A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots

William A. Saupe*/Alan H. Gluskin**/Ryle A. Radke, Jr***

Abstract
The intraradicular reinforcement of structurally compromised roots has been advocated for endodontically treated teeth with thin remaining walls. The purpose of this in vitro study was to investigate the validity of intraradicular reinforcement. After the crowns were removed, forty structurally weakened central incisors were divided into two main groups for morphologic dowel rehabilitation or resin reinforcement and dowel rehabilitation. Within both these groupings, half the specimens were ferruled to assess the effects of a ferrule on fracture resistance. All dowels were cemented with resin cements. The resistance to a simulated masticatory load of a resin-reinforced post and core system was significantly greater than that of a morphologic post and core procedure. When a bonded resin reinforcement and dowel cementation was used on structurally weakened roots, there was no statistically significant difference between post and core restorations that used a ferrule and those without a ferrule. (Quintessence Int 1996;27:483-491.)

Clinical relevance
The advent of predictable resin composite bonding and reinforcement through the use of a smooth, light-transilluminating post has facilitated the intraradicular restoration of endodontically treated, thin-walled teeth and improved their structural resistance to fracture over that provided by conventional morphologic dowel restoration.

Introduction
The structural rehabilitation of a pulpless tooth is critically important to ensure a successful restorative outcome following endodontic treatment. A dowel and core is often indicated for the retention and reinforcement of the final restoration. The clinical situation is significantly more challenging if the root has extensive structural damage or exhibits immature development or if the canal has been cariously involved, overinstrumented, or previously restored with a too-large dowel and core. The residual structure that remains is a thin root wall that can compromise the prognosis for a long-term successful restoration of the tooth.

A number of guidelines have been suggested for restoring endodontically treated teeth, and they are supported by research findings, literature reviews, and retrospective clinical studies. The guidelines aid the practitioner in choosing which dowel and core system will be used to retain the final restoration in endodontically treated teeth. Traditionally, two dowel and core systems with different design characteristics have been recommended. In the first system, the cast dowel and core closely reproduces the morphology of the root canal space. In addition, a post can be prefabricated to provide a standardized length and cross section. The retention and resistance to displacement under masticatory loads of the prefabricated dowel system are dependent on a combination of canal preparation, luting agents, and surface configurations.
cally, the prognosis for restored thin-walled teeth was considered guarded.\textsuperscript{1}

The second system incorporates the use of adhesive materials and techniques for the intraradicular reinforcement of roots with thin walls, taking advantage of advances in restorative technologies. Extremely favorable clinical results with resin reinforcement and dowel and cores in structurally weakened teeth have been reported by some clinicians.\textsuperscript{7,8}

The intraradicular reinforcement of compromised root structure derives from resin bonding techniques used in enamel and dentinal bonding of compromised tooth structure.\textsuperscript{9,10} Here, the internal dimension of remaining root structure is reinforced with a resin bonded to dentin. The resin composite increases the diametral thickness of the root as measured from the external surface to the dowel interface within the reinforced root canal space. In addition to increasing internal thickness, the composite material lessens the likelihood that the metal post will show through a thin root wall to darken the overlying gingival tissues.\textsuperscript{11}

The rationale for the use of dentin-bonded resin composite for intraradicular rehabilitation is well established.\textsuperscript{9,10} The apparently favorable clinical performance in bonding,\textsuperscript{12} tensile,\textsuperscript{13} and shearing behavior\textsuperscript{14} of composite to dentin bodes well for its excellent potential to clinically reinforce thin-walled roots.\textsuperscript{7,8,11} However, studies under controlled laboratory conditions that simulate masticatory loading have been lacking.

The purpose of this in vitro study was to investigate the validity of clinical reports citing the potential of intraradicular reinforcement. The behavior of two dynamically different dowel and core systems cemented by a similar resin bonding system were studied in endodontically treated teeth with structurally compromised root walls. The restorative systems involved (1) the use of a morphologic cast dowel and core, cemented with a bonded resin cement and (2) the intraradicular reinforcement of the root with bonded resin followed by cementation of a cast dowel and core with a bonded resin cement. In addition, the variable of use of a ferrule was investigated for any significance to the final restoration’s resistance to fracture.

