HEAT TESTING METHODOLOGY COMPARISON

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Abstract

Pre-operative pulpal and periapical diagnosis is critical for effective and appropriate endodontic treatment. Occasionally patients present with a chief complaint involving hypersensitivity to heat – a hallmark sign of irreversible pulpitis. In an attempt to replicate this chief complaint, a variety of clinical methods have been developed to deliver a heat stimulus to a tooth. Friction from a burlew wheel, heated gutta-percha, a heated instrument, and hot water have all been used to warm teeth. Recently, an instrument has been developed which is heated electronically and placed directly against a tooth. The aim of this study was to determine which of these methods produces the most consistent temperature rise within the pulp of a tooth. The value of this consistency is that it allows clinical differentiation between a normal pulp and a pulp demonstrating irreversible pulpitis. The present study used extracted maxillary teeth with thermocouples mounted within the pulp chamber. Four operators applied the following methods to the teeth: heated gutta-percha, heated ball burnisher, hot water, and an electronic probe attached first to a System B™ and then to an Elements™ unit. Each test was performed for 60 seconds, and the temperature recorded every half-second. Analysis of the data revealed the most consistent warming of the pulp was accomplished with the electronic probe attached to the Elements™ unit. The lowest level of consistency was found with hot water. The electronic probe also yielded temperature changes which were more consistent between operators compared to the other three methods.

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Heat Testing Methodology Comparison

When a patient presents for endodontic treatment, appropriate pre-operative diagnosis is imperative for effective treatment. Occasionally, patients will present with a chief complaint of heat sensitivity. To correctly identify the tooth responsible for the symptoms it is imperative that the clinician reproduce the patient's chief complaint. While a majority of endodontic chief complaints do not require the use of heat testing, there are occasions where this test is valuable and necessary. Several techniques of delivering heat to a tooth have been used in the past, and more recently, the use of an electronic probe has been introduced as a heat source for endodontic testing. These methods of delivering heat to a tooth for diagnosis are variable and providing too much heat may damage the pulp or periodontium. A safe and repeatable testing method is needed to ensure standardized results.

Pulpal Insult and Injury

It has been established that bacteria are the principal cause of pulpal inflammation (Kakehashi et al., 1965). Bacterial contamination often occurs from dental caries (Reeves, Stanley, 1966) or through cracks and fractures (Stanley, 1968). As caries proliferates through the dentin, the pulpal inflammation may begin as a low-grade chronic process and then advance to widespread acute inflammation. Seltzer et al. observed how dynamic this process can be, sometimes oscillating between acute and chronic, localized and widespread inflammation (Seltzer et al., 1963). As a result of this inflammation, allodynia and hyperalgesia may occur, causing the pulp to become hypersensitive to temperature changes (Dachi, 1965). Dachi found that 57% of pulps classified as "hyperemic" were sensitive to heat and 75% were sensitive to cold.

Another study found the highest incidence of heat sensitivity (30%) in teeth exhibiting chronic partial pulpitis with partial necrosis. The lowest incidence of a response to heat was observed in teeth with necrotic pulps (Dummer et al., 1980). Yet another study found that 25 of the 26 teeth with pulpitis were sensitive to both heat and cold (Mitchell, Tarplee, 1960). An apparent explanation for these changes in sensation could be that nociceptive C-fibers in the pulp are more resistant to hypoxia than Aδ nociceptors and can be activated by multiple stimuli, such as thermal, mechanical or even inflammatory mediators such as histamine and bradykinin (Närhi et al., 1984; Närhi, 1985). As these inflammatory mediators impact the pulp, along with neuropedties like substance P and calcitonin gene related peptide, peripheral sensitization of the sensory nerves begins to occur. If the painful stimulus is allowed to continue, then central sensitization may also occur. The end result may be that heat which normally has little to no effect on a tooth suddenly becomes excruciatingly painful.

