Dislodgement pushout resistance of five bioceramic root-end filling materials

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This study evaluated the dislodgement push-out resistance of five bioceramic materials. One hundred single-rooted teeth with one canal had the apical 3 mm and crown resected to create a 14 mm standardized length. The canals were instrumented to an apical size 80 with a 3 mm root-end preparation made with ultrasonic diamonds. The prepared roots were randomly divided into 5 root-end restorative groups (n=20). ProRoot MTA, Biodentine, EndoSequence Root Repair Material, EndoSequence Fast Set Putty, and EndoSequence BC Sealer with each material placed following manufacturer’s instructions and stored at 100% humidity for 2 weeks. An apical-to-coronal static testing load with the identified dislodgement force converted into MPa with mean results analyzed with Kruskal-Wallis and Dunn’s post hoc tests (α=0.05). ProRoot MTA and Biodentine displayed similar push-out stress resistance and exhibited significantly greater stress resistance than the similar Endosequence materials. However, all materials failed cohesively and were not dislodged from the root canal surface.

Keywords: Root end filling, Push out resistance, Endodontic apical surgery, Bioceramics, Hydraulic cements

INTRODUCTION

The objective of non-surgical root canal therapy is to treat and prevent apical periodontitis by disinfecting the canal system, as bacteria and their by-products are considered to be the primary etiologic agents of pulpal necrosis and apical lesions1-3. Unfortunately endodontic therapy does not totally eliminate microbial products but only reduces the bacterial load and obturation may entomb remaining bacteria4 while attempting to establish a barrier to prevent future egress of bacteria and toxins5-7. Most root canal fillings have been described to not completely fill the root canal system in three dimensions8,9 and these voids may harbor remaining bacteria that may thrive and induce inflammation if nutrients are available10. The host’s immune reaction to this inflammatory process may ultimately result in treatment failure11-13 which may be first addressed by nonsurgical retreatment techniques14-15. Inability to resolve chronic periapical inflammation may lead to the consideration of surgical treatment options16-17 that provides direct access to the periapical area to allow direct cleansing and correct anatomical defects that is then repaired with a suitable root end filling to improve the periapical seal18.

Historically, many different materials have been proposed to serve as retrograde or root-end fillings19-21 but hydraulic calcium silicate materials have become popular in recent years22,23. The first marketed material of this class was mineral trioxide aggregate (MTA) (ProRoot MTA, Dentsply Tulsa Dental, Johnson City, TN, USA) which has been extensively studied and has demonstrated excellent sealing properties and biocompatibility24-25. MTA has been reported to have poor clinical handling characteristics, staining of natural tooth structure, and physical properties can be affected by the water to powder ratio26-27. Additional root-end filling materials that have been introduced include Biodentine (Septodont, St Maur des Fosses, France), EndoSequence Root Repair Material (ERRM) (Brasseler USA, Savannah GA, USA), EndoSequence RRM Fast Set Putty (FSP) (Brasseler USA), and EndoSequence BC Sealer (BC Sealer) (Brasseler USA). These materials have demonstrated similar success in animal and clinical studies13-33 but these studies have been accomplished with different methodologies and material variations34-38.

The push-out test is a common method used to evaluate the shear bond strength or dislocation resistance of a restoration by applying tensile forces along the longitudinal root axis to measure a material’s dislodgement resistance39-43. Push-out strength investigations are represented by many different methodologies30,36,40,44-47 and the results are influenced by many variables36,45,48-50, such as root filling technique, tooth type, tooth portion, slice thickness, storage time, and load velocity that may affect results48. In fact, a systematic review by Brichko et al.46 reported that these study design variabilities could limit push-out strength testing validity and limit comparison to values within each individual study, rendering direct comparison doubtful between different studies46.

Published push out bond strength testing results have been generally limited as these studies have either reported few materials, variation of one material, and/
or placement conditions. Accordingly, evaluated materials are usually restricted in number with most studies evaluating only two or three materials, and push-out testing involving more than three materials is infrequently reported in the literature. The purpose of this study was to directly compare under one protocol the push-out resistance to dislodgement of five bioceramic materials: ProRoot MTA, Biodentine, EndoSequence Root Repair Material, EndoSequence RRM Fast Set Putty, and EndoSequence BC Sealer. The null hypothesis was that there would be no difference in the push-out failure resistance between any of the five materials tested.

