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# Heat Generation Changes With Electrically-Heated Pluggers After Multiple Autoclave Cycles at Different Operating Temperatures

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## Abstract

**Introduction:** Electrically-heated pluggers are the most commonly used instruments during warm obturation techniques. This study aimed to evaluate the effect of sterilization and operating temperature settings on the heat generation of pluggers of various taper sizes. **Methods:** Fifty pluggers were sterilized at 270 degrees Fahrenheit (°F) for 25 minutes for a total of 150 cycles. Group 1 consisted of 25 pluggers tested at an operating temperature setting of 200°C whereas group 2 consisted of 25 pluggers tested at 400°C. The heat generation at their tip surface was measured with T-type thermocouples at 0, 50, 100, and 150 autoclave cycles. Unpaired t-test was used to compare the time it took the pluggers to reach 60°C and the mean maximum temperature change. **Results:** After 50 autoclave cycles, all of the 0.04 pluggers in group 1 failed to reach 60°C. After 150 autoclave cycles, some of the 0.10 taper (5/15) and 0.12 taper (1/15) pluggers in group 1 did not reach 60°C. The mean increase in time to reach 60°C ranged between 723 to 3925 milliseconds and 322 to 1520 milliseconds for groups 1 and 2, respectively. The mean maximum temperature change decreased between 12 and 30°C and 25 and 116°C for groups 1 and 2, respectively. **Conclusions:** After multiple autoclave cycles and higher operating temperature utilization, the electrically-heated pluggers transferred less heat to the tip surface potentially making them less effective.

## Key Words

Sterilization, electrically-heated plugger, temperature, thermocouple

Electrically-heated pluggers have become very popular and have arguably replaced traditional flame-heated pluggers for the treatment of teeth requiring endodontic therapy. The manufacturer (1) recommends cleaning and sterilizing these pluggers before every use in order to maximize the therapeutic efficacy of these instruments. Although the effects of sterilization procedures on stainless-steel hand files, Gates Glidden drills, and finger spreaders have been studied (2-6), they have not been investigated for dead soft stainless-steel electrically-heated pluggers. Knowledge of the metallurgy of electrically-heated pluggers, methods of usage, and a comprehensive evaluation of the external stresses placed on the instrument during sterilization will enable practitioners to produce predictable results during non-surgical root canal therapy and endodontic retreatment.

The warm obturation techniques introduced by Dr Schilder (7) require a heat-induced phase transformation of gutta-percha from beta to alpha at 42°C to 49°C and from alpha to amorphous at 53°C to 59°C (8). Gutta percha must reach 60°C in order to undergo its various phase transformations to achieve an adequate three-dimensional obturation (9, 10). One potential concern is that heat stresses placed on the pluggers after each sterilization cycle may have a cumulative effect, significantly impacting the heat production and efficacy of the instrument.

The pluggers may also fail to generate a consistent and reliable heat source if used at higher operating temperature settings. The manufacturer states that their life is shortened as the operating temperature settings are increased and that all pluggers will gradually lose their heating efficiency over some time (1). Currently, there are many non-surgical root canal therapy and retreatment techniques employed that require different operating temperature settings on gutta-percha heating devices. The manufacturer-recommended operating temperature setting for the continuous wave of condensation technique is 200°C (1). Some plastic carrier removal techniques utilize electrically-heated pluggers during endodontic retreatments. However, these methods require a considerable increase in the plugger's operating temperature to range from 225°C to 400°C (11, 12).

The purpose of this study was to determine if the heat stresses endured by the pluggers during autoclaving and utilization at temperatures higher than the manufacturer recommendation have a cumulative effect that could significantly impact their heat generation and efficacy.

## Significance

Multiple autoclave cycles and utilization of the electrically-heated pluggers at extremely high operating temperature settings could potentially impact their efficacy. Therefore, the use of these instruments could impact the efficiency and predictability of non-surgical root canal therapy and endodontic retreatment.

