RESEARCH ARTICLE

Impact of repeated activation on the heat output of electric pluggers

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Why Is This Important?

The accuracy and reliability of heat delivery by electric heat pluggers may degrade over time with repeated activations, potentially negatively affecting the effective obturation of the root canal system during endodontic therapy. In this study, extra fine (0.04 taper) pluggers exhibited lower heat generation than expected, and fine (0.06 taper) and fine medium (0.08 taper) pluggers generated heat close to expected, with all plugger sizes exhibiting low reliability, although still sufficient to thermoplasticize gutta-percha at the level of the instrument tip. Degradation of mean heat generation over repeated activations was not observed, although 3 of 5 extra fine pluggers failed before reaching 2,000 activations. Clinicians should be aware of the potential variability in accuracy and reliability of different heat plugger sizes and their impact on root canal obturation.

Abstract

Background. Electric pluggers that output accurate and reliable heat are required to thermoplasticize gutta-percha for endodontic obturation. This study aimed to evaluate the accuracy and reliability of heat output by Buchanan electronic pluggers (Kerr Endodontics) after repeated activation cycles.

Methods. The Elements Obturation Unit (Kerr Endodontics) was operated in downpack mode according to the manufacturer’s recommendations with a temperature of 200 °C and automatic cutoff after 4 seconds of continuous activation. Fifteen Buchanan Heat Pluggers were tested: 5 of each of sizes extra fine (XF) (0.04 taper), fine (F) (0.06 taper), and fine medium (FM) (0.08 taper). Pluggers were allowed to cool for 5 to 10 seconds between activations and were activated 25 times per day for 80 days, totaling 2,000 activations per plugger. A thermocouple and an electronic data logger were used to record a single peak temperature for each plugger at the final activation of each day.

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Results. There was no degradation in heat generation across 2,000 activations for any of the plugger sizes. Heat output for XF (0.04 taper) pluggers was significantly lower than for F (0.06 taper) and FM (0.08 taper) pluggers. Three of the 5 XF pluggers lost functionality before reaching 2,000 activations.

Conclusions. The heat output for F (0.06 taper) and FM (0.08 taper) pluggers was close to expected (temperatures) and did not degrade over 2,000 activations. All plugger sizes showed high variance in heat output. XF (0.04 taper) pluggers may be prone to lower temperature output than larger plugger sizes and prone to failure before 2,000 activations.

Key Words. Obturation; heated plugger; gutta-percha; temperature; heat; thermocouple.

Introduction

Gutta-percha is the most commonly used material for obturating the root canal system in nonsurgical treatment.1 It is a naturally occurring polymer that exists in 2 crystalline forms known as α and β. The α form is soft, pliable, and compactable, whereas the β form is solid. Commercially available gutta-percha is usually in the β form, which, when heated to above 56 through 62 °C, melts into a compatible, amorphous solid.2,3

The warm vertical compaction technique, as described by Schilder,4 takes advantage of the phase changes of gutta-percha by using a heated plugger to thermoplasticize the material, which can then be compacted into the intricacies of the root canal system. In modern endodontics, the ability to heat gutta-percha within the root canal is most commonly achieved with an electric heat plugger. These instruments come in various sizes to match common canal preparation sizes and can be set to a specific temperature by the operator.

The accurate and reliable delivery of heat via an electric plugger is of critical importance to both patient safety and clinical efficiency. In vitro and animal studies have shown that elevating the temperature of the root surface for more than 1 minute and setting the heat source to 250 °C or higher can cause damage to the bone and surrounding tissues.5,7 If the heat output of the electric plugger significantly exceeds the expected temperature on the basis of the instrument setting, tissue damage could occur. Alternatively, effective compaction of warm gutta-percha requires a minimum temperature of 53 to 59 °C, which can be difficult to achieve in the most apical extent of a canal.3,5,6 Previous studies have shown that electric heat pluggers may not reach the stated temperature setting on the heating unit.10-13 In addition to these factors, gutta-percha can vary in its thermal conductivity, potentially resulting in insufficient plasticization of gutta-percha and contributing to an inadequate seal of the root canal system.11,14,15 A lack of reliability by electric heat pluggers reduces clinical efficiency and could negatively affect the safe and effective obturation of the root canal system.

Accuracy and consistency of heat delivery may be reduced over time with repeated use of electric pluggers. A study by Correa et al16 showed a reduction in the life span of pluggers and an increase in malfunctions with repeated autoclave cycles or use at high-temperature settings. However, a PubMed search revealed no studies evaluating the life span of electric pluggers after repeated activations independent of autoclave sterilization. Our study aimed to evaluate the accuracy and reliability of electric heat pluggers after repeated activation cycles independent of autoclave cycling.

