In Vitro Fracture Resistance of Immature Permanent Incisors after MTA Apexification

Thesis

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Abstract

Objective: The purpose of this study was to evaluate root strengthening abilities of intracanal flowable composite, glass ionomer cement and conventional gutta percha obturation after apexification with mineral trioxide aggregate (MTA).

Methods: One hundred extracted human incisors were obtained in this in vitro analysis. Teeth were radiographed by a standardized operator to ensure no fractures or anatomical abnormalities were present. Two millimeters of the apical tip of each root were resected to remove any apical deltas and standardize the canal exit to the center of the root. Coronal access was made with #330 bur and an Endo-Z bur. A divergent open apex was prepared by instrumenting the canals with a #6 gates-glidden bur until this bur passed freely out the apex. Root diameter was measured by a standardized operator with digital calipers (General Tools, New York, NY, USA) in both a buccal-lingual and mesial-distal dimension. Teeth were stratified into similar dimension groups to identify and eliminate outliers of original tooth dimensions. Teeth of all dimension groups were included in all experimental and control groups. Working length was determined visually with a stainless steel hand file flush with the apical opening. A 4mm apical barrier of gray MTA was placed in each tooth (except for the negative control group). The teeth were mounted in a block of Jet acrylic (Lang Dental Wheeling, IL, USA) and subjected to fracture resistance using an Instron Universal Testing Machine.
Results: No statistically significant differences (P > .05) were found between any of the control or experimental groups.

Conclusions: It seems clear that with the current protocol, fracture resistance was minimally affected by preparation or restoration. We cannot conclude as to the reinforcing ability of the materials tested. The current protocol will need to be modified in future research to yield a statistically significant difference between the control groups before any conclusions about the experimental groups can be made.
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**Introduction**

Dental trauma to the anterior dentition is common in the young adolescent patient 1. Prevalence estimates suggest that up to one-half of children, ages 5-18, will incur some type of dental injury during their school years. 2 Wilson, et al (1997) also showed that the majority of dental trauma occurred before the age of 12 (86%). Trauma leading to complicated crown fractures and/or pulp necrosis can be a significant problem in this population due to incomplete root development commonly found in these teeth. An incompletely formed tooth is left with thin dentin walls highly susceptible to fracture 3, 4. These thin-walled teeth also have a higher incidence of cervical root fracture which reduces the long-term restorative and overall prognosis of the tooth 3, 4. Historically, treatment of these teeth has been limited to extraction or heroic endodontics. In the past, an effective treatment has been apexification with long-term calcium hydroxide treatment followed by obturation with gutta percha. This treatment has been demonstrated repeatedly in the literature to be successful at resolving periapical lesions. However, this therapy requires many appointments and can take over 1 year to treat 5. In spite of the documented success of this treatment, calcium hydroxide apexification can still leave the tooth weakened with thin dentinal walls. Furthermore, there is evidence that this treatment allows the remaining tooth structure to be prone to fracture 6. With the advent of mineral trioxide aggregate (MTA), apexification could be completed predictably in
one appointment. MTA has been advocated as a replacement for calcium hydroxide in apexification treatment. There has been concern that MTA may replicate the root weakening seen with calcium hydroxide due to a similarly alkaline pH. In a 2008 study looking at fracture resistance and histological finding in immature teeth treated with MTA, the roots of immature ovine incisors were not weakened. The teeth were filled with either calcium hydroxide or MTA from the apical end, so there was no access preparation. Teeth from each group, including an unrestored control, were fractured at 2 weeks, 2 months and 1 year. MTA demonstrated the highest fracture resistance at 1 year. Histological analysis revealed a protein expression pattern unique to the MTA group that the authors hypothesized prevented destruction of the collagen matrix in the root dentin, thereby preventing loss of physical properties.

Following an apical MTA plug, these teeth are typically obturated with gutta percha. The gutta percha does not reinforce the tooth, still resulting in a weak root prone to fracture. Recent developments in the management of traumatized, immature teeth, specifically a revascularization protocol, may soon become the standard of care for these cases, providing a possibility of physiologically mediated continued root formation. However, with this therapy still in its nascent stage of development, the treating dentist is still left with a dilemma of managing these challenging cases.