MATERIALS AND METHODS

The materials used in this evaluation are listed in Table 1. One hundred extracted, single-rooted bicuspid teeth were used in this study. These teeth had been extracted for routine clinical indications and were obtained from local oral surgery sources following established World Medical Association Declaration of Helsinki ethical guidelines under local institutional review board (IRB) oversight. The external surfaces were cleansed of all debris and the presence of only one apical foramen was confirmed both radiographically as well as visually at 20× magnification. All teeth were decoronated with the apical 3 mm resected using separating discs (Dedeco International, New York, NY, USA) to create specimens with a standardized 14 mm root length. Working length was established with a 15/0.02 hand file and the canals were then instrumented with nickel titanium (NiTi) rotary instruments (Vortex Blue, Tulsa Dental, Dentsply, Philadelphia, PA, USA) using a crown-down technique to a final size of 50 with an 0.04 taper. The apical segment was then prepared to size 80 using LightSpeed LSX (Kerr Endodontics, Orange, CA, USA). All procedures were accomplished using 6% sodium hypochlorite (NaOCl) irrigation. A root end preparation approximately 3 mm diameter and 3 mm depth was prepared with a diamond coated ultrasonic preparation tip (SF 979, Komet USA, Rock Hill, SC, USA) with copious irrigation keeping the resultant preparation walls as parallel as possible. Preparation dimensions were confirmed with a periodontal probe and then gutta-percha points were firmly fitted without sealer to provisionally obturate the coronal 11 mm canal space to serve as a matrix to pack the root-end filling materials against.

The teeth were randomly divided into 5 groups (n=20): Group 1: ProRoot MTA; Group 2: Biodentine; Group 3: EndoSequence Root Repair Material (ERRM); Group 4: EndoSequence Fast Set Putty (FSP); and Group 5: EndoSequence BC Sealer. Each material was prepared and placed according to the manufacturer instructions with the adequacy of the root end filling placement confirmed both visually and radiographically by a board-certified endodontist (Fig. 1). The prepared and restored specimens were stored in a sealed container placed on a rack above the surface of 0.2 M phosphate buffered saline (PBS) providing 100% humidity at 37°C for 2 weeks prior to testing and were then mounted in a vise arrangement.
Preoperative images and radiographs of root end restorations. Top row: Radiographic imaging of placed root-end filling; Bottom row: Visual images of placed root end filling material in preparations of resected root surface.

Transillumination assistance with testing probe alignment.

The restored preparation was aligned using transillumination with a custom 2.5 mm probe (Fig. 2). To avoid desiccation during alignment the root end preparations were kept moist with PBS applied to the apical surface. Static force along the root long axis in an apical to coronal direction was applied 0.5 mm/min load with failure force recorded in Newtons that was converted into MPa based on the preparation surface area. The interfaces both before and after failure was accomplished using visual examination at 120× magnification using a digital stereomicroscope (Hirox 7700, Hirox USA). Mean data was first analyzed with the Shapiro-Wilk and Bartlett’s test which identified irregularities in both the data distribution as well as variance homogeneity. The data was then analyzed using Kruskal-Wallis and Dunn’s multiple comparisons test at a 95% level of confidence ($\alpha=0.05$).

RESULTS

Table 2  Mean push out failure stress (MPa)

<table>
<thead>
<tr>
<th>Material</th>
<th>Failure stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BioDentine</td>
<td>3.0 (0.9) A</td>
</tr>
<tr>
<td>EndoSequence Root Repair Material</td>
<td>1.5 (0.5) B</td>
</tr>
<tr>
<td>EndoSequence Putty</td>
<td>1.6 (0.6) B</td>
</tr>
<tr>
<td>EndoSequence BC Sealer</td>
<td>1.5 (0.5) B</td>
</tr>
<tr>
<td>ProRoot MTA</td>
<td>5.2 (1.1) A</td>
</tr>
</tbody>
</table>

$n=20$; Same capital letters identify similar groups (Kruskal-Wallis/Dunn’s; $p=0.05$)

DISCUSSION

The results of the push out test are presented in Table 2. There was no significant difference ($p=0.146$) observed in the push out resistance stress between ProRoot MTA and BioDentine, and both demonstrated significantly greater ($p<0.002$) dislodgement stress resistance than that observed with the similar ($p>0.999$) EndoSequence materials. Visual failure mode analysis assisted by mesh-enhancement of the specimen topography suggests that essentially all failures were cohesive in nature and were not dislodged from the root canal dentin (Fig. 3).
and it must be appreciated that push out testing results cannot predict clinical performance\(^{46,51}\). Over the approximately past 10 years over 23 published works involving a push out testing methodology have been published\(^{36,38,40,44,45,47-50,53,55-63,65-67}\), and these reports demonstrate the previously-discussed methodology variation that undesirably renders meaningful comparisons between these studies difficult, if not impossible\(^{43-46}\). In this study an ultrasonic preparation tip was used by one researcher for root-end preparations attempting to establish parallel internal dentin walls\(^{47}\), but admittedly obtaining true parallelism within a root canal is difficult. The preparation was not sectioned to alleviate potential additional stress imposed to the material and the internal canal surface interface while also preserving sample length that would be lost due to the sectioning blade thickness. A customized approximate 2.5 mm testing plunger was modified from an endodontic plunger/condenser that allowed contact with the root end repair materials but avoided direct contact with the canal walls. Additionally, the modified tester allowed a plunger/preparation ratio of less than 0.85 as recommended by Chen et al.\(^{42}\). Transillumination assisted the customized plunger alignment to apply forces as evenly as possible while also attempting contact with root canal dentin and static forces were then applied in an apical-to-coronal direction as recommended by Neelakantan et al.\(^{52}\).