Method and materials
Forty extracted, intact maxillary central incisors were used in this study. Teeth were selected for similarity in size, shape, and root anatomy. The teeth were transilluminated with fiberoptic light to ensure absence of caries, surface cracks, and fractures and radiographically examined to confirm similarity in internal root diametral thickness and canal configuration.

Canal preparation
The crowns of the selected teeth were reduced perpendicular to the root axis, leaving 1.00 to 2.00 mm above the cementoenamel junction (CEJ). The root canal of each tooth was instrumented with a conventional stepback technique to an International Standardization Organization (ISO) file size of 35 at the apical constriction. The canals were irrigated with sodium hypochlorite solution (2.5%) throughout preparation and dried with paper points. Each canal was obturated by lateral condensation of gutta-percha points against an ISO 35 primary gutta-percha cone. AH26 (DeTrey/Dentsply) root canal cement, which contains no eugenol, was used as the sealer. Gutta-percha was then removed from each canal until 4 mm of material remained at the apex.

To simulate extensive clinical structural damage, the canal space of each root was further prepared by routing out the internal dentin, leaving testing specimens with 8.00 mm of dowel space length and a residual dentinal wall thickness of 0.50 mm to 0.75 mm at the CEJ. The buccal aspect of each residual root at 2.50 and 5.00 mm below the occlusal surface was measured for uniformity in thickness (0.50 to 0.75 mm) among the specimens. A No. 4 Classic Post System reamer (Dentatus USA) was then used to produce a positive seat, centered in the apical 2.00 mm of each 8.00-mm dowel space (Fig 1).

The 40 specimens were randomly divided into two main groups of 20 teeth each. Each main grouping of teeth was further subdivided into two groups of 10 teeth. Ten specimens in each main group were restored with either a morphologic cast dowel and core or intraradicular resin reinforcement followed by cementation of a cast dowel and core. All restorations were cemented with Enforce (Caulk/Dentsply), a self-curing resin crown-and-bridge cement.

A 2.00-mm ferruled collar with 3 degrees of taper on the root wall was prepared on 10 morphologic and 10 resin-reinforced specimens:

1. Group A: morphologic dowel and core (nonferruled)
2. Group B: resin-reinforced root and dowel and core (nonferruled)
3. Group C: morphologic dowel and core (ferruled)
4. Group D: resin-reinforced root and dowel and core (ferruled)
Intraradicular restoration

Morphologic group (Figs 2a and 2b)
A custom (morphologic) dowel and core was used as a variable because of its wide acceptance as a means of restoring thin-walled, endodontically treated teeth. Twenty specimens were restored with a cast dowel and core constructed from patterns made with the LXG (Dentatus USA) castable resin gel and the Luminex No. 4 grooved plastic post. Each casting was centered in the apical 2.00 mm of the dowel space. The core portion was fashioned with Forms-To-Fit (Dentatus USA) by transmitting light through the Luminex Smooth Light Transilluminating Post (SLTP) (Dentatus USA) to polymerize the resin gel material for 60 seconds. The patterns were made to have intimate
The internal form of the root. The lingual aspect of each core had an indentation at 60 degrees to the root axis. Specimens with the ferrule were restored by extending the core material to the prepared occlusal margin of the exposed root surface.

Resin-reinforced group (Figs 3a and 3b)
The root canal spaces of 20 specimens were prepared by etching the surface with 32% phosphoric acid for 15 seconds followed by rinsing with water for 30 seconds and air drying. Both Pro Bond primer and adhesive (Caulk/Dentsply) were placed according to manufacturer's directions. Visible light-cured TPH composite (Caulk/Dentsply) was injected into the canal space. The SLTP No. 4 was inserted and centered in the dowel space, and the resin was allowed to compact around it. The resin was light cured by transmitting light through the SLTP pattern for 1 minute and another 20 seconds following the removal of the pattern. The dowel space was refined with a No. 4 post system reamer (Dentatus).

The specimens were similarly restored with castings constructed from light-cured patterns made with the LXG castable resin gel, a No. 4 Luminex grooved plastic post, and core portions fabricated with castable resin gel molded by Forms-To-Fit shells. The coronal aspect of the post space was slightly flared to allow a smoother transition from post to core in the casting. On the core, a lingual indentation was similarly fashioned at 60 degrees to the root axis. Specimens with the ferrule were restored by extending the core material to the prepared occlusal margin of the exposed root surface.