Surgical removal of tooth structure weakens the remaining tooth. Restorative dentistry removes coronal tooth structure, and weakens cusps and marginal ridges, increasing the likelihood of fracture as compared to a sound tooth. Arunpraditkul, et al (2009) compared the fracture resistance of coronal tooth structure with 4 walls versus 3 walls. Their results demonstrated a mean fracture resistance of 1190 kg for 4 walls versus
a mean of 578 kg, 786 kg, and 785 kg for three walls (buccal, lingual and mesial wall missing, respectively). There was no significant difference between the 3-walled groups, but the 4-walled group was significantly different than the 3-wall groups (p < 0.05). Bader et al (2004) in their case control study on risk indicators for posterior tooth fracture demonstrated that a 10 percent increase in the relative volume of the restoration yielded a six-fold increase in likelihood of cusp fracture. Their conclusion was dentinal support is the most important factor in reducing incidence of cusp fracture. Root canal therapy removes radicular tooth structure leaving the root more susceptible to fracture. Root fracture is the same concern that clinicians have with the immature tooth, but the clinical problem is amplified by the fact that many immature teeth have considerably less radicular tooth structure than a sound tooth that has undergone root canal therapy. In 1992, Sornkul and Stannard, in their study evaluating the strength of roots before and after endodontic treatment demonstrated that preparation of the canal significantly weakened the root. Their experiment tested composite resin cores and two types of posts with respect to root strengthening ability. They concluded that three factors were important for preventing future root fracture: a) the amount of remaining tooth structure, b) the strength of the post/core material, and c) the bonding between the core material and dentin. The amount of remaining tooth structure was singled out as the most important factor of the three.

There has been recent research into alternative obturating materials for these teeth that might increase their resistance to fracture, while mitigating some of the problems of a cast post. Cauwels, et al (2010) proposed an in vitro model for evaluating different obturating materials and their ability to strengthen a standardized cylinder made of
bovine femur with a simulated canal. They acknowledge the limitations of the in vitro nature of the study, but they also contend that the standardized nature of the design more accurately test the properties of the intracanal material by eliminating many of the variables encountered in testing natural teeth. They found that all obturating materials tested, including gutta percha, MTA and calcium bone phosphate cement, produced significant increase in fracture resistance as compared to the empty canal specimens. Ungor, et al (2006) in their study comparing push-out bond strengths of several obturating material and sealer combinations suggested that materials that adhere either chemically or micromechanically to the root canal dentin surface will strengthen the remaining tooth structure. Wu, et al (2007) in their study on the effectiveness and dentin bond strengths of two material for reinforcing thin walled roots evaluated the bond strength to root canal dentin and reinforcing ability of a dual cure resin based composite and a glass ionomer cement. Twenty-one teeth were decoronated and endodontically treated. The cervical area was prepared to leave a 1mm dentin wall thickness. The control group was restored with a cast nickel-chromium post cemented with resin luting cement. The first test group was restored with BIS-CORE, a dual cure composite resin, and then a post hole was prepared in the composite material leaving a 1mm rim of composite resin around the post preparation. A smaller nickel-chromium post was fabricated and cemented as in the control group. The second test group was restored with Chemfil Superior, a glass ionomer cement, and then a post hole was prepared as in the first test group, followed by a smaller nickel-chromium post. The roots were covered in a thin layer of silicone rubber to simulate a periodontal ligament, and then mounted in a cube of die stone. Fracture resistance was measured by loading the teeth at 135 degrees to the
lingual surface, to simulate occlusion between maxillary and mandibular incisors, until the point of fracture using an Instron universal testing machine. The composite resin collar/metal post group showed significantly higher fracture resistance. The microtensile bond strength of the two materials to root canal dentin was also evaluated. The dual cure composite resin showed significantly higher bond strength to root canal dentin compared to the glass ionomer cement with RBC averaging 20 MPa and GIC averaging 12 MPa (P=0.002). These findings, specifically higher bond strength and fracture resistance with the same material, are in agreement with Sornkul and Stannard (1992) who concluded that three factors were important for preventing future root fracture: a) the amount of remaining tooth structure, b) the strength of the post/core material, and c) the bonding between the core material and dentin.