Methods

Fifteen Buchanan Heat Pluggers (Kerr Endodontics) were evaluated in our study, 5 for each commonly used size: extra fine (XF) (0.04 taper), fine (F) (0.06 taper), and fine medium (FM) (0.08 taper) (Figure 1D). The corded, plug-in-powered Elements Obturation Unit (Kerr Endodontics) (Figure 1B) was selected for use in our research over other units to remove the additional variable of battery charging and battery-powered operation.

A custom jig was designed and fabricated by the 3-D Medical Application Center at Walter Reed National Military Medical Center using the Solidworks 2016 (Dassault Systèmes) and printed on a form 2 3-dimensional printer (Formlabs) using a High Temp (high temperature) resin (Formlabs) (Figure 1C).17 The jig included indented channels allowing for secure placement of the plugger and intimate contact with the K-type thermocouple (Omega Engineering Inc). This thermocouple was connected to a 4-channel RDXL-SD series portable thermometer and data logger (Omega Engineering Inc) to record temperatures (Figure 1A). Data were automatically exported to an Excel (Microsoft) spreadsheet, and maximum temperature data points were collected.

The Elements unit was set to the manufacturer’s preset downpack mode, featuring a 200 °C temperature setting with automatic heat cutoff after a 4-second activation. Each of the 15 pluggers was tested individually with repeated activation cycles. The maximum temperature over the 4-second activation was recorded. A cooling cycle of 5 to 10 seconds between each activation was allowed to mimic a clinical scenario more closely.

An initial baseline maximum temperature was recorded for each plugger, and another maximum temperature was recorded on the 25th activation. Activation cycles were limited to 25 each day for each plugger to simulate the
number of daily activations representative of normal clinical use. The maximum temperature at the tip of the heat plugger was recorded every 25th activation cycle until 2,000 activations per plugger were completed. This resulted in 80 days of data collection and 81 data points for each of the 15 pluggers (Figure 2). All measurements were taken at room temperature (20 °C; range 18-22 °C).

One-way analysis of variance and Kruskal-Wallis tests were performed to assess statistical significance, and the Tukey post hoc multiple comparison test was performed to compare the heat output between the 3 different plugger sizes.

Results

The data showed mean heat output over time did not decrease for all pluggers that functioned to 2,000 activations. The functioning XF (0.04 taper) pluggers produced an initial mean maximum temperature of 115.5 °C, a mean maximum temperature of 176.2 °C on day 10 after 250 activations, and a final mean maximum temperature of 144.5 °C after 2,000 activations. The F (0.06 taper) pluggers produced an initial mean maximum temperature of 171.6 °C, a mean maximum temperature of 236.6 °C on day 11 after 1,275 activations, and a final mean maximum temperature of 181.2 °C. The FM (0.08 taper) pluggers output an initial mean maximum temperature of 160.7 °C, a mean maximum temperature of 244.4 °C on day 11 after 275 activations, and a final mean maximum temperature of 177.3 °C.

The overall mean maximum temperature output for F (0.06 taper) pluggers was 193.85 °C (19.33 °C), 96.93% of the expected heat output of 200 °C, with a coefficient of variation (CV), which is SD divided by the mean, of 9.97%. FM (0.08 taper) pluggers showed an overall mean maximum temperature output of 196.87 °C (20.51 °C), 98.44% of the

Figure 1 Experimental setup. A. A 4-channel RDXL-SD series portable thermometer and data logger (Omega Engineering Inc) and K-type thermocouple (Omega Engineering Inc). B. Elements Obturation Unit (Kerr Endodontics). C. Three-dimensional printed custom jig with indented channels. D. Buchanan Heat Pluggers (XF, F, FM) (Kerr Endodontics).
expected, with a CV of 10.42%. The XF (0.04 taper) pluggers produced a mean maximum temperature output of 134.00 °C (18.41 °C), 67% of expected, with a CV of 13.73%.

One-way analysis of variance and the Kruskal-Wallis statistical test procedures both confirmed statistically significant differences in the mean heat output of the 3 different plugger sizes ($P < .005$). The Tukey post hoc multiple comparison tests indicated that there were no statistically significant differences between the F (0.06 taper) and the FM (0.08 taper) pluggers ($P = .583$). However, the XF (0.04 taper) pluggers produced significantly lower heat output than both the F (0.06 taper) and FM (0.08 taper) pluggers ($P < .005$).

In addition to lower mean heat output, 3 of the 5 XF (0.04 taper) pluggers lost functionality before reaching 2,000 activations. The Elements unit produced the Check Tip Indicator error indicator for XF (0.04 taper) pluggers 5, 4, and 1 after 238, 313, and 421 activations, respectively. These pluggers remained nonfunctional throughout the remainder of the study.

