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IMPACT OF REPEATED ACTIVATION ON HEAT OUTPUT OF ELECTRIC PLUGGERS

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ABSTRACT

Impact of Repeated Activation on Heat Output of Electric Pluggers

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Introduction: Multiple obturation techniques require reliable heat output by pluggers to thermoplasticize gutta percha to seal the root canal system. This study aimed to evaluate the accuracy and reliability of electrically heated plugger heat production after repeated activation cycles. **Methods**: The Elements Obturation Unit (Kerr Endodontics) and 15 Buchanan Heat Pluggers (Kerr Endodontics), five of each of the following sizes: XF (30/0.04), F (55/0.06), FM (55/0.08), were tested. A K-type thermocouple (Omega Engineering) connected to a 4-Channel RDXL-SD series portable thermometer/data logger (Omega Engineering) was used to record a single maximum temperature for each plugger every 25 activations, up to 1,000 activations. One-way analysis of variance (ANOVA) and the Kruskal Wallis statistical test procedures were used to assess statistical significance and the Tuckey Post Hoc multiple comparison procedure was performed to compare the heat output between the three different plugger sizes. **Results**: 0.06 and 0.08 taper pluggers generated heat with no statistically significant changes up to 1,000 activations. 0.04 pluggers produced heat at a statistically-significant lower temperature compared to the 0.06 and 0.08 pluggers. Three of the five 0.04 taper pluggers stopped functioning before 1,000 activations (238, 313 and 421 activations, respectively). **Conclusions**: 0.06 and 0.08 Buchanan Heat Pluggers can reliably output heat at a level appropriate to thermoplasticize gutta percha for up to 1,000 activations. 0.04 taper

pluggers produce lower temperature output and have a shorter lifespan than the 0.06 and 0.08 pluggers.

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LIST OF ABBREVIATONS

ANOVA	Analysis of Variance
°C	Degrees Celsius
XF	Extra Fine (plugger size (30/0.04)
F	Fine (plugger size (55/0.06)
MF	Medium Fine (plugger size 55/0.08)
mm	millimeters

INTRODUCTION

Gutta-percha remains the most common obturation material used to seal the root canal system (1). It is an organic polymer that exists in two crystalline geometric phases: the alpha phase is soft and pliable and the beta phase is a solid mass. However, when the beta phase is heated above 53-59°C, the solid mass form becomes amorphous and thermoplastic, allowing it to move into and better seal the complex root canal system (2).

Obturation techniques such as vertical compaction and continuous wave leverage the gutta-percha phase changes by using heated pluggers to warm and thermoplasticize gutta-percha. Schilder introduced the vertical compaction technique in 1967, recommending the use of heat pluggers and cold pluggers to stepwise heat, downpack and seal the root canal system from the apical to the coronal segments (3). Advances in electronic heat pluggers allowed for Buchanan to introduce the continuous wave technique, where an electronic heat plugger is activated and pushed apically in a single continuous motion, with a thermoplasticized gutta-percha used to backfill the middle and coronal aspects of the canals (4).

Reliable and predictable heat generation by electronic heat pluggers is essential to clinical efficiency using these techniques, and also to patient safety. Classic studies show osseous tissue damage with excessive heat (5,6), and also that heat pluggers have the ability to produce temperatures above these thresholds (7,8). Ideally, heat pluggers should demonstrate consistent heat production within safe and tolerable ranges. Several studies have found that heat pluggers either did not reach the manufacturers' stated temperature, or that plugger temperatures were not reported (9,10,11,12,13). Further complicating the process, gutta percha may transport heat irregularly when heated with pluggers (14). Inaccuracy and unreliability reduce confidence in electronic heat plugger temperatures, potentially exacerbated by degradation over time with repeated use.