Carvalho, et al (2005) in their study on structural resistance in immature teeth using root reinforcements aimed to evaluate the ability of light-cured composite resin and zirconia fiber posts to strengthen the roots of simulated immature teeth, in vitro. Bovine incisors were length standardized and then the canals were instrumented to the point that the root wall was 2mm thick, simulating immature human incisors. The canals were restored with light-cured composite resin utilizing a translucent curing post, or a zirconia fiber post cemented with resin cement. The roots were dipped in silicone adhesive to simulate a PDL and then embedded in an autopolymerizing acrylic resin leaving 5mm of tooth structure exposed. The teeth were tested with an Instron universal testing machine, and the load at fracture was recorded. This group found both reinforcing techniques to be effective at strengthening the root to near values for unprepared teeth. Teixeira, et al (2004) in their study on fracture resistance of endodontically treated roots obturated with
the Resilon versus gutta percha found that Resilon significantly reinforced the
decoronated root samples when subjected to a vertical loading force from an Instron
of a resin glass ionomer in the restoration of immature roots in vitro evaluated Vitremer
(a dual-cure glass ionomer product) versus no restoration with respect to resistance to
fracture from vertical load. The roots were simulated to be immature using a #3
Elargisseur bur (1.65mm diam) in the cervical area. The Vitremer group was restored
using a Centrix syringe to place the material and a translucent curing post to facilitate
light curing in the apical areas. The teeth were decoronated and subjected to a vertical
load until fracture was achieved using an Instron universal testing machine. The Vitremer
group showed significantly higher mean fracture values than the unrestored group.
resistance with intracanal composite resin versus gutta percha found that intracanal
autopolymerizing flowable composite significantly increased fracture resistance. The
canal was widened until a #8 Profile (1.24mm diameter) passed out the apex. An
apexification was simulated with MTA and the canal was then restored with the test
material. The teeth were loaded until the point of fracture with an Instron universal
simulated immature teeth reinforced with gutta percha, resilon, autopolymerizing
flowable composite or autopolymerizing hybrid composite found that of all the groups
only the hybrid composite group significantly increased the fracture resistance compared
to controls. The immaturity of the teeth was simulated by widening the canal until a size
120 file freely passed out the apex. The teeth were mounted in acrylic and subjected to a
load perpendicular to the facial surface until the point of fracture with an Instron universal testing machine.\(^9\)

Ribiero, *et al.* (2008) in their study evaluating the influence of different endodontic filling materials on root fracture susceptibility determined that core materials, namely gutta percha and resilon, were not able to increase the root fracture resistance in canals subjected to chemomechanical preparation.\(^10\) Katezbah, *et al.* (1998) in their study on strengthening immature teeth during and after apexification evaluated the ability of an internal resin bonding technique to reinforce the cervical area of immature incisors undergoing calcium hydroxide apexification. One hundred human maxillary central incisors were endodontically treated: the cervical area was further prepared to simulate the thin root walls of an immature tooth. The negative control had no restoration in the cervical area, and the positive control was unprepared in the cervical area. All test groups were restored with hybrid composite in the cervical area by utilizing a curing post to leave a channel through which the underlying calcium hydroxide could be accessed for future apexification appointments. One test group used a translucent curing post to ensure complete cure in the deepest portion of the composite. The second test group used an opaque post, to evaluate the need for a translucent post at the depth of the cervical area. The third test group was restored as the first, and then a metal post was cemented in the remaining channel with autopolymerizing resin cement. The teeth were subjected to a force applied perpendicular to the long axis of the tooth until fracture using an Instron universal testing machine. None of the experimental groups were significantly stronger than the positive control, but among the experimental groups, the metal post group was significantly stronger than the group using the translucent curing post.\(^21\)
Kazandag, et al (2009) evaluated the fracture resistance of roots using different canal filling systems evaluated extracted human teeth. After crown removal, the canals were prepared and obturated with 2 types of gutta percha and a resin monoblock system. These teeth were subjected to a vertical load with an Instron universal testing machine. The rationale for a vertical load was to evaluate whether or not a resin system that claims to bond to the canal wall would be able to withstand a splitting force. The group concluded that none of the tested obturating materials were able to reinforce the root against a vertical load22. A 2006 study by Stuart et al examined reinforcing immature roots with gutta percha, resilon, and autopolymerizing flowable composite. No significant differences between any of the treatment groups were noted. Immature root development was simulated by passing a #5 peeso reamer (1.5mm diam) out the apex. The teeth were then restored, mounted in acrylic and fractured with an Instron universal testing machine loading the tooth at a 45 degree angle to the lingual surface. They further suggested that canal wall reinforcement of teeth with a canal diameter of 1.5mm or less may not be necessary23. Kivanc, et al (2009) in their study on fracture resistance of thin walled roots restored with different post systems evaluated several resin composite posts versus cast posts. These materials were evaluated at differing remaining root wall thicknesses of 2mm, 1.5mm and 1mm. The cast post was the only system found to be significantly different from the rest of the test groups. Additionally, differences were noted with each material with respect to remaining root wall thickness24. This finding is in agreement with several previous studies. Pene, et al (2001) in their study on the evaluation of fiber composite laminate in the restoration of immature, nonvital maxillary central incisors compared no obturation with obturation with composite resin and
composite resin with reinforcing fibers. Extracted human central incisors were mounted in acrylic resin and simulated to be immature by enlarging the canal with gates glidden drills, and then further enlarged to a final canal diameter of 3mm with an engineering twist drill. The teeth were restored and subjected to a 130 degree lingual-labial load with an Instron universal testing machine to simulate the contact between maxillary and mandibular incisors. Significant differences were found between the groups with the highest mean fracture strengths coming from the composite only group.\textsuperscript{25}

Resin composites show the greatest promise for reinforcing immature, apexified teeth due to their superior physical properties. Current studies aim to find a material that will increase the fracture resistance of these teeth and improve long-term prognosis. While many materials and methods have already been explored, no group has yet investigated the \textit{in vitro} root strengthening ability of flowable composite resin and glass ionomer cement versus gutta percha after a simulated MTA apexification.