Bioceramic material adaptation to the root canal dentin was assumed as most bioceramic materials have been reported to exhibit a 0.6 to 6% net setting expansion\(^{24}\), which could facilitate root end repair material retention and thereby enhance push-out resistance\(^{68}\). Material expansion can also possibly induce localized residual stresses due to wedging and serve as crack-initiation nidus that may predispose the material to cohesive failure. Under the conditions of this study no significant difference was identified in the push out resistance stress between MTA and Biodentine, while both were found to demonstrate greater resistance stress than that observed with the similar EndoSequence materials. Visual failure mode analysis using visual microscopic observation and 3D imaging implies that all products failed cohesively within the material. This may interestingly suggest that although the different material’s cohesive strength may differ, the conditions of this study did not overcome the interfacial forces between the root-end material and internal canal dentin wall. While resistance to dislodgement stress results of this study may be encouraging, clinicians must appreciate that no correlation exists between interfacial bond strengths and leakage resistance\(^{69}\).

As previously observed, caution is advised when attempting to definitively compare push out strength results between studies\(^{46}\), but observation of some generalized trends may be conceivable. Under this study’s conditions, the push out stress resistance of ProRoot MTA and Biodentine was similar. This has been reported also by Dawood et al.\(^{36}\), Marques et al.\(^{45}\), Nagas et al.\(^{63}\), and Ballal et al.\(^{70}\), while contrary to that found by Ackay et al.\(^{71}\). The work of Ackay et al.\(^{71}\) evaluated both MTA and Biodentine under apical microsurgery conditions and performed the push out evaluation based on one apical slice from the preparation area. While these authors did report comparable Biodentine push out stress to the present study, MTA was reported to have significantly less stress resistance. A definitive reason for the reduction in MTA push out stress resistance is not known, but it is conjectured that the application of MTA in very small quantities is more difficult than the bulk application accomplished in this study. This study identified that ProRoot MTA and Biodentine
demonstrated significantly greater push out stress resistance than the EndoSequence materials, similar to that described by reports from Silva et al. However, few reports exist that compare EndoSequence materials with both Biodentine and ProRoot MTA under one protocol, and the authors assume that this work may be one of the few to report such.

As with other push out strength testing, this study’s results must be interpreted in view of this study’s limitations. Admittedly, the attempts to maintain internal preparation parallel walls is difficult as well as the absolute alignment of the preparation with the long axis of the root canal. Also, gutta percha placement was only to serve as a matrix to limit the root end filling to the preparation, and to avoid any additional feature that could reinforce the root end filling. This study did not definitively obturate the root canals. It is aptly recognized that this does not fully replicate the clinical situation. Importantly, it should be recognized that apical canal anatomy variability did not allow application of uniform controlled forces and the possible effect on results cannot be dismissed. This study would also have benefitted from a stress analysis, but was not possible due to technical limitations. Also, the preparation diameter and depth were chosen for testing convenience and may not necessarily represent preparations made during actual apical surgery. Due to technology limitations this study did not evaluate the same products using apical microsurgery techniques and the results of this study cannot be interpreted to apply to microsurgery conditions. Lastly, clinicians are advised to interpret this study’s results not in absolute terms but in generalized trends.

CONCLUSIONS

This study could possibly be one of the first to evaluate the push out dislodgement stress resistance of all EndoSequence materials compared to ProRoot MTA and Biodentine. Under the conditions of this study both ProRoot MTA and Biodentine were found to have similar resistance to dislodgement while both materials demonstrated significantly greater dislodgement stress resistance than the EndoSequence materials evaluated. However, all products were observed to demonstrate cohesive failure within the material with the dentin and root-end repair material interface not disturbed. Clinicians are advised to interpret these results in generalized trends due to the heterogenic research methods of other push out tests.

REFERENCES