A more recent study by Correa, et al., showed that repeated autoclave cycles and/or using electronic heat pluggers at high temperatures shortens the lifespan of the pluggers and increases the likelihood of malfunction (15). However, a PubMed search revealed no studies that establish a baseline for the lifespan of electronic heat pluggers over time with repeated use independent of autoclave sterilization. The purpose of this study is to evaluate the accuracy and reliability of electronic plugger heat production after repeated activation cycles alone.

MATERIALS AND METHODS

Fifteen Buchanan Heat Pluggers (Kerr Endodontics, Orange, CA) were evaluated in this study, five of each of the most commonly used sizes: Extra Fine (XF: 30/0.04), Fine (F: 55/0.06) and Fine Medium (FM 55/0.08). The electrically-powered Elements Obturation Unit (Kerr Endodontics, Orange, CA) was selected for use in this research over other obturation units to control for 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 Solidworks 2016 (Dassault Systémes, Waltham, MA) and printed on a Form 2 3-D printer (Formlabs, Somerville, MA) using "High Temp" high temperature resin (Formlabs, Somerville, MA), (Figure 1B), (16). The jig includes indented channels allowing for secure placement of the plugger and the attachment of the K-type thermocouple (Omega Engineering Inc, Stamford, CT). This was connected to a 4-Channel RDXL-SD series portable thermometer/data logger (Omega Engineering Inc, Stamford, CT) to record temperatures (Figure 1A). Data was automatically exported to a Microsoft Excel spreadsheet, and then maximum temperature data points collected.

A B

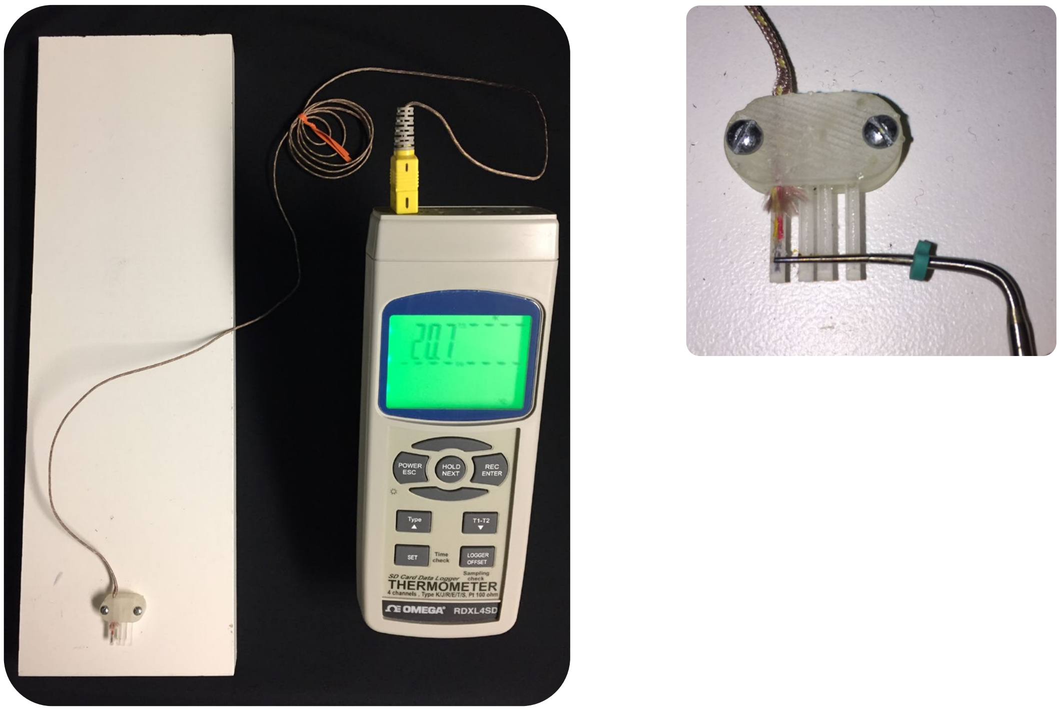

Figure 1. (A) Data logger, thermocouple and custom jig, and (B) Custom jig with secured thermocouple and Buchanan heat plugger in place

The Elements unit was set to the manufacturer's preset "downpack" mode, featuring a 200°C temperature setting with automatic heat cutoff after a four-second activation. Each of the 15 pluggers were tested individually with repeated activation cycles. The maximum temperature over the four-second activation was recorded. A cooling cycle of five to ten seconds between each activation allowed the heat plugger tip to cool and more closely mimic a clinical setting than simple repeated activation with no cooling.