**Objectives**

The objective of the present study was to evaluate the root strengthening ability of intracanal flowable composite resin, both auto- and light-polymerized, as well as glass ionomer cement compared to the conventional gutta percha obturation after apexification with MTA. The null hypothesis is that there is no difference in the root-strengthening ability of the groups, composite, glass ionomer cement and gutta percha.
Methods

The material consisted of 100 non-curious extracted human maxillary central and lateral incisors. The teeth were examined with 2.5x loupes and those with microcracks were excluded. Pre-operative bucco-lingual and mesio-distal radiographs were made to rule out aberrant anatomical morphology and fractures. Teeth with class III restorations at least 3mm away from the cervical area were included. All teeth with class V restorations or severe cervical abrasions affecting the root area at or below the CEJ were excluded. The teeth were disinfected with 5% sodium hypochlorite for 2 hours, and then stored in distilled water until testing.

All teeth were measured in a bucco-lingual and a mesio-distal direction just below the CEJ with a digital dial caliper (General Tools, New York, NY, USA). The bucco-lingual and mesio-distal dimensions were averaged for each tooth to yield a root diameter. This number was halved to obtain an estimated radius for each tooth. Root area just below the CEJ was then calculated for each tooth using the formula $\text{Area} = \pi r^2$. Teeth were distributed among experimental and control groups to yield no statistically significant difference between the mean root area of each group.

Two millimeters of the apical tip of each root was resected to remove any apical deltas and to standardize the canal exit to the center of the root. Coronal access was made
with a #330 bur and an Endo-Z bur (Dentsply, Tulsa, OK). All teeth had a notch prepared in the incisal edge to allow absolute straight line access. A divergent open apex was prepared by instrumenting the canals with a #6 gates-glidden bur (1.4mm diameter) (Maillefer, Tulsa, OK, USA) until this bur passed freely out the apex. The diameter of the gates-glidden bur was determined by direct measurement with a digital dial caliper (General Tools, New York, NY, USA). Working length was determined visually, with 2.5x loupes, using stainless steel hand files flush with the apical opening. A 4mm apical barrier of gray MTA (ProRoot, Dentsply, Tulsa Dental) was placed in each tooth (except for the negative control group) using an endodontic microscope (Global, MO, USA) and endodontic pluggers. Bucco-lingual and mesio-distal post treatment radiographs were made to ensure uniformity of treatment.

Group 1: Negative Control (10 specimens): The teeth in this group received apical resection, and had no canal preparation.

Group 2: Positive Control (10 specimens): The teeth in this group received apical resection, canal preparation as described above, no obturation or apical barrier, and the access was restored with resin composite, (AELITE All-Purpose Body, Bisco).

Group 3: Experimental—Gutta Percha (GP) (20 specimens): The teeth in this group received apical resection, canal preparation as described above, a 4mm apical barrier of MTA (ProRoot, Dentsply, Tulsa Dental) placed with the microscope as described above, obturation with gutta percha and AH Plus sealer (Dentsply, Tulsa, OK)
via cold lateral condensation, and the access was restored with resin composite, (AELITE All-Purpose Body, Bisco).

Group 4: Experimental—Self Cure Composite (SC): The teeth in this group received apical resection, canal preparation as described above, and a 4mm apical barrier of MTA (ProRoot, Dentsply, Tulsa Dental) placed with the microscope as described above. The teeth were etched with 37% phosphoric acid for 30 seconds and bonding agent (AllBond 2, Bisco) was applied per the manufacturer’s recommendations for self-cure applications. Paper points were used to aid in drying the canal between rinsing steps. The teeth were obturated with self-cure flowable composite (Bisfil 2B, Bisco) using an E/Z syringe and needle tubes (Centrix) to backfill the canals. The access was restored with hybrid resin composite, (AELITE All-Purpose Body, Bisco)