## Materials and Methods

Sixty pluggers of varying taper size (0.04, 0.06, 0.08, 0.10, and 0.12) were divided into four groups. For all four groups, a thermocouple measured the temperature change over a 15-second plugger activation cycle at gutta-percha heating device operating temperature settings of 200°C or 400°C. Since the manufacturer claims that the tip reaches the preset temperature in less than a second and that the heat travels from the tip towards the shaft of the electrically-heated plugger, we measured the temperature change at the pluggers' tip surface in real time. Each plugger was allowed to return to ambient temperature (25°C) before subsequent activations. Two values were extracted from this data. The first was the peak temperature recorded on the plugger's tip surface over 10 seconds after activating each gutta-percha heating device (average of 3 recordings). This recorded the maximum temperature change. The second was the time required in milliseconds to reach 60°C after a 10-second plugger activation (average of 3 recordings). This recorded the gutta-percha heat-induced phase transformation temperature requirement. The same thermocouple and data collecting system as that used by Demopoulos et al (13) was utilized to measure the temperature change (Figure 1).

Since the manufacturer does not calibrate the gutta-percha heating device (System B™, Kerr Corporation, Orange, CA email correspondence), an internal calibration was completed before each testing period. Three gutta-percha heating devices were used with the same unsterilized pluggers of each taper to complete the internal calibration. The gutta-percha heating device was operated at its full power setting of 10, and extra steps were taken in order to ensure that the device remained as close to fully charged as possible at all times (1). For each testing period, three 15-second plugger activation cycles, utilizing the same operating temperature settings, were completed for the pluggers in groups 1-4 in a repeat measure design. In groups 1 and 2, after the initial tests, the pluggers were cleaned with water and a mild, non-abrasive detergent and dried thoroughly. The pluggers and a sterilization indicator strip (3M Comply Steam Chemical Integrator Class 5) were placed in a sterilization pouch and into the steam autoclave unit, avoiding contact with other instruments (14). The autoclave was set at 270°F

and ran for 25 minutes (10). Sterilization indicator strips were inspected after every sterilization cycle to ensure that the appropriate exposure time and temperature had reached the instruments, deeming them sterile. The pluggers were cleaned and autoclaved for 50 cycles after each testing period (0, 50, 100, and 150 cycles) until a total of 150 cycles were completed prior to the final testing period. Groups three and four, served as controls for temperature settings of 200°C and 400°C, respectively, without being cleaned and autoclaved between testing periods.

To compare the 0 autoclave cycle subgroup with the 50, 100 and 150 autoclave subgroups at a significance level of  $p < 0.05$ , an unpaired, double-tailed t-test was used for groups 1 and 2 while a paired double-tailed t-test was used for groups 3 and 4.

## Results

Electrically-heated pluggers maximum temperature change decreased as they endured more autoclave cycles. The mean and SEM values are noted in Table 1. Graphic illustrations of the results are in Figure 2. The highest maximum temperature change recordings for groups 1 and 2 were 97°C and 211°C, respectively. The maximum temperature change decreased for all of the pluggers in both groups 1 and 2 after 150 autoclave cycles when compared to their respective 0 autoclave cycles subgroups. The 0.04, 0.06, 0.08, 0.10, and 0.12 taper pluggers in group 1 decreased by 13°C, 27°C, 29°C, 23°C and 22°C, respectively. In group 2, the 0.04, 0.06, 0.08, 0.10, and 0.12 taper pluggers decreased by 24°C, 49°C, 100°C, 116°C, and 95°C, respectively, demonstrating greater decreases than observed in group 1. Unpaired t-test showed that the difference between the maximum temperature change of all pluggers was statistically significant compared to their respective 0 autoclave cycles subgroups.

The pluggers also took longer to reach the desired 60°C temperature as they endured more autoclave cycles. Values for the mean and SEM for the time to reach 60°C for each subgroup at various autoclave cycles are in Table 2. Graphic illustrations of the results are in Figure 2. Only one of the 0.04 taper pluggers in group 1 failed to reach 60°C at 0 autoclave cycles, but after 50 autoclave cycles, all group 1 0.04 pluggers failed to reach 60°C. After 100 autoclave cycles, some of the 0.10 (5/15 activation cycles) and 0.12 (1/15 activation cycles) taper pluggers in group 1 did not reach 60°C. One of the 0.04 taper pluggers in group 2 malfunctioned and did not generate any heat after 150 autoclave cycles. Excluding the pluggers that failed to reach 60°C, the mean increase in the time it took the rest of the pluggers in groups 1 and 2 to reach 60°C was 4 and 2 seconds, respectively.