### Discussion

The results of our study show that electric pluggers size F (0.06 taper) and FM (0.08 taper) achieve a mean maximum heat output during a 4-second activation cycle that is close to the instrument setting of 200 °C (Table) and do not significantly degrade over 2,000 activations. The Elements unit produced the Check Tip Indicator error indicator for XF (0.04 taper) pluggers 5, 4, and 1 after 238, 313, and 421 activations, respectively. These pluggers remained nonfunctional throughout the remainder of the study.

![Figure 2](image-url) Mean maximum heat output temperatures by plugger size over time. Measurements were made at activation 1 and every 25 activations after that. The 0.04 taper pluggers that failed after 238, 313, and 421 activations were not included in the average maximum heat output calculation for that group after failure.

![Table](image-url) Mean (SD) values for overall maximum heat output for each plugger size across 2000 activations.

<table>
<thead>
<tr>
<th>Plugger Size</th>
<th>Maximum Heat Output, Mean (SD), °C</th>
</tr>
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<tbody>
<tr>
<td>0.04 taper</td>
<td>134.00 (18.41)</td>
</tr>
<tr>
<td>0.06 taper</td>
<td>193.85 (19.33)</td>
</tr>
<tr>
<td>0.08 taper</td>
<td>196.87 (20.51)</td>
</tr>
</tbody>
</table>

*For each plugger size, maximum heat output (°C) during each 4-second activation cycle was measured at activation number 1 and every 25 activations after that for a total of 81 measurements per plugger. For the 0.04 taper group, 3 pluggers failed after 238, 313, and 421 activations and were not included in the overall mean maximum heat output calculation for that group after they failed (ie, zero values for heat output were not included). The XF (0.04 taper) pluggers produced significantly lower heat output than both the F (0.06 taper) and FM (0.08 taper) pluggers ($P < .005$).
surface temperature that may contribute to tissue damage, including osseous necrosis. Alternatively, activations with lower heat output may not fully thermoplasticize the gutta-percha or thermoplasticize it to the expected apical extent. This could result in deficient vertical compaction of the gutta-percha, contributing to an inadequately sealed root canal.

Previous studies have shown that repeated sterilization of pluggers and operation of pluggers above manufacturer-recommended temperatures may result in a reduction in heat output. Our findings with these controlled variables showed that the heat output of pluggers that maintained functionality did not degrade after 2,000 activations. However, size XF (0.04 taper) pluggers may be more susceptible to failure over time. Repeat activations at the manufacturer-recommended settings without autoclaving, bending, or repeated vertical pressure applied to the pluggers rendered 3 of 5 XF (0.04 taper) pluggers nonfunctional after only a few weeks of simulated clinical operation. When a nonfunctional plugger was inserted into the handpiece, the Elements unit emitted an error sound and displayed the Check Indicator Tip warning. According to the trouble-shooting section within the owner’s manual, the Elements unit uses an electrical sensor to determine if a plugger is connected and will display these faults if an incorrect or worn out plugger is inserted. Within the parameters of our study, repeated activation did not negatively affect the service life of the F (0.06 taper) and FM (0.08 taper) pluggers. Given the limited number of plugger sizes used, further studies are needed to gain a greater understanding of the failure rate of these pluggers. In addition, combining controlled activations with autoclave cycles and repeated vertical pressure applied to or bending of pluggers may also contribute to a reduction in the service life of these plugger tips.

The variability in heat output that was observed throughout our study may not be of significant magnitude, which would affect the safety of the obturation unit or pluggers. The risk of tissue necrosis is partially mitigated by the 4-second activation limit of the downpack mode. Although previous studies in animal models suggest that the plugger temperatures reached at the tips of each plugger size in our study would be safe to surrounding osseous tissue, our study was not designed to specifically assess heat transfer through a tooth root or simulated tooth model.

Conclusions

On average, Buchanan Heat Pluggers in size F (0.06 taper) and FM (0.08 taper) produced heat at the plugger tip close to the heating unit setting of 200 °C, and the mean maximum output did not degrade across 2,000 activations. The XF (0.04 taper) pluggers showed significantly lower heat generation. Further studies are needed to determine if the reduced heat output of the XF pluggers is still sufficient to thermoplasticize gutta-percha 2 to 3 mm beyond the tip of the instrument in clinical operation.

Disclosure

None of the authors reported any disclosures.

Author Credit Statement

Anthony G. Fioretti: conceptualization, methodology, investigation, writing–original draft, visualization; Andrew D. Henning: investigation, writing–original draft, visualization; Susan E. Hinman: conceptualization, methodology, writing–reviewing and editing, supervision; Rodney V. Scott: conceptualization, methodology, writing–reviewing and editing, supervision; Nancy H. Osborne: conceptualization, methodology, formal analysis, resources, writing–reviewing and editing, supervision; and Nicholas J. Hamlin: methodology, formal analysis, resources, writing–reviewing and editing, supervision, project administration, funding acquisition.

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References