Group 5: Experimental—Light Cure Composite (LC): The teeth in this group received apical resection, canal preparation as described above, and a 4mm apical barrier of MTA (ProRoot, Dentsply, Tulsa Dental) placed with the microscope as described above. The teeth were etched with 37% phosphoric acid for 30 seconds and bonding agent (AllBond 2, Bisco) was applied per the manufacturer’s recommendations for light-cure applications. The teeth were obturated with light-cure flowable composite (Aeliteflo, Bisco) using an E/Z syringe and needle tubes (Centrix) to backfill the canals. A size 3 grooved translucent curing post (Luminex, Dentatus) was inserted into the uncured composite and then cured for 40 sec. The protruding post was resected. The access was restored with hybrid resin composite, (AELITE All-Purpose Body, Bisco).
Group 6: Experimental—Glass Ionomer Cement (GIC): The teeth in this group received apical resection, canal preparation as described above, and a 4mm apical barrier of MTA (ProRoot, Dentsply, Tulsa Dental) placed with the microscope as described above. The teeth were etched with 37% phosphoric acid for 10 seconds. Glass ionomer cement was mixed and applied per the manufacturer’s instructions. The teeth were obturated with glass ionomer cement (Ketac-Cem, 3M ESPE) using an E/Z syringe and needle tubes (Centrix) to backfill the canals. The access was restored with hybrid resin composite, (AELITE All-Purpose Body, Bisco).

The teeth were mounted in a cylindrical block of JET acrylic (Lang Dental IL, USA) using a plastic form (see fig 2-6). No attempt was made to simulate a PDL using a silicone adhesive as seen in similar studies, because this adhesive affected the retention of the teeth in the acrylic block during fracture testing in the pilot study. The specimens were mounted in an aluminum jig that securely held the acrylic block on the test table (see figs 7-9). The teeth were then subjected to a load directed at 90° to the facial surface of the tooth to simulate an impact injury to which these teeth are most susceptible. Fracture resistance was measured using an Instron Universal Testing Machine (Instron Corp, Canton, MA, USA) (see figs 10-11). A crosshead speed of 500 mm/min was used as this was the maximum velocity for the Instron machine. The teeth were fractured and the load at the point of complete cervical fracture was recorded in newtons. All specimens were retained in the acrylic resin block during loading. All specimens fracture just below the CEJ through the experimental material zone.
Results

Means were calculated for root area in each group before any preparations. Table 2 shows a one-way ANOVA confirming no differences were present in the mean root area at the CEJ of each group (p = 0.87). Table 3 presents the mean fracture resistance for each group and the results of a one-way ANOVA that determined there was no statistically significant difference between the mean fracture loads of the groups (p=0.44). Table 4 presents the results of a pair-wise Tukey-Kramer test. No significant differences were found between any of the group pairs, including the positive and negative control groups. No p-values in the pair-wise analysis approached significance.

Additional statistical analyses were carried out to determine if any significant findings were present. Outliers were thrown out and the data were re-analyzed. An outlier was defined as a value that was outside 2 standard deviations from the mean in any group. A one-way ANOVA run after removing the outliers still resulted in no statistical significance (p=0.39). The restored groups were pooled and a one-way ANOVA looking at restored teeth versus controls revealed no statistical significance (p=0.25). Lastly, the 2 composite resin groups were pooled and a one-way ANOVA analyzing composite versus gutta percha vs controls revealed no statistical significance (p=0.32).
**Discussion**

In the present study, we utilized an experimental model that simulated immature maxillary incisors to evaluate the root strengthening ability of intracanal flowable composite resin, both self and light cured, as well as glass ionomer cement compared to the conventional gutta percha obturation after apexification with MTA. 

*In vivo* studies to evaluate the current question are impossible due to obvious ethical reasons. Likewise obtaining large numbers of caries-free immature incisors for research is very difficult, if not impossible. We are limited to *in vitro* research that models the *in vivo* situation as closely as possible.

There is inherent variability when using biologic samples in controlled research. Efforts were made to minimize the effect this variability had on the results of the current study. Human maxillary incisors were selected because these are the teeth that most often present with the clinical problem in question. Gutmann, et al (1995) reported that in a survey of 434 cases of dental trauma, 82% of the teeth traumatized were maxillary incisors, 64% central, 15% laterals and 3% canines. Teeth in general vary in size in all dimension including length, diameter, taper. To control as best we could the variation in tooth size, the teeth were distributed into groups based on their measured and calculated root area at the level of the CEJ. Means for root area at the CEJ were calculated for each group before any preparations were made. The means for root area were found to not be
significantly different. We therefore assumed that tooth dimension would not have a significant effect on the final results.