All of the controls achieved a consistent and reproducible maximum temperature change and time to reach 60°C throughout this study. The mean maximum temperature change difference was 3°C for group 3 and 5°C for group 4. All of the pluggers in groups 3 and 4 reached the 60°C requirement during every activation cycle with the mean time remaining 3 and 2 seconds, respectively. Paired t-test did not show a statistically significant difference between any of the autoclave subgroups when compared to their respective 0 autoclave cycle subgroup.

## Discussion

The raw data showed much variability towards the end of the activation cycle. While one showed no increase in temperature and another showed marked temperature increases and decreases, the most common pattern towards the end of the activation cycle showed a slow increase in temperature over time until the end of the activation. The manufacturer claims that the tip reaches the preset temperature in less than a second and that heat travels from the tip towards the shaft of the electrically-heated plugger. When the final temperature is reached, the heating power is cut off to the low level needed to keep the tip at the preset temperature. If the tip temperature drops, the heating power is immediately increased to regulate the temperature (10). Due to the logistical challenges of repeated sterilization cycles, the pluggers for groups 1 and 2 were tracked as subgroups and not individually. Therefore, it is possible that variations in the specific pluggers could be responsible for these various patterns; however, the controls were tracked individually and consistently demonstrated these three patterns of temperature change at the end of the activation cycle.

This study confirmed the manufacturer's claim that the utilization of the pluggers at higher operating temperature settings will decrease their life expectancy over time. The maximum temperature change for each subgroup decreased more in group 2 when compared to group 1. In contrast, the time required to reach 60°C for each subgroup increased more in group 1 compared to group 2. These findings seem logical since increasing the operating temperature setting to 400°C would initially produce a more rapid temperature increase reaching 60°C faster, regardless of the number of autoclave cycles.

Similarly, sterilization negatively impacted the life expectancy of all the pluggers. All pluggers that endured the heat stresses of sterilization had a marked decrease in the maximum temperature change over time. Even though stainless-steel has a lower potential of undergoing metal oxidation, usually due to the presence of chromium, it is still not immune to this phenomenon. Chromium forms a passive surface layer when interacting with moisture to protect the stainless steel from corrosion, but the limit of this corrosion resistance may be exceeded

under certain harsh environments (15). In endodontics, such conditions include the repeated exposure of the pluggers to corrosive liquids containing chlorine ions (sodium hypochlorite, mild, non-abrasive detergents etc.) and high temperatures during utilization and autoclaving. Chlorine ion exposure may lead to pitting corrosion which may cause chloride stress corrosion cracking. These cracks propagate at higher rates when stainless-steel is exposed to temperatures above 60°C, and they may ultimately lead to the penetration of moisture into the instrument (16). Disassembly of one of the pluggers allowed us to examine the various layers of these instruments. The outermost layer is composed of stainless steel while the center contained a metallic core encapsulated by a resin-like material, most likely a semiconductor. Galvanic corrosion could occur if two dissimilar metals, such as the outermost stainless-steel layer and the metallic core, come into contact with each other and an electrolyte, such as water. Galvanic corrosion accelerates the corrosion of the less noble metal, impeding its heat conductivity and ultimately interfering with the heat generating capacity of the pluggers (17).

Our findings indicate that sterilization and operation of these instruments at extremely high-temperature settings will not allow them to reach 60°C and may even cause them to malfunction altogether. One way to mitigate this issue is to increase the operating temperature setting to 250°C instead of the manufacturer-recommended setting of 200°C. A pilot study was conducted at an operating temperature setting of 250°C on the same pluggers that had failed to reach 60°C at 200°C, and they all successfully reached 60°C. A concern to some providers is that by increasing the operating temperature settings to 250°C, harm to the periodontium may occur. Floren et al. (18) found that utilization of these instruments at 250°C would increase the extraradicular temperature by 10°C which was found to cause irreversible damage to osseous tissue by Erikson and Albrektsson. However, it must be emphasized that in this study, this critical temperature was only reached for a few seconds and not the full minute as tested by Erikson and Albrektsson (19). Also, many studies have found that operating these instruments at 250°C will not lead to an extraradicular temperature increase of 10°C (20-24). These findings further suggest that the likelihood of irreversible damage to the periodontium by operating these instruments at 250°C instead of 200°C is unlikely.