A baseline maximum temperature was recorded for each plugger, and then another maximum temperature was recorded on the 25^{th} activation. 25 activation cycles were completed each day for each plugger, limiting the number of daily activations to a workload more in range of normal clinical use. The maximum temperature at the tip of the heat plugger was recorded every 25 activation cycles until 1,000 activations per plugger were completed. This resulted in 40 days of data collection and 41 data points for each of the 15 pluggers. All measurements were taken at room temperature (20ºC ± 2ºC) and all tests and data collection were completed by a single observer.

One-way analysis of variance (ANOVA) and Kruskal Wallis tests were performed to assess statistical significance and the Tuckey Post Hoc multiple comparison test was performed to compare the heat output between the three different plugger sizes.

RESULTS

The data show no significant decrease in mean heat output over time for all pluggers that functioned to 1,000 activations (Figure 2). The functioning 0.04 pluggers produced a baseline mean temperature of 115.5°C, a maximum mean temperature of 176.2°C on day 10 after 250 activations, and a final data point of 133.2°C after 1,000 activations. The 0.06 pluggers produced a baseline mean temperature of 171.6°C, a maximum mean temperature of 230.4° C on day 10 after 250 activations, and a final data point of 197.7°C after 1,000 activations. The 0.08 pluggers produced a baseline mean temperature of 160.7°C, a maximum mean temperature of 244.4°C on day 11 after 275 activations, and a final data point of 190.2°C after 1,000 activations.

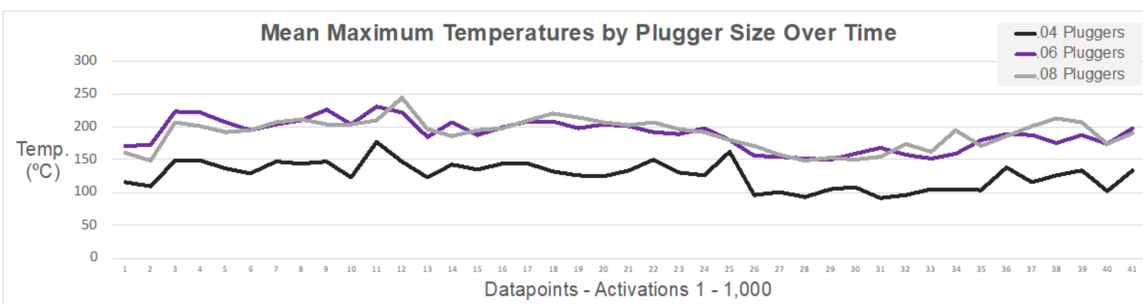

Figure 2. Mean Maximum Temperature by Plugger Size Over Time.

The overall mean maximum temperature for 0.06 and 0.08 pluggers was 188.8 ± 22.7°C and 190.3 ± 22.6°C, respectively. The 0.04 pluggers produced a mean maximum temperature of 126.7 ± 20.3°C.

One-way analysis of variance (ANOVA) and the Kruskal Wallis statistical test procedures both confirmed statistically significant differences in mean heat output of the three different plugger sizes (p-value < 0.005). The Tuckey post hoc multiple comparison test indicated that there were no statistically significant differences between the 0.06 and the 0.08 pluggers (p-value = 0.95). However, at the .05 level of significance, each of them was statistically different from the 0.04 taper pluggers (p-value < 0.005).