Teeth also vary in substance. Mature dentin is a metabolically inactive tissue and therefore it is susceptible to age-related protein damage. Dentin changes as we age. The teeth of clinical concern to the present study are young teeth of patient ages 7-11 years old. The teeth obtained for the sample all came from adult patients or donors, many of whom were elderly. Brackett, et al (2008) in their study on the effect of subject age on microtensile bond strengths of a resin and resin-modified glass ionomer adhesive on tooth structure evaluated dentin from patients over 60 years of age compared with dentin from young patients. No significant differences in adhesion of resin or glass ionomer to dentin were found for aged versus young teeth. Elderrat et al (2007) evaluated age-related changes in the ac-impedance spectroscopy of normal human dentin and were able to demonstrate structural changes in human dentin related to age. Dentin from extracted 3rd molars from a group of 20 year old patients was compared with that from a group of 50 year old patients. They showed that there were significant differences in impedance between young and older dentin. This increase in impedance is a consequence of continuous deposition or peritubular dentin with age. Peritubular dentin is a more highly mineralized tissue with fewer collagen fibers than intertubular dentin. Over time, peritubular dentin forms around the tubules thickening them. These structural changes in the dentin that occur with time can have an effect on the physical properties of the overall tooth. Nazari, et al (2009) in their study on aging and the reduction in fracture toughness of human dentin evaluated resistance to fracture and crack extension in dentin obtained from extracted 3rd molars from young (18-35 year old) patients, and old patients (greater
than 55 years old). For the old dentin, the resistance to crack initiation, and fracture toughness were significantly less than those values obtained for young dentin \((p<0.0001)\). Knowing that there are such differences between young and aged dentin, care must be taken when extrapolating these results to the young teeth in the young patients that we see. There is still value in the present results. With every tooth coming from a mature adult, the effects of aging on the dentin in the sample teeth is minimized because every tooth is already aged. With all teeth of a similar age, the physical properties of the dentin in the sample teeth is controlled for and the current method would theoretically still measure the reinforcing effect of the experimental restorative materials.

A recently published study by Cauwels, et al (2010) utilized a new more standardized method for evaluating fracture resistance and reinforcement of immature roots. Standardized cylinders were cut out of bovine femurs. The height of the cylinders was \(10.5 \pm 0.1\text{mm}\). The diameter of the cylinders was \(7.0 \pm 0.1\text{mm}\). This diameter is similar in size to the average diameter measured in the current study which was 6.1mm. A central canal 3.5mm in diameter was drilled to obtain a test sample. Positive and negative controls included samples that were solid with no canal preparation and hollow with canal preparation, but no restoration, respectively. The experimental groups consisted of obturation with gutta percha (GP), both cold lateral and warm vertical condensation, MTA and calcium phosphate bone cement (CPBC). CPBC was tested because of its biocompatibility and its ability to promote hard tissue formation at the apex when used as a root end filling. Fracture resistance was evaluated by applying a vertical, splitting force using a Lloyds mechanical testing machine (similar to an Instron universal testing machine) until failure occurred. The maximum force the sample could withstand
before fracture was recorded. Restoration in general showed significant reinforcement of
the hollow samples (p < 0.001). Further, MTA and CPBC were not significantly different
from each other; however, they were both significantly better at reinforcing hollow
samples as compared to GP. The authors state that this model was developed to exclude
some of the factors that complicate studies using biologic samples14. The current method
was utilized to approximate as closely as possible the in vivo clinical situation. More
biologic variability has to be accounted for with the current method than with this
standardized bovine bone method.

The crosshead speed of the Instron universal testing machine is a user defined
input with a maximum value of 500mm/min. Many different speeds to evaluate fracture
resistance have been reported in the literature: 0.5mm/min31, 32, 1mm/min8, 10, 14, 17-19, 22, 24,
33, 34, 2mm/min16, 5mm/min9, 12, 20, 23, 25, 50mm/min21 and 500mm/min4. Carvalho, et al
(2005) suggested that a speed of 1mm/min simulated a compression force, while a higher
speed on the order of 300mm/min could simulate an impact17. In all of these studies the
speed of the head on the Instron machine was reported, but no rationale was given for
choosing the reported speed. The objective of the present study was to evaluate the root
strengthening ability of intracanal flowable composite resin, both self and light cured, as
well as glass ionomer cement compared to the conventional gutta percha obturation after
apexification with MTA. Further the crosshead speed of 500mm/min was chosen because
it was the maximum value available with the Instron universal testing machine and it
approximated a traumatic impact to the facial surface to which these immature teeth are
most susceptible.
Many different loading angles have been utilized in the literature to evaluate fracture resistance of different intracanal restorative materials. Several studies use a vertical load as a means to split the tooth to the long axis of the tooth, to the facial surface of the tooth, to the lingual surface of the tooth, to the lingual surface of the tooth. 130° was chosen in these studies because it simulates the average angle of contact between maxillary and mandibular incisors in class I occlusion. The other loading angles were reported but did not report any rationale for their use. The present study utilized a loading angle of 90° to the facial surface of the tooth to simulate a traumatic blow that an individual might experience.

