al. (2006) and Wilkinson et al. (2007), the distinct but statistically insignificant difference in the mean load for root fracture with flowable CR, Resilon and GP can be attributed to presence or absence of a simulated PDL space.[35,36]

4.2. *Root reinforcement materials*

Several case reports have shown CR and MTA as effective root reinforcement materials.[47–49]

The traditional apexification procedure, using calcium hydroxide, usually takes 6–9 months.[50,51] Approximately two-thirds of all cervical root fractures observed by Cvek (1992) in a retrospective study were during the long-term calcium hydroxide dressing stage prior to root filling.[10] More recently, studies have shown the adverse effects of long-term calcium hydroxide on the physical properties of root dentine.[20,52] Rabie et al. (1986) successfully used CR to reinforce the weak root and crown of an immature maxillary incisor during an apexification procedure.[49] After placement of CR in the canal, a plastic post was passed through the material to maintain patency with the apex in order to refresh calcium hydroxide dressings and for root filling with GP. Andreasen et al. have recommended placing calcium hydroxide for a maximum of 4 weeks followed by filling the canal with MTA.[53] This reduces the duration of the high fracture risk phase of calcium hydroxide dressing and allows much earlier placement of strength enhancing restorative materials.

In mature anterior teeth, restoring the access cavity after root filling with CR and extending this material into the root canal resulted in higher fracture strength of teeth compared to GP or a metal post in the canal. Bonding of CR in the access cavity and root canal displayed superior strength than restoring the access cavity alone. Trope et al. (1985) speculated that CR penetrates deeper into the etched dentinal tubules of the root canal walls and 'holds the tooth together', increasing its resistance to fracture.[54] Flowable or hybrid CR restorations in root canal and access cavity provided superior fracture resistance in human and sheep immature tooth models.[34–36]

In experiments with simulated weak tooth models, CR has been shown to improve the strength of the root.[32,33] Some studies have suggested use of a light transmitting post for greater polymerisation of CR deep into the root canals. Further reinforcement of the root was recommended, with a metal post in the channel formed after removal of the light transmitting curing post.[27–30] No additional strengthening effects were observed with fibre reinforcement of a CR restoration.[31] Goldberg et al. (2002) demonstrated significant strengthening of weak roots with resin glass ionomer cement and light transmitting curing posts.[28]

In an *in vitro* experiment, Resilon filled teeth showed higher mean fracture load than GP filled teeth under vertical loading forces.[55] The experiments conclude that GP and Resilon failed to adequately reinforce simulated immature teeth under oblique forces.[34–37] The fracture strength of roots filled with these materials was not significantly different to empty canals.[35,36] GP and Resilon have demonstrated very low cohesive strength and elastic modulus for satisfactory reinforcement of roots of endodontically treated teeth.[56]

In an *in vitro* study, Andreasen et al. demonstrated that, after 100 days, immature sheep teeth filled with MTA displayed higher fracture strength than those filled with calcium hydroxide, though sample sizes were small, and the differences were not statistically significant.[53] In the paper by Bortoluzzi et al. concerning MTA reinforcement of the root canal, the concept of placing a metal post in the mass of MTA was adopted from the principles of civil engineering where beams and pillars are supported and strengthened by a metallic framework embedded in Portland cement.[37] Portland cement and MTA have similar structural properties and physicochemical behaviour.[57] Roots reinforced with a metallic post/MTA had fracture strengths almost four times higher than those of the empty root canals and twice that of the roots with an apical MTA plug and a backfill of GP.[37]

4.3. *Post placement in immature teeth*

Posts may be used in root filled teeth to retain coronal restorations. There is consensus that posts do not strengthen the root, but change the stress distribution along the root and put the tooth at higher risk of fracture.[58–60] Finite element analysis suggest that, if a post is to be used, that a long, thin fibre post should be chosen to reduce the stresses that cause tooth fracture.[61] Case reports have discussed the use of posts to improve fracture resistance following root filling in addition to retaining coronal restorations.[47,48]

In experiments with mature teeth with cast post/cores, prefabricated stainless steel posts and carbon fibre reinforced composite resin posts all displayed similar fracture resistance,[62] but quartz reinforced fibre posts offered significantly higher fracture strength compared to zirconia or titanium posts.[63] Fibre reinforced posts display a more favourable mode of failure to metal posts.[63,64] In contrast, in an *in vitro* model where excessively prepared large canals of maxillary incisors were used, cast post and cores cemented with autopolymerising resin cement further reduced the fracture resistance of the teeth. When titanium posts were cemented with resin cement in the CR-reinforced root canals, the strength of the teeth improved significantly.[29] Another study with weak bovine incisor roots reinforced with zirconium fibre posts cemented with a dual cure resin cement demonstrated fracture strength similar to CR reinforcement of root canals, and approximately twice that of control teeth.[27] Superior retention of posts has been observed with dual cure resin luting cements.[65]

The feasibility of improving the physical properties of weak immature anterior teeth using posts remains unclear. Further laboratory-based and clinical evaluations are necessary.

4.4. *Complications following post-endodontic restorations*

Cervical root fractures of immature anterior teeth are challenging injuries with guarded prognosis. There are difficulties in accessing the deep sub-gingival or sub-crestal margins by surgical 'crown lengthening' procedures or extruding teeth using orthodontic forces. The use of a post with luting agents in the root canal has been suggested to stabilise fractured fragments.[48,49] CR or MTA materials in the root canal may make future endodontic retreatment difficult, while titanium, ceramic and zirconium posts are problematic to retrieve. Microleakage around CR restorations in access cavities could be a potential problem. A study to assess microleakage around these restorations noted that chemically cured CR material featured less dye penetration than photopolymerising CR restorations.[66]

5. Conclusions

Pulpless immature anterior teeth have a higher susceptibility to cervical root fracture.[10] Post-endodontic restorations may have great significance in preventing root fracture in these thin walled and weak teeth. The *in vitro* studies reviewed agree that various CR restorations of crowns and their extension into the root canal substantially enhance the strength of MTA-filled immature teeth. Reducing the amount of coronal root canal filling and replacing it with CR should have the secondary benefit of reducing coronal leakage, thereby contributing to endodontic success.[22]

Metal posts supported by MTA improved the fracture resistance of simulated immature anterior teeth in an *in vitro* experiment.[37] The role of metal and tooth-coloured posts and luting agents of various types in reinforcing root filled immature anterior teeth remains unclear. Further laboratory-based research using a standardised immature tooth model, together with long-term clinical data is required.

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