In addition to lower mean heat output, three of the five 0.04 pluggers stopped functioning prior to 1,000 activations (Figure 3). The Elements Obturation unit produced the "Check Tip Indicator" error indicator for 0.04 pluggers 5, 4 and 1 after 238, 313 and 421 activations, respectively, and the pluggers never re-gained functionality.

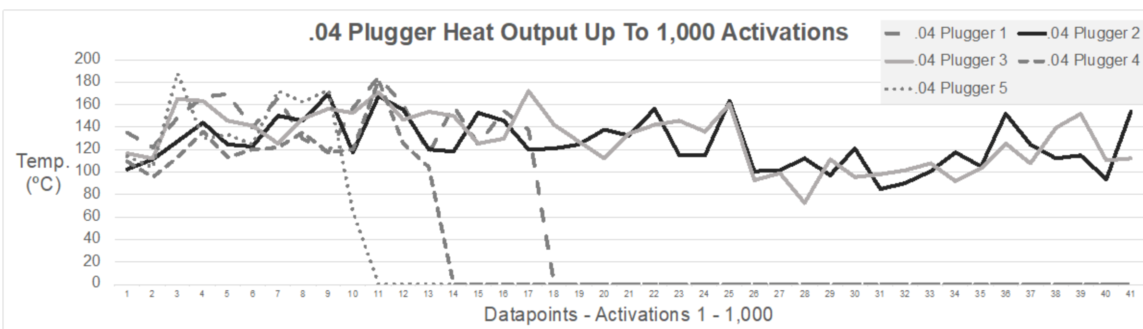

Figure 3. 0.04 Plugger Heat Output Up To 1,000 Activations

DISCUSSION

The findings of this study show that heat pluggers can generally produce temperatures to safely thermoplasticize gutta percha up to 1,000 activations. While statistical analysis showed significant differences between 0.04 pluggers and the larger sizes, and notable variability in general, all functioning pluggers produced heat sufficient to surpass the 53-59°C threshold to thermoplasticize gutta percha. This presents a clear view of plugger performance in a controlled benchtop setting. This also represents a limitation of this study, as the methods do not replicate a realistic clinical scenario involving autoclave cycles and manipulations of the pluggers.

Earlier studies have shown that sterilization of pluggers and operating pluggers at temperatures above the manufacturer's recommendations may lead to reduced heat output (15,17). Our findings indicate that size 0.04 pluggers may be unreliable despite these variables controlled. Based on repeated activations with no bending or manipulation of the pluggers, no autoclaving, and operating at the manufacturer's preset settings for obturation, three of the five 0.04 pluggers were non-functional after what would could represent only a few weeks of clinical operations. Upon failure of the pluggers, the Elements unit emitted a warning sound, the same one made when trying to activate the plugger handpiece with no plugger inserted, and flashed the "Check Indicator Tip" symbol on the screen. According to the Owner's Manual troubleshooting section, an electrical circuit automatically senses if a plugger is connected and will display the "Check Tip Indicator" if an "incorrect" or "worn-out" plugger is installed in the handpiece (18). This renders the ability to increase temperature settings unfeasible as the Elements unit senses no plugger at all. Future research continuing activations beyond

1,000 may contribute to a greater understand of the service life of the 0.06 and 0.08 pluggers. Additionally, controlled activations alone should be compared and combined with autoclave cycles and potential bending or simulated clinical manipulation as additional factors that could contribute to limiting the service life of these heat plugger tips.

The data showed variability in heat output by each individual plugger and the mean of each set of five pluggers (Figure 2), with few noticeable trends. The overall patterns of mean maximum temperature output appear similar except from the 13th to the 25th datapoints, where the 0.04 plugger curve is generally concave upward and the 0.06 and 0.08 plugger curves appear convex downward. This represents data collection days 12-24 or between 300-625 activations. This is potentially caused by the reduced N of the 0.04 pluggers in and leading up to this time frame due to the aforementioned failures at 238, 313 and 421 activations. However, this could not be proven statistically.