Several other studies used a rubber or silicone adhesive applied in a thin film to simulate a periodontal ligament prior to mounting in a rigid block of material, either acrylic or die-stone. These studies claim that simulating the shock-absorbing capability of the natural periodontal ligament is necessary to approximate the in vivo situation. The authors that did not use a simulated periodontal ligament claimed that not doing so eliminated a variable as it is difficult to ensure a uniform thickness of adhesive material on each tooth and between subsequent teeth. The present investigation attempted to use a silicone adhesive in the pilot study, but 2 problems caused us to remove this step from the method. The first, it was not possible using our adhesive (GE, NC, USA) to reliably obtain a uniform film thickness on the tooth. Additionally, it was found that many of the teeth mounted with silicone adhesive were dislodged from their acrylic mounting instead of fracturing the tooth during fracture testing with the Instron universal testing machine.
The long-term calcium hydroxide apexification technique has a historical success rate of greater than 90%\textsuperscript{36}. This technique, however, has disadvantages. The treatment requires several appointments over an extended period of time, which can present a problem with patient compliance. There is also concern with increased fracture incidence after long-term calcium hydroxide treatment\textsuperscript{3,37}. In 1999, Torabinejad and Chivian\textsuperscript{38} published an article recommending the use of mineral trioxide aggregate (MTA) as an artificial apical barrier. MTA can be placed in one appointment\textsuperscript{39}, saving months of treatment time compared to calcium hydroxide apexification. MTA is biocompatible\textsuperscript{40}, and has the ability to interact with tissue fluids to induce the formation of hard tissue\textsuperscript{41}. MTA has since replaced long-term calcium hydroxide as the method of choice for apexification. Research has been conducted to evaluate the thickness of MTA needed as an apical barrier for adequate retention and apical seal. In a 2002 study, Hachmeister \textit{et al} evaluated the sealing ability and retention characteristics of mineral trioxide aggregate in a model of apexification\textsuperscript{42}. This study demonstrated that a 4mm barrier of MTA resisted displacement forces significantly better than only a 1mm barrier. This same study demonstrated that 92% of the 4mm MTA apical barriers had bacterial leakage by day 10. Lawley \textit{et al} (2004) evaluated ultrasonically placed MTA using the same model of apexification used by Hachmeister (2002)\textsuperscript{42}. A 4mm apical barrier of MTA in this study was found to have only 33% demonstrating bacterial leakage by day 90\textsuperscript{20}. This study concluded that the sealing ability of MTA is technique sensitive. The manufacturer of MTA recommends a 3 to 5-mm thickness of MTA be placed at the apex for the apexification procedure. The present study elected to use a 4mm barrier of MTA. This is in agreement with the current literature and manufacturer recommendations.
There is no consensus in the literature as to whether or not intra-canal composite, either auto- or light-polymerized has the ability to reinforce the tooth and prevent subsequent fracture. Many studies contend that this technique makes a significant difference in the fracture resistance of the teeth compared with gutta percha obturation\(^9\), \(^{17,20,21,25}\). Several other studies demonstrated no difference in fracture resistance regardless of intracanal restorative material\(^{23,32}\). The current study in agreement with the latter in that we found no significant differences in fracture resistance based on the intracanal restorative material with the protocol used. A 2006 study by Stuart et al examined reinforcing immature roots with gutta percha, resilon, and self-cure flowable composite. No significant differences between any of the treatment groups were noted. Immature root development was simulated by passing a #5 peeso reamer (1.5mm diam) out the apex. The teeth were then restored, mounted in acrylic and fractured with and Instron universal testing machine loading the tooth at a 45 degree angle to the lingual surface. They further suggested that canal wall reinforcement of teeth with a canal diameter of 1.5mm or less may not be necessary\(^{23}\). The current study used a size 6 gates-glidden drill which produced a canal diameter of 1.4mm. The results of the current study support the theory that reinforcement of teeth with canal diameters in this range may not be necessary.

Glass ionomer is an attractive material in this clinical scenario. Light-curing is difficult deep in the root canal of a tooth. Glass ionomer has a characteristic acid-base setting reaction that insures the complete setting of the material\(^{43}\). Glass ionomer is biocompatible and has a coefficient of thermal expansion similar to that of dentin\(^{44}\). Resin modified glass ionomer has been evaluated for fracture resistance\(^{19}\). Goldberg, et al
(2002) in their study on the reinforcing effect of a resin modified glass ionomer in the restoration of immature roots in vitro evaluated vitremer (a dual-cure glass ionomer product) versus no restoration with respect to resistance to fracture from vertical load. The vitremer group showed significantly higher mean fracture values than the unrestored group. No study has yet evaluated the ability of glass ionomer cement to increase the fracture resistance of an immature incisor. The current study elected to include glass ionomer cement because it has not yet been evaluated by others, is has a favorable setting reaction applicable to the clinical scenario, and it is an easy to handle material that any pediatric dentist would have on hand and be familiar with.