In conclusion, sterilization and utilization of electrically-heated pluggers at extremely high-temperature settings shortens their lifespan potentially making them less effective during endodontic procedures. We suggest not utilizing these instruments at extremely high operating temperature settings in order to increase their lifespan and decrease the potential for malfunction. We also suggest the utilization of these instruments at 250°C instead of the

manufacturer-recommended setting of 200°C to mitigate the effects of sterilization. This ensures proper plasticization of the gutta-percha to predictably fill the prepared root canal space.

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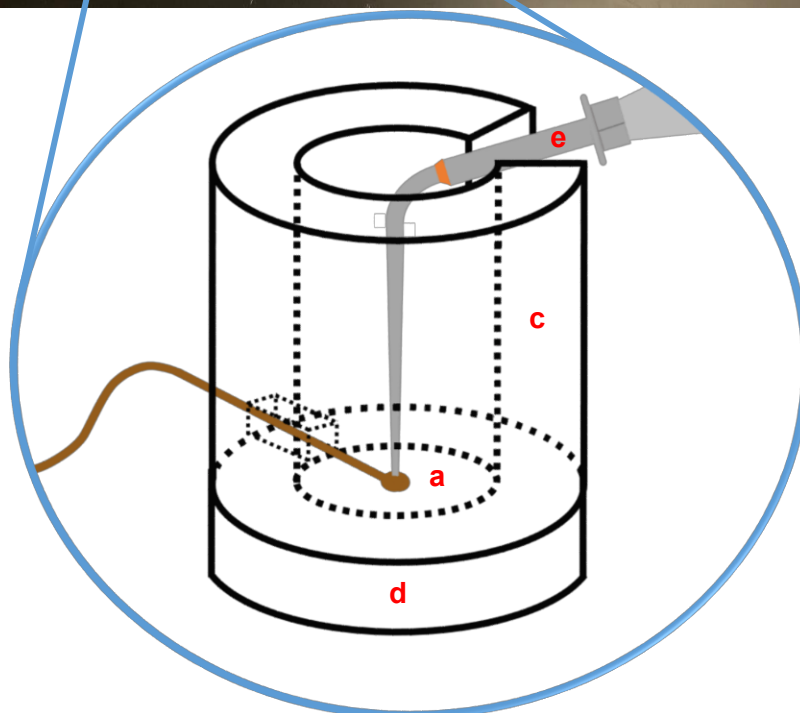
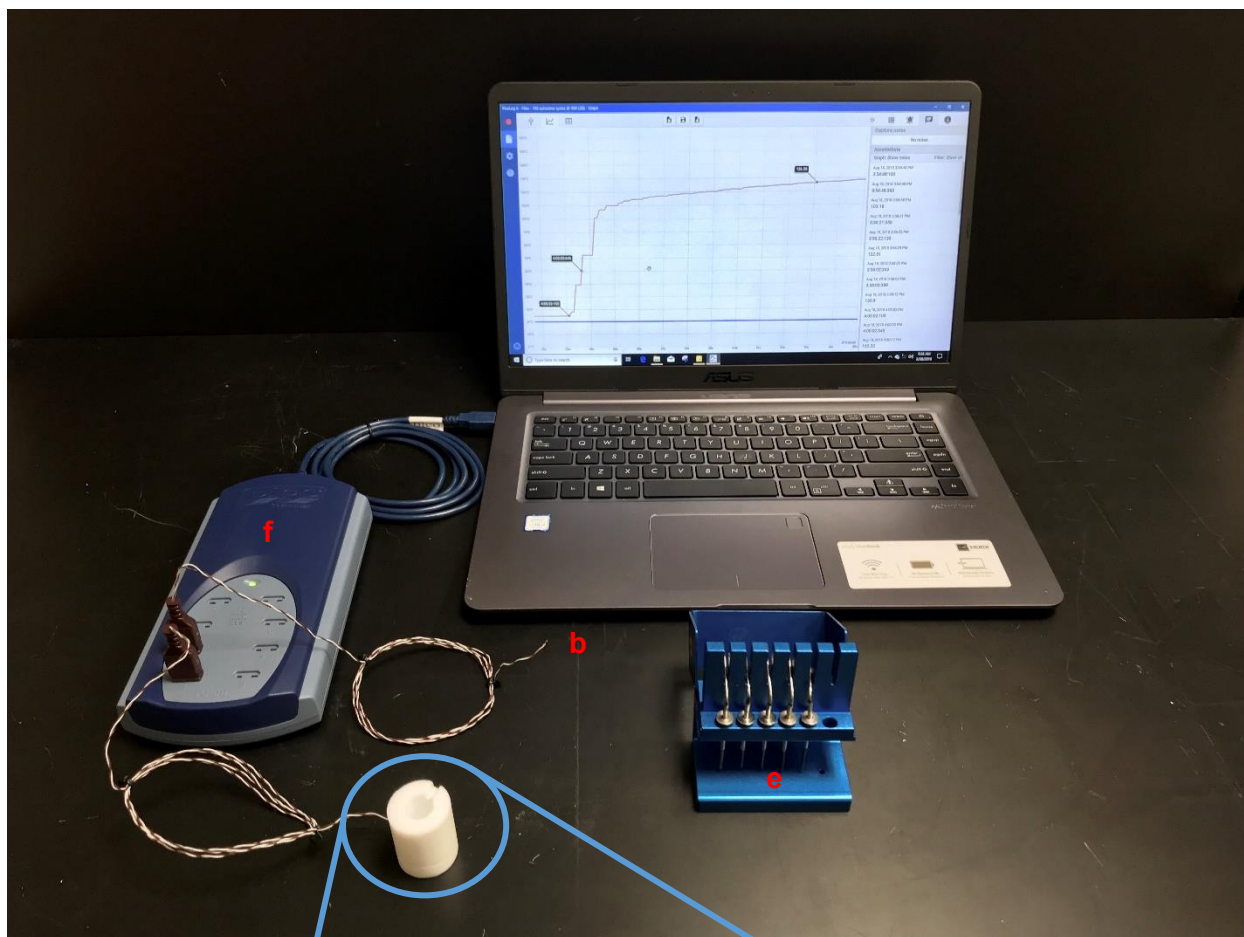
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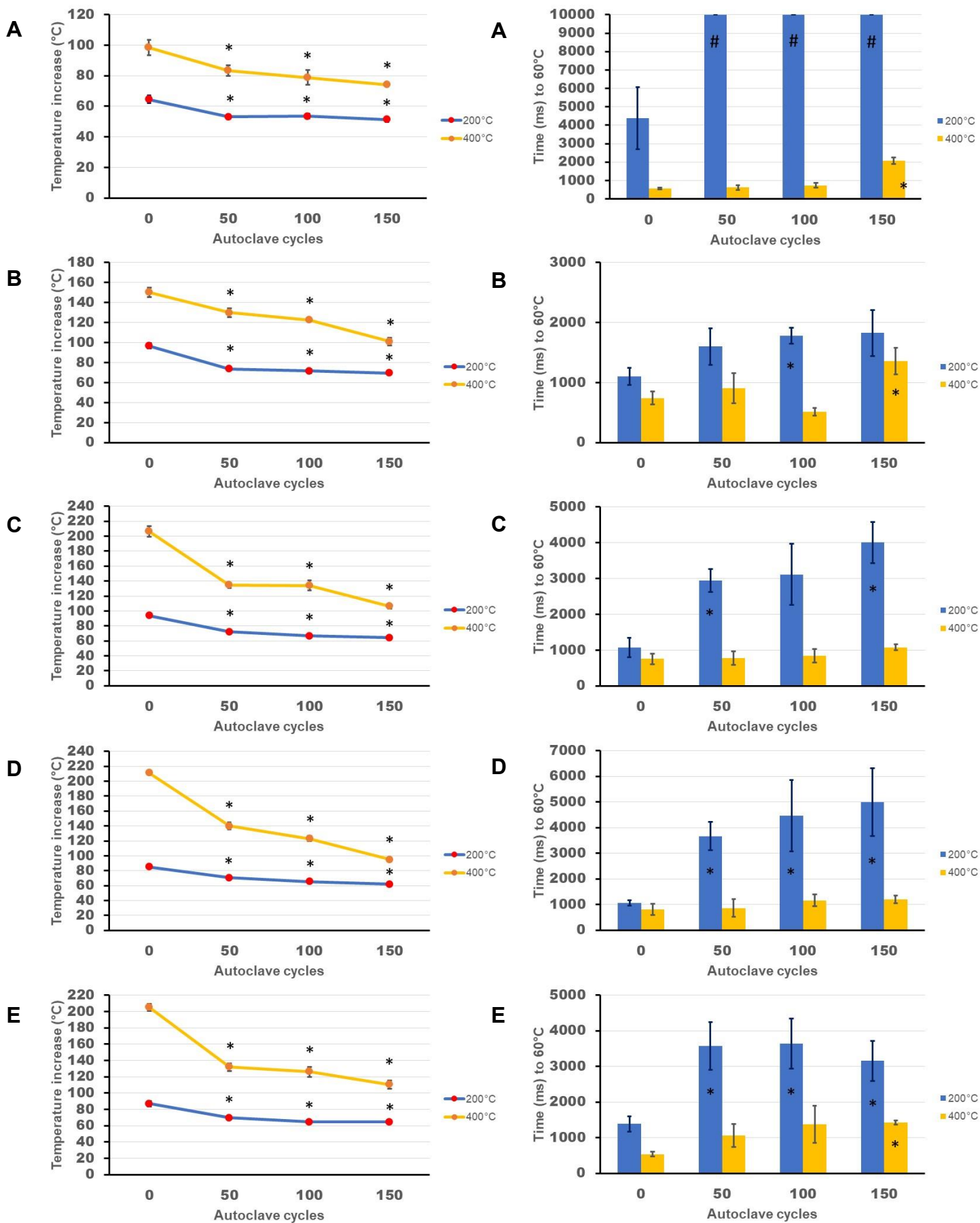
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**Figure 1.** The experimental setup: (a) thermocouple used to record temperature changes on the plugger tip surface, (b) thermocouple used to record ambient temperature changes, (c) PTFE cylinder, (d) PTFE disk, (e) electrically-heated plugger(s), (f) TC-08 Thermocouple Data Logger