Tooth Sensitivity

In the past, significant amounts of research have been done to establish how the dental pulp senses temperature changes. Early studies in pulp sensitivity focused on a direct sensation of the applied stimulus assuming the pulpal nerves acted as thermoreceptors. However, the finding that some normal pulps do not respond to temperature changes is not explained by this theory. For example, Degering had difficulty eliciting any patient response when applying heat to a variety of teeth which were assumed to have normal pulps (Degering, 1962). Also, some pulps are very sensitive to temperature changes despite the pulp being mostly necrotic. Since the nerve tissue does not survive necrosis (Mullaney et al., 1970), this sensitivity is not explained by a direct sensation theory of dentin sensitivity (Brännström, 1966). Because of this confusion regarding how the pulp “feels” temperature changes, further research was done on other theories of pulpal sensitivity. Two different theories have been considered in more contemporary research: the hydrodynamic theory and the theory that microcirculatory changes alter the pressure in the pulp and results in triggering pulpal sensory nerves. Kim investigated circulation changes in the pulp during different temperature applications and found that a 20°C rise in tooth surface temperature caused the pulpal blood flow to increase by 40% (Kim, 1986). He therefore proposed the inflammatory response changes the pulpal blood flow and thereby the microcirculatory response to a painful stimulus is altered resulting in hyperalgesia and allodynia. Currently, the hydrodynamic theory of dentin sensitivity seems to explain our thermal testing with the best correlation to our clinical findings. In 1963, Brännström first proposed that temperature changes to enamel and dentin may cause the contents of the dentin tubules to shift, thereby generating a neurological response (Brannstrom, 1963). From that initial proposal, further research was done to show that causing movement of the fluid within dentin tubules generates a response from the patient. The following year, Brännström published findings, which demonstrated that placing dry paper disks on freshly cut dentin would elicit pain. However, when wet paper disks were placed on the dentin no sensitivity was felt (Brannstrom, Astrom, 1964). Further research demonstrated that applying cold to a tooth caused a rapid movement of pulpal fluid outward through the dentin and heating a tooth caused a significant inward fluid movement (Brannstrom, Johnson, 1970). It was also demonstrated that these fluid movements were significant enough to change the pressure within the intact dental pulp. Heating a tooth was found to increase the pressure within a tooth by 45 mm of Hg (Beveridge, Brown, 1965). Further confirmation to this theory of dentin sensitivity was provided by research showing that patients respond to thermal changes before measurable changes in tooth temperature have occurred (Hensel, Mann, 1956; Trowbridge et al., 1980). It has also been demonstrated that temperature changes applied to dentin will cause strain within the dentin and, therefore, result in fluid movement (Linsuwanont et al., 2008b). Based on these studies, it seems most plausible that the early and rapid movement of the pulpal fluid is responsible for triggering the neurologic response which is interpreted as tooth pain. Many studies have focused on the way cold moves fluid within dentin tubules, but several have also investigated the effect of heat testing techniques. Brännström noted that applying heat to a tooth moved fluid into the pulp of the tooth (Brannstrom et al., 1968) and did so with a higher volume than that seen with cold (Brannstrom, Johnson, 1970). Clinically, most teeth are much more responsive to cold than to heat and this is not explained only on the basis of the volume of fluid movement. Rather, the authors proposed that the bulk of the pulp tissue provided a resistance against the inward fluid movement caused by heating the crown and therefore attenuated the neurologic response. Other investigations have found that teeth having symptoms of pulpitis sometimes have odontoblasts aspirated into the dentin tubules and therefore proposed that outward fluid movement disrupting these odontoblasts is responsible for the neurologic response (Brannstrom, 1963; Lilja et al., 1982). By contrast, heating the crown on the tooth would move the odontoblasts away from the dentin tubules and not into them. As a counter to this viewpoint, Brännström observed that sometimes areas of the tooth that exhibit sensitivity do not contain vital odontoblasts at the adjacent pulp-dentin interface and, therefore, the neurologic response must be coming from something besides the odontoblasts.