Final restoration
All cast dowels were reproduced in Type III gold (Jelenko) and air abraded by 50-μm silica particles. Each had 8.00 mm of length and 8.00 mm of core height. Prior to cementation of the cast dowel, the dowel space of the morphologic grouping was similarly etched, rinsed, primed, and coated with adhesive resin as described for the intraradicular resin-reinforced group. A layer of resin cement (Enforce) was applied to each cast dowel before seating. A static loading force of 3 kg was applied occlusally on the castings for 10 minutes, and the restored teeth were placed in distilled water at 37°C. The restored teeth were then thermocycled 1,500 times in three temperature baths in the following order: 5 seconds in 9°C, 20 seconds in 37°C, and 5 seconds in 55°C. There was a 6-second travel time between each bath.
Experimental setup of the Instron device. The specimen demonstrates the contact angle for loading.

Mean loads to fracture of the two post and core procedures.

Fracture testing

The root of each restored tooth was thinly covered with self-curing rubber to simulate a periodontal pocket and embedded in acrylic blocks so that 3.00 mm of natural root structure was exposed. The specimens were coded and randomly chosen for transverse loading in a universal testing device (Instron). The machine applied a load against the redesigned indentation on the lingual aspect of the stub. The lingually directed load simulated a Class I occlusal contact angle. Transverse loading was maintained under a constant crosshead speed of 2.00 mm/min until failure resulted, measured by a sudden release of load on the specimen (Fig 4).

Results

The mean load values and other descriptive statistics are summarized in Table 1. The experimental design in this study examined the effects of the presence or absence of a ferrule and the effects of use of either a cast orthologic post and core or the Luminex system post and core procedures on the resistance to simulated incisal loading. A two-factor analysis of variance was used as a statistical test to specifically focus on the effects of (1) the ferrule and (2) the post and core procedures.

Summaries of these statistical test procedures can be found in Tables 2 to 4. Scheffe's post-hoc test was used to determine which of the test groups were statistically different from each other. A summary of the treatment cells means is found in Fig 5. The statistical analysis of the data revealed that, when a bonded resin system was used to reinforce and act as the luting agent in structurally compromised teeth, there was no statistically significant difference between post and core restorations that use a ferrule and those without a ferrule.

Furthermore, there was a statistically significant difference ($P<.001$) in the resistance to a simulated masticatory load of the Luminex system post and core procedure and that of the morphologic post and core procedure. The Luminex system post and core procedure (groups B and D) demonstrated mean load failure values between 41.1% and 52.4% greater than those obtained with the morphologic cast post and core procedure (groups A and C). This significant increase in mean load values occurred irrespective of whether a ferrule was or was not used.

When mode of failure was quantified, the majority of failures (more than 80%) occurred by root fracture (Figs 6a to 6d). Because the study was designed to simulate structurally weakened teeth, the high percentage of fractured roots at failure was an expected outcome. Resin bond failure, which occurred in fewer than 15% of specimens, may be attributed to loading or thermocycling during the experiment. Collectively, failure occurred in these specimens either by adhesive failure at the resin-dentin interface or at the resin-post interface.
Table 1  Load to fracture (kg) of two post and core procedures

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Morphologic, no ferrule</th>
<th>Morphologic, with ferrule</th>
<th>Luminex, no ferrule</th>
<th>Luminex, with ferrule</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>116</td>
<td>168</td>
<td>175</td>
</tr>
<tr>
<td>2</td>
<td>134</td>
<td>120</td>
<td>110</td>
<td>185</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>104</td>
<td>125</td>
<td>165</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>76</td>
<td>230</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
<td>140</td>
<td>185</td>
<td>130</td>
</tr>
<tr>
<td>6</td>
<td>164</td>
<td>88</td>
<td>230</td>
<td>140</td>
</tr>
<tr>
<td>7</td>
<td>148</td>
<td>204</td>
<td>120</td>
<td>170</td>
</tr>
<tr>
<td>8</td>
<td>68</td>
<td>96</td>
<td>195</td>
<td>205</td>
</tr>
<tr>
<td>9</td>
<td>130</td>
<td>150</td>
<td>250</td>
<td>205</td>
</tr>
<tr>
<td>10</td>
<td>114</td>
<td>114</td>
<td>120</td>
<td>210</td>
</tr>
</tbody>
</table>

n 10 10 10 10  
Minimum 67 76 110 120  
Maximum 164 204 250 210  
Median 122.0 115.0 176.5 172.5  
Mean 113.7 120.8 173.3 170.5  
SD 34.7 36.8 52.7 32.2  
Variance 1209.8 1354.8 2774.5 1035.8  
SEM 11.0 11.6 16.7 10.2  
CV 30.6 30.5 18.9  

SD = Standard deviation; SEM = standard error of the mean; CV = coefficient of variation.