**Figure 2.** Effect of sterilization on the mean maximum temperature and time required to reach 60°C at the tip surface of (A) 0.04, (B) 0.06, (C) 0.08, (D) 0.10, and (E) 0.12 tapered pluggers after a 10 second activation at an operating temperature setting of 200°C and 400°C. (Vertical lines represent SEM.)

# Pluggers did not reach 60°C after 10 second activation.

\* Statistically different from the 0 autoclave cycle subgroup ( $p < 0.05$ ).

Table 1. Results of mean maximum temperature after 10 second activation †

Group / Cycles	Electrically- heated Plugger Taper Size (n = 60)					
	0.04	0.06	0.08	0.10	0.12	
200°C	(n = 5)					
	0	64.58 ± 2.66	96.80 ± 2.85	93.67 ± 1.79	85.27 ± 1.34	86.93 ± 2.93
	50	53.20 ± 0.68*	73.60 ± 1.50*	72.07 ± 0.61*	70.47 ± 1.50*	69.67 ± 1.93*
	100	53.47 ± 1.58*	71.53 ± 2.11*	66.73 ± 1.40*	65.40 ± 2.72*	64.87 ± 1.39*
150	51.40 ± 1.49*	69.47 ± 1.33*	64.27 ± 1.03*	61.93 ± 1.35*	64.67 ± 1.52*	
200°C Control	(n = 1)					
	0	62.75 ± 2.47	99.19 ± 0.45	87.20 ± 2.33	81.01 ± 2.80	79.01 ± 2.80
	50	61.12 ± 0.26	97.36 ± 2.30	89.53 ± 7.90	78.19 ± 2.99	81.47 ± 3.92
	100	61.98 ± 0.90	97.42 ± 4.31	87.20 ± 4.42	79.66 ± 4.49	82.53 ± 8.86
150	61.87 ± 1.55	99.98 ± 2.70	88.99 ± 5.73	79.56 ± 2.07	82.29 ± 6.02	
400°C	(n = 5)					
	0	98.53 ± 5.11	150.27 ± 4.66	206.07 ± 7.02	211.33 ± 2.23	205.20 ± 4.31
	50	83.33 ± 3.48*	129.93 ± 4.47*	134.40 ± 3.59*	140.07 ± 4.43*	131.87 ± 4.57*
	100	78.87 ± 4.95*	122.60 ± 1.15*	134.20 ± 6.65*	123.13 ± 3.45*	126.13 ± 6.15*
150	74.25 ± 1.27*	100.93 ± 3.56*	105.87 ± 2.98*	95.20 ± 1.56*	110.53 ± 5.10*	
400°C Control	(n = 1)					
	0	108.11 ± 6.03	175.75 ± 0.45	181.98 ± 2.33	197.55 ± 2.80	187.33 ± 2.80
	50	109.02 ± 3.05	172.08 ± 2.30	181.98 ± 7.90	191.88 ± 2.99	189.41 ± 3.92
	100	110.40 ± 2.26	168.53 ± 4.31	177.23 ± 4.42	193.03 ± 4.49	187.50 ± 8.86
150	108.71 ± 6.49	174.44 ± 2.70	186.17 ± 5.73	192.99 ± 2.07	192.05 ± 6.02	