Other investigations have explored what nerves are present in the dental pulp and what causes their activation with the resultant signal to the central nervous system. By dissecting the inferior alveolar nerve of dogs and then monitoring the neural output during dentin stimulation, Matthews was able to determine that different nerves carry the signal for cold and hot stimuli applied to teeth (Matthews, 1977). Of the 55 nerves he could isolate from the IAN, only 5 responded to hot water being applied to a tooth, whereas 17 responded to cold. Additionally, this study found the cold-sensitive nerves gave a smaller response of shorter latency while the heat-sensitive nerves continued to signal longer after the stimulus was removed. Also of interest was the finding that pre-heating the tooth potentiated the neural response to the subsequent application of cold, however when a tooth was pre-cooled, the neural response to heat was diminished. One may suppose that these findings also support the hydrodynamic theory of dentin sensitivity in the following manner: as the dentin is pre-heated, this allows the cold which follows to more rapidly and dramatically draw the fluid in the dentinal tubules outward. However, since the inverse was not the case when the tooth was pre-cooled and then heated, it would seem that the neurologic response to heat is generated in a manner different from the response to cold. Physiologic studies of nerve function have investigated how heat stimuli were transmitted in the cat (Närhi et al., 1982). In this study, teeth were heated slowly to avoid triggering mechanosensitive nerve fibers via a hydrodonamic fluid movement. Of 73 different nerve fibers dissected, 37 were found to respond to heat stimuli and had a slow mean conduction velocity of 1.7 meters per second. None of the heat sensitive nerves transmitted at a speed of higher than 3.5 meters per second. Additionally, this study reported the mean threshold for stimulating 30 of the 37 heat sensitive nerves was 43.8°C; however, the threshold could be elevated with repeated heat application. Based on these studies, it appears that while cold sensitivity is best explained by the hydrodynamic theory, heat sensitivity may be due to the pulpal C-fibers acting as thermoreceptors.

Heat Testing Techniques

Several techniques have been employed in dental practice to create warming of the dental pulp in order to establish whether or not a particular tooth is sensitive to heat. The use of friction has been previously described as a method of generating heat within the dental pulp (White, Cooley, 1977). The use of a rotary instrument such as a burlew wheel or rubber polishing cup can create enough friction to generate heat. Another technique has been the use of heated gutta-percha. Several authors have described this process: heating a piece of temporary gutta-percha stopping until it begins to slump or smoke, and then applying this to the tooth (Stephan, 1937; Beveridge, Brown, 1965; Bhaskar, Rappaport, 1973; Brannstrom, Johnson, 1970; Dachi, 1965; Degering, 1962; Dummer et al., 1980; Hall, Freer, 1998; Linsuwanont et al., 2008a; Lundy, Stanley, 1969; Mitchell, Tarplee, 1960; Mumford, 1967; Peterson et al., 1999; Rickoff et al., 1988; Trowbridge et al., 1980; Keir et al., 1991). Covering a tooth in hot water has also been described in past literature (Brannstrom, Johnson, 1970; Linsuwanont et al., 2008a; Matthews, 1968; Selden, 2000). This method usually involves isolating a single tooth with a rubber dam, and then slowly adding hot water to bathe the tooth, while suctioning away the excess water. Still another method which has been described is the application of a heated instrument (Lundy, Stanley, 1969). By heating an instrument, such as a ball burnisher, in a flame and then placing it against a tooth, pulpal warming can also be achieved.

Heat Testing Difficulties

While utilization of these techniques has been developed to detect an association between heat sensitivity and pulpitis, challenges remain with this clinical test.

The primary problem with thermal testing is that it does not establish a true histologic diagnosis. For example, Mitchell and Tarplee found a strong correlation between heat sensitivity and inflammation. However, their investigation revealed the amount of inflammation ranged from just a pulp horn near dental caries to inflammation affecting the entire canal system (Mitchell, Tarplee, 1960). Another study demonstrated how, after a traumatic injury, teeth that do not respond to thermal stimulation can still have vital pulp tissue and lack periapical disease (Bhaskar, Rappaport, 1973). Seltzer and Bender attempted to correlate thermal sensitivity to a particular pulpal status, but instead found "pain responses to specific thermal stimuli, such as heat or cold, are not pathognomic for specific types of pulpal inflammation" (Seltzer et al., 1963). Still another investigation found no correlation between clinical signs/symptoms and the histologic status of the dental pulp, stating: "Thus it is impossible to classify accurately the pulp condition of all painful teeth or to differentiate clearly between savable and non-savable pulps" (Dummer et al., 1980).