Table 2  Two-factor analysis of variance

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Sum of squares</th>
<th>Mean of squares</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrule</td>
<td>1</td>
<td>46,225</td>
<td>46,225</td>
<td>0.0290</td>
<td>.8657</td>
</tr>
<tr>
<td>Core type</td>
<td>1</td>
<td>29,866.2000</td>
<td>29,866.2000</td>
<td>18.7398</td>
<td>.0001</td>
</tr>
<tr>
<td>Ferrule/core interaction</td>
<td>1</td>
<td>245.0250</td>
<td>245.0250</td>
<td>0.1537</td>
<td>.6973</td>
</tr>
<tr>
<td>Residual</td>
<td>36</td>
<td>57,374.3000</td>
<td>1,593.7300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>87,531.8000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

df = degrees of freedom.

Table 3  Factorial cell means

<table>
<thead>
<tr>
<th>Cell</th>
<th>No ferrule</th>
<th>With ferrule</th>
<th>Overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphologic cast</td>
<td>113.7</td>
<td>120.8</td>
<td>117.3</td>
</tr>
<tr>
<td>post &amp; core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminex post &amp; core</td>
<td>173.3</td>
<td>170.5</td>
<td>171.9</td>
</tr>
<tr>
<td>Overall mean</td>
<td>143.5</td>
<td>145.7</td>
<td></td>
</tr>
</tbody>
</table>

Table 4  Statistically significant differences between means (P < .05)

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Difference of means (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminex, no ferrule, vs morphologic, no ferrule</td>
<td>173.3 - 113.7 = 59.6 (52.4%)</td>
</tr>
<tr>
<td>Luminex, no ferrule, vs morphologic, with ferrule</td>
<td>173.3 - 120.8 = 52.5 (43.5%)</td>
</tr>
<tr>
<td>Luminex, with ferrule, vs morphologic, no ferrule</td>
<td>170.5 - 113.7 = 56.8 (50.0%)</td>
</tr>
<tr>
<td>Luminex, with ferrule, vs morphologic, with ferrule</td>
<td>170.5 - 120.8 = 49.7 (41.1%)</td>
</tr>
<tr>
<td>Overall mean, Luminex vs overall mean, morphologic</td>
<td>171.9 - 117.3 = 54.6 (46.6%)</td>
</tr>
</tbody>
</table>
Discussion

Although numerous investigators have shown that, when preparing the post space, the practitioner must exercise care to remove only minimal tooth structure from the canal,\textsuperscript{16,17} this study was designed to utilize structurally weakened roots with minimal remaining dentinal thicknesses. The overenlarged post space, whether operator-created or an outcome of dental disease, is at risk for fracture during cementation of the post or during subsequent function. When post diameters were evaluated as a factor in root fractures, larger diameters (1.8 mm) showed less resistance to root fracture than did smaller diameters (1.3 mm).\textsuperscript{17} Consequently, if internal stresses are greater as post diameters increase, resistance to root fracture is directly related to remaining tooth structure.\textsuperscript{16} The recommendation that the root canal be enlarged only

the amount necessary to enable retention and strength of the dowel is sound.

This study has shown that, in the structurally weakened root, where remaining tooth structure is of immediate critical concern, intraradicular rehabilitation is a viable clinical answer to the cementation and functional stresses that normally lead to root fracture. The rationale for placing posts has shifted in the last two decades, from efforts to strengthen roots to provision of retention and resistance to displacement of the core materials. In teeth with prior loss of significant amounts of coronal and radicular tooth structure, it has become important to assess alternatives to morphologic dowel rehabilitation.