† All numbers expressed in degrees Celsius (mean ± SEM).

\* Significantly different from respective 0 autoclave cycles subgroup (p &lt; 0.05).

Table 2. Results of mean time required to reach 60°C after 10 second activation †

Group / Cycles	Electrically- heated Plugger Taper Size (n = 60)				
	0.04	0.06	0.08	0.10	0.12
200°C	(n = 5)	(n = 5)	(n = 5)	(n = 5)	(n = 5)
0	4974 ± 1685	1103 ± 145.64	1069 ± 267.54	1071 ± 105.89	1391 ± 214.50
50	10000 ± 0#	1602 ± 305.39	2937 ± 319.97*	3670 ± 545.21*	3577 ± 666.30*
100	10000 ± 0#	1782 ± 134.09*	3116 ± 852.74	4471 ± 1395.19*	3640 ± 698.74*
150	10000 ± 0#	1826 ± 382.09	4040 ± 568.68*	4996 ± 1316.47*	3155 ± 555.88*
200°C	(n = 1)	(n = 1)	(n = 1)	(n = 1)	(n = 1)
Control	5449 ± 2003.58	740 ± 158.30	797 ± 32.16	1136 ± 346.06	914 ± 134.46
50	6471 ± 2021.40	955 ± 411.73	726 ± 154.38	1237 ± 447.73	1761 ± 764.04
100	1791 ± 270.31	471 ± 107.24	1768 ± 1149.40	1236 ± 533.11	2230 ± 1227.90
150	4571 ± 1259.59	781 ± 192.30	1373 ± 728.87	2064 ± 336.31	2397 ± 361.06
400°C	(n = 5)	(n = 5)	(n = 5)	(n = 5)	(n = 5)
0	554 ± 46.32	741 ± 108.86	758 ± 147.04	812 ± 208.84	540 ± 70.07
50	617 ± 134.6	907 ± 248.05	775 ± 184.12	866 ± 350.95	1061 ± 320.51
100	740 ± 129.73	510 ± 64.70	842 ± 190.08	1166 ± 226.10	1380 ± 524.58
150	2074 ± 174.4*	1358 ± 218.47*	1080 ± 76.36	1206 ± 141.69	1426 ± 53.42*
400°C	(n = 1)	(n = 1)	(n = 1)	(n = 1)	(n = 1)
Control	2144 ± 1421.39	262 ± 17.49	502 ± 50.74	406 ± 159.03	315 ± 15.56
50	320 ± 92.79	337 ± 67.68	539 ± 74.75	328 ± 79.83	673 ± 253.66
100	2313 ± 1650.53	1638 ± 423.60	1509 ± 919.79	229 ± 117.44	704 ± 241.80
150	122 ± 30.77	275 ± 17.71	663 ± 438.06	333 ± 60.73	550 ± 192.64

† All numbers expressed in milliseconds (mean ± SEM).

# Pluggers did not reach 60°C after 10 second activation.

\* Significantly different from respective 0 autoclave subgroup ( $p < 0.05$ ).