Since heat testing does not reveal the true histological status of the dental pulp, and due to the inconsistencies of each method, the issue of false negatives and positives arises. For example, Petersson and Sodderstron found that a non-sensitive response to heated gutta-percha only detected a necrotic pulp 48% of the time (Peterson et al., 1999). They also discovered that 83% of the positive responses correctly identified vital teeth. Rates of heat sensitive teeth range anywhere from 30% to 57% with pulpitis (Dummer et al., 1980; Dachi, 1965), and from 0% to 96% with normal pulps (Degering, 1962; Mitchell, Tarplee, 1960). This further demonstrates that either this test is only an adjunct to other clinical tests used to assess endodontic disease, or heat testing should be further refined to make the results more useful.

Another challenge encountered when applying various heat testing methodologies is the lack of consistency from one use to the next. Often the use of a heated instrument or heated gutta-percha can result in dramatic differences in temperature from one test to the next. With hot water, a non-uniform application over a tooth could result in variable pulpal temperature changes. The use of heated gutta-percha can also produce variable heating of a tooth. One study reported an average temperature of 150°C for heated gutta-percha and that it was difficult to control the temperature (Hall, Freer, 1998). Dachi reported the heated gutta-percha used in their study was an average of 131°F (55°C) (Dachi, 1965). Still another study used heated gutta-percha with an average temperature of 120-130°C, but ranged anywhere from 90-140°C (Linsuwanont et al., 2008a). In the investigation by Lundy and Stanley, the authors reported difficulty with false negative responses due to considerable heat loss within the gutta-percha before it could be applied to a tooth (Lundy, Stanley, 1969). After having such false negatives, they "corrected" them by using a heated ball burnisher but worried that this instrument may be too hot and could damage a healthy pulp. Additionally, these authors discussed the challenges of consistent application when employing such testing devices. If the material or instrument used varies in its area of contact or time between heating and application, the opportunity for inconsistent warming of a tooth increases even more. Mumford described such inconsistency in the diameter of gutta-percha used for heat testing (Mumford, 1967). They also found that some normal teeth would be non-sensitive to heat while others gave severely painful responses despite their best efforts to standardize the application of the gutta-percha, and therefore labeled such testing as "crude."

Another weakness of heat testing, relative to other thermal or electrical methods, is that heat has the potential to cause damage to pulp or periodontal ligament cells. During endodontic diagnostic testing, normal healthy teeth are usually subjected to diagnostic tests in order to look for contrasting responses between the diseased tooth and the normal teeth. Of course, in an effort to avoid iatrogenic damage, we do not want these tests to harm any normal teeth or surrounding tissues during this testing process. Many earlier studies in the practice of modern dentistry considered how our treatment modalities could heat a tooth to the point of damaging the pulp tissue. One study even went so far as to declare that "Excessive heat is the most serious single insult to the pulp." (Robinson, Lefkowitz, 1962). When Lundy and Stanley commented that they had several false negatives when using heated gutta-percha, they would turn to a heated ball burnisher to elicit a more accurate response from the test teeth. However, these authors also expressed concern in using such an instrument as it may damage the pulp or burn other intraoral tissues (Lundy, Stanley, 1969). These authors even suggested the pulpal changes seen in the test teeth possibly could have been from the heated burnisher rather than the induced saliva exposure. Of the 26 teeth which were histologically examined within 12 days of pulp testing, 7 demonstrated focal abscesses and 2 had pus-filled blisters. Based on these observations, the authors proposed that the heat application could be responsible for these histologic changes in the pulp. It has been found that a temperature of 42-42.5°C applied to dentin can be high enough to cause damage to the pulp (Pohto, Scheinin, 1958). Zach and Cohen discovered that a pulp temperature rise of 4°C only caused minimal temporary changes in the pulp tissue, but a temperature rise of 10°C caused much more significant changes (Zach, Cohen, 1965). Additionally, they discovered that temperature increases of 20°C were able to cause necrosis within the pulp. In addition to damaging the dental pulp, it is known that excessive heat applied to the tooth can damage the periodontal ligament and bone that supports a tooth. Research performed in the bone of rabbits has demonstrated that heat (47°C) applied to bone for a period of 1 minute causes minor damage to the bone. However, temperatures of 47°C for 5 minutes, or 50°C for 1 minute, were capable of causing severe damage to bone (Eriksson, Albrektsson, 1983). Thus, when a method of applying heat to healthy tissue is considered, these temperature limits should be observed to avoid iatrogenic damage.

OBJECTIVES

The purpose of this study was to evaluate the manner in which electronic heat testing instruments warm a tooth and to compare these instruments to more traditional heat testing methods and evaluated for consistency, safety, and potential for clinical effectiveness.

MATERIALS AND METHODS

Prior to performing this study, the Institutional Review Board at the University of Minnesota determined the following protocol to be exempt from review. Five different heat testing sources were selected for comparison: the electronic tip on the Elements™ unit, the electronic tip on the System B™ unit, heated pellets of gutta-percha, a heated ball burnisher, and water warmed to 60°C. Each of the heat sources were applied to the test tooth for a period of 60 seconds with the pulpal temperature recorded during this period. A repeated measures model was designed by using four different operators and four different extracted teeth where each heat source was applied to each tooth by each operator. This resulted in 16 trials for each heat source. Four negative controls were used as described below.

Experimental Apparatus

Four non-restored previously extracted maxillary first premolars with fully formed roots were selected for the experimentation. While some authors have proposed that the thickness of dentin is critical in the conduction of heat (Robinson, Lefkowitz, 1962), other clinical studies have found this does not play a significant role in heat transfer and patient response (Trowbridge et al., 1980) therefore no attempt was made to standardize the dentin thickness of the test teeth. Each tooth had a K-type thermocouple placed into the pulp chamber against the buccal wall. This location was chosen so the quickest and largest increase in pulpal temperature could be measured. This aided in determining which methods had the potential to heat the tooth too much and cause pulpal damage. Prior to installation, the thermocouples were tested to verify agreement between each of the four. Placement within the pulp chamber was achieved by drilling a hole into the middle of the coronal pulp from the lingual side of the crown. The opening created was just large enough to allow the thermocouple to be inserted into the pulp and advanced until it contacted the buccal wall of the pulp chamber. No attempt was made to remove any existing pulp tissue. Each thermocouple was then secured to the tooth using cyanoacrylate. To simulate the heat sink that normal periradicular tissues would provide in a clinical situation, the teeth were mounted in a circulating water bath which was maintained at 37°C. Each tooth was carefully positioned so the water level was at the visible CEJ.

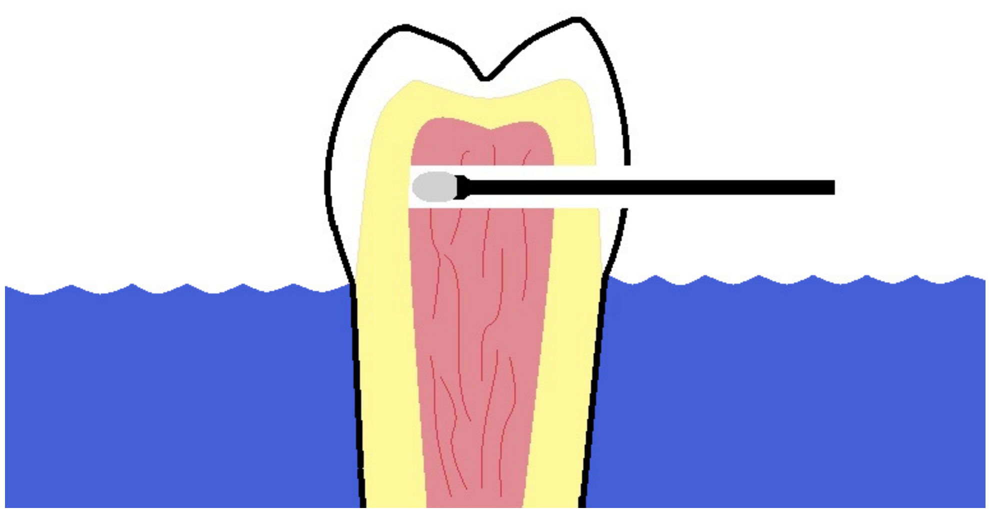

Figure 1. Experimental Apparatus

Each of the heat sources, with the exception of the hot water, was applied to the middle of the facial surface of the experimental teeth. As the tooth was being warmed, the readouts from the multimeter and digital stopwatch were videotaped to record the data.

Heat Application

Prior to each test, the temperature of the tooth was allowed to stabilize to a baseline temperature and any testing instrument was also allowed ample time to cool to room temperature. The four different operators were given the following instructions to guide the use of the heat sources:

Gutta-Percha

A gutta-percha pellet designed for use in a thermoplastic injection gun was used for this test. The operator would heat the pellet in a gas flame until it just began to smoke or slump, as previously described by several authors (Stephan, 1937; Mitchell, Tarplee, 1960; Dachi, 1965; Brannstrom et al., 1968; Beveridge, Brown, 1965; Mumford, 1967; Bhaskar, Rappaport, 1973; Trowbridge et al., 1980; Hall, Freer, 1998; Linsuwanont et al., 2008a). The warmed gutta-percha was then applied to the mid-facial surface of the test tooth and held in place for 60 seconds.

Heated Ball Burnisher

A #29 ball burnisher instrument was heated in a flame until it just slightly began to glow red, as previously described by Lundy and Stanley (Lundy, Stanley, 1969). Once it began to glow, it was immediately removed from the flame and the operator held the instrument in the open air and count off five seconds. Next, the instrument was placed against the mid-facial surface of the tooth for 60 seconds.

Hot Water

To simulate the clinical application of this test, a rubber dam was placed around the CEJ of the test tooth, excluding the water bath from the water applied for testing. The rubber dam was positioned to allow the test water to immediately drain off of the crown of the test tooth. Tap water was heated to 60°C and was maintained at this temperature during the testing process. For each test, two 10 ml Monoject syringes were filled with the hot water immediately before application. Each syringe was slowly applied directly over the crown of the tooth over a period of 30 seconds, resulting in a total of 20 ml of hot water applied over the 60-second test period. The water was not allowed to pool over the tooth as the rubber dam was sloped to carry the water away. The operator was notified of each 10-second interval in order to maintain a uniform application rate.

Electronic Probe – System B™ Unit

The electronic heat-testing tip was attached to the handpiece of the System B™ unit, and the tip was loaded with just enough gutta-percha to fill the depression in the end. The System B™ was then adjusted to the highest power (10) and temperature (599°C) settings. The operator would then contact the instrument tip with the mid-facial surface of the test tooth and simultaneously activate the device. The device remained activated for the 60 second test period and contact was maintained between the gutta-percha and the tooth.

Electronic Probe – Elements™ Unit

The exact same protocol used with the System B™ was used for the Elements™ instrument with the exception of the instrument settings – the Elements™ was used on its factory preset of 200° for heat testing.

Electronic Probe – System B™ Unit as a negative control

Using the same protocol as the System B™ described above, the device was set to 200°C to match the factory preset of the Elements™ instrument. Over the 60-second test period no measureable change in temperature was found. This test therefore served as the negative control for this study.

Data Recording

The videotape of the multimeter and stopwatch was replayed in slow motion, and the temperature was recorded every half-second. This resulted in 120 data points for each trial. The data for each trial was then adjusted by subtracting the starting temperature to calculate the temperature increase from the baseline temperature.

<u>**Results**</u>

The following charts demonstrate the data acquired from the experimental trials. The temperature shown is the amount of increase from the baseline temperature. The black lines indicate the mean of the 16 individual tests which are shown in color.