Finally, the variability in heat output and plugger failure found in this study should not affect the safety of the obturation unit and pluggers. The 4-second activation of “downpack” mode limits the risk of tissue necrosis from heat and the variability in temperatures and plugger failures found in this study are not a risk to threaten the established temperature thresholds (5).

In conclusion, Buchanan Heat Pluggers size F (55/0.06) and FM (55/0.08) produce heat at a level appropriate to safely and reliably thermoplasticize gutta percha for up to 1,000 activations. The XF (30/0.04) pluggers may be susceptible to lower temperature output overall that should not affect clinical operations. However, the shorter service life of 0.04 pluggers may impact clinical operations.

REFERENCES

1. Johnson WT, Kulil JC, Tay F. Obturation of the Cleaned and Shaped Root Canal System. Cohen's Pathways of the Pulp, 11th Edition; 280-322. St. Louis, MO: Mosby Elsevier; 2016.
2. Goodman A, Schilder H, Aldrich W. The Thermomechanical Properties of gutta-percha. II. The history and molecular chemistry of gutta-percha. Oral Surg Oral Med Oral Pathol Oral Radiol 1974;37:954-61.
3. Schilder H. Filling root canals in three dimensions. Dent Clin North Am 1967;723-744.
4. Buchanan L.S. The continuous wave of condensation technique: a convergence of conceptual and procedural advances in obturation. Dent Today 1994;10:80-5.
5. Eriksson A, Albrektsson T, Grane B, McQueen D. Thermal injury to bone. A vital-microscopic description of heat effects International Journal of Surgery 1982;11:115-21.
6. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent 1983;50:101-7.
7. Floren JW, Weller RN, Pashley DH, Kimbrough WF. Changes in root surface temperatures with in vitro use of the system B HeatSource. J Endod 1999; 25, 593-5.
8. Lipski M. Root surface temperature rises during root canal obturation, in vitro, by the continuous wave of condensation technique using System B HeatSource. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99:505-10.
9. Er O, Yaman SD, Hasan M. Finite element analysis of the effects of thermal obturation in maxillary canine teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:277-86.
10. Lee FS, Van Cura JE, BeGole E. A comparison of root surface temperatures using different obturation heat sources. J Endod 1998;24:617-20.
11. Silver GK, Love RM, Purton D.G. Comparison of two vertical condensation obturation techniques: Touch 'n Heat modified and System B International Endodontic Journal. 1999;32:287-95.
12. Sweatman TL, Baumgartner JC, Sakaguchi R.L. Radicular temperatures associated with thermoplasticized gutta-percha. J Endod 2001;27:512-5.
13. Venturi M, Pasquantonio G, Falconi M, Breschi L. Temperature change within gutta-percha induced by the System-B Heat Source. International Endodontic Journal 2002;35:740-6.
14. Briseno Marroquin B, Wolf TG, Schurger D, Willershausen B. Thermoplastic properties of endodontic gutta-percha: a thermographic in vitro study. J Endod 2015;41:79-82.

15. Correa M, Dutner J, Phillips M, Sidow S, McPherson J. Heat Generation Changes with Electrically Heated Pluggers after Multiple Autoclave Cycles at Different Operating Temperatures. J Endod 2019;45:1529-34.
16. Nelson K. (2018). Accuracy of Digital Settings of Endodontic Obturation Units. Uniformed Services University of Health Sciences, Naval Postgraduate Dental School, Bethesda, MD.
17. Black SW, Bergeron BE, Roberts MD, et al. (2013). Effect of repeated sterilization and simulated clinical use on the heating capacity of System B heat source pluggers. Endod Pract US 2013;6:50–4.
18. Kerr Endodontics. (2019). Elements Obturation Unit - Instructions for Use. Orange, CA: Kerr Endodontics.