There has been at least one study that has evaluated the effect of varying canal diameter on fracture resistance\textsuperscript{24}. Kivanc, et al (2009) in their study on fracture resistance of thin walled roots restored with different post systems evaluated several resin composite posts versus cast posts. These materials were evaluated at differing remaining root wall thicknesses of 2mm, 1.5mm and 1mm. The cast post was the only system found to be significantly different from the rest of the test groups. Additionally, differences were noted with each material with respect to remaining root wall thickness. Across the groups the larger canals were less resistant than the narrow canals. These findings, specifically that as remaining dentin decreases, so does fracture resistance, are in agreement with Sornkul & Stannard (1992) who concluded that the most important factors for preventing future root fracture the amount of remaining tooth structure\textsuperscript{4}.

These results have clinical relevance. If remaining tooth structure is the most important factor to resisting future root fracture, then obviously, these teeth should be prepared as little as possible on the canal surface during treatment. Additionally, if a post-
op film of restorative treatment shows a bubble in the intracanal restorative material, then the clinician should proceed with caution. If the clinician expects that additional dentin removal would be necessary to remove the restorative material and re-restore the tooth, then the clinician should consider leaving the void, as additional preparation could further weaken the tooth. The subsequent restoration could give a more ideal radiographic appearance, but if that better radiographic appearance came at the cost of radicular dentin removal, then the tooth may actually be more prone to fracture with the “better” root filling. Some of the experimental root filling procedures used in this study are very technique sensitive compared to traditional gutta percha obturation. The results of this study lead this author to conclude that at a canal diameter of 1.4mm, it is not necessary to alter the conventional treatment approach of gutta perch obturation in an attempt to reinforce the root.

The most striking result to this author is the fact that there was no statistically significant difference between the positive and negative controls. This demonstrates that the preparation protocol used in this study did not weaken the tooth appreciable. This finding makes the different restorative materials impossible to compare to one another. A topic of future research in this area should include further investigation into the canal diameter at which weakening of the root becomes statistically significant. Once this diameter, or related root wall thickness, is established research into different restorative materials for restoring weakened immature incisors would be more meaningful. In addition, future research could include sectioning samples before and after fracture load testing to evaluate possible porosities in the obturating material, as well as bonding of the obturating material to the canal walls.
Conclusions

1) The current protocol demonstrated no statistically significant differences between any controls or experimental groups with respect to fracture resistance.

2) At a canal diameter of 1.4mm or less, it is unnecessary to restore these teeth with any new obturating methods.
Appendices
Appendix A – Tables
<table>
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**Table 1-Control and Experimental Groups**
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<th>Group</th>
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Table 2 – One-way ANOVA for Mean Root Area at the CEJ

p=0.87
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Table 3 – One-way ANOVA for Mean Load at Fracture
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Table 4 – Tukey Kramer Pair-wise analysis for Fracture Load

No significant differences between any of the group pairs
Figure 2: 3mm thick ethylene vinyl acetate (EVA) mouthguard material was used to create a mounting jig for the acrylic stent. A series of these mouthguard squares were fabricated with varying hole diameters to accommodate varying tooth sizes while still holding the tooth firmly at the CEJ for mounting.

Figure 3: A view from the underside of the mouthguard sheet. The tooth is held firmly with the inferior surface of the mouthguard sheet flush with the CEJ. The MTA can be seen at the apex of the tooth.
Figure 4: The jig was filled with JET acrylic and the root of the tooth, securely held in the mouthguard material, was placed into the acrylic before its initial set. Enough acrylic was used to ensure some expression of excess between the jig and the mouthguard material to avoid a liquid meniscus at the interface.

Figure 5: Facial view of a tooth in its final acrylic block. Note the acrylic is flush with the CEJ.

Figure 6: Lateral view of the acrylic mounting. The tooth was centered in the acrylic block.

Figure 7: The acrylic block was secured in this aluminum mounting for testing on the Instron machine.
Figure 8: The aluminum mounting from above

Figure 9: Lateral view of the aluminum mounting.

Figure 10: The aluminum mounting was placed on the test table of the Instron machine. The test fixture pictured was used to apply a shearing force at the CEJ. This produced a reliable fracture through the test material just below the CEJ.

Figure 11: Catastrophic failure of the tooth through the test material. The pictured tooth was restored with Gutta Percha.
References