The alternative of using a dentin-bonded resin composite for intraradicular reinforcement is highly desirable. The rationale for the use of dentin-bonded resins is well documented.\textsuperscript{9,10} The difficulty of achiev-
ing an intimacy of fit to the dentin interface with core techniques was overcome, in the present study, with the light-transmitting technique for bonded composite rehabilitation. The intraradicular composite undergoes polymerization shrinkage in the direction of the bonded interface, resulting in volumetric space for post manipulation and cementing materials. Because of shrinkage away from the light-transmitting post, there was relatively easy removal of the plastic pattern for casting. Clinical application of this two-step procedure is highly appropriate as is the use of a size-integrated matching prefabricated post for use in a one-step procedure.7

In assessing dowel core failure, researchers have focused on the following variables: adhesive failure at the cement-dentin interface or cement-dowel interface; cohesive failure of the cement; dowel failure; and root fracture. A primary reason for these many failures is the traditional cements. Conventional cements are non-adhesive, inorganic luting agents that rely primarily on mechanical interlocking to retain the dowel core. These inorganic cements have relative high rigidity and low elasticity. Use of a rigid, nonadhesive cement to lute a rigid post to dentin, which has a high coefficient of elasticity, concentrates stress at the dentin-cement-dowel interface. These stresses tend to break the mechanical interlock or cause cohesive failure of the cement.

In a new world of etchants and adhesive materials, the possibilities for new and creative cementing mediums and techniques are boundless, and true internal support may now be possible.9,10 With intimate fit, intraradicular reinforcement appears to decrease fracture potential, enhance resistance to post displacement, and even improve esthetics by masking large morphologic dowels, which can discolor an exposed root surface. Because cementing materials have classically been the weakest aspect of fixed prosthodontics, adhesion to tooth structure and/or metal in the absence of microleakage appears to provide significant benefits. Choice of a resin cement over conventional cementation materials is based on its ability to chemically bond the dentin and the post. A number of studies recently have shown that resin-based cements provide higher retention forces for prefabricated posts than do conventional cements.18-20

The present results show that, even with wide variability in canal shape, rehabilitation of the dowel space with resin and a single dowel size can significantly improve fracture resistance of structurally weakened roots.

Lui21 has shown that light-transmitting posts used with the Luminex system allow resin composite to be polymerized up to three times deeper than do control posts. As the diameters of the light-transmitting posts increases from 1.05 to 1.80 mm, depth of cure also increases, to a maximum of 11 mm. Composite reinforcement strengthens damaged and weakened teeth, allowing them to be rehabilitated.8,22 The marriage of these reinforcement techniques with a light-transmitting post has greatly enhanced the ability to reinforce weakened dentin.

The advantages of using a resin cementation system that have been shown in this study are supported by data that describe the modulus of elasticity of resin as approaching that of dentin.23 The replacement and reinforcement of intraradicular tooth structure with material that is elastically compatible with dentin is far better than replacement of the destroyed intraradicular structure with a morphologic dowel. The morphologic post system has a very high modulus of elasticity, which has the potential to transfer and concentrate applied stresses to the surrounding compromised root structure. In contrast, the Luminex system’s relatively thick composite core has a comparatively lower modulus of elasticity, which distributes stresses more equally to the surrounding dentin.

Summary

Under the conditions of this study, the following conclusions were made:

1. When root and dentinal support are compromised, the Luminex resin-reinforced dowel system can offer up to 50% more resistance to fracture than can a conventional morphologic cast post and core.
2. When tooth structure is compromised, the use of the Luminex bonded resin reinforcement system and post adhesion with resin cements can eliminate the time-honored requirements of a ferrule. The use of a ferrule, under weakened structural conditions, provides no additional benefit for retention and resistance to fracture and will necessitate additional loss of structure.
3. The loss of resin bonded reinforcement and resin cements may equalize the enhancing effects of a ferrule that have been shown in studies of conventional cementation of dowels.
4. Esthetics can be enhanced in structurally weakened roots by use of the Luminex resin-reinforced dowel system while foregoing the use of a ferrule.
Acknowledgments

This study was supported by a grant from Dentatus USA.

The authors wish to gratefully acknowledge the support for this project and statistical assistance of Dr Joseph P. Moffa, President of the Pacific Dental Research Foundation, University of the Pacific, School of Dentistry. The authors also wish to acknowledge the thoughtful efforts of Dr Chi D. Tran in supplying the support for graphics in illustrating this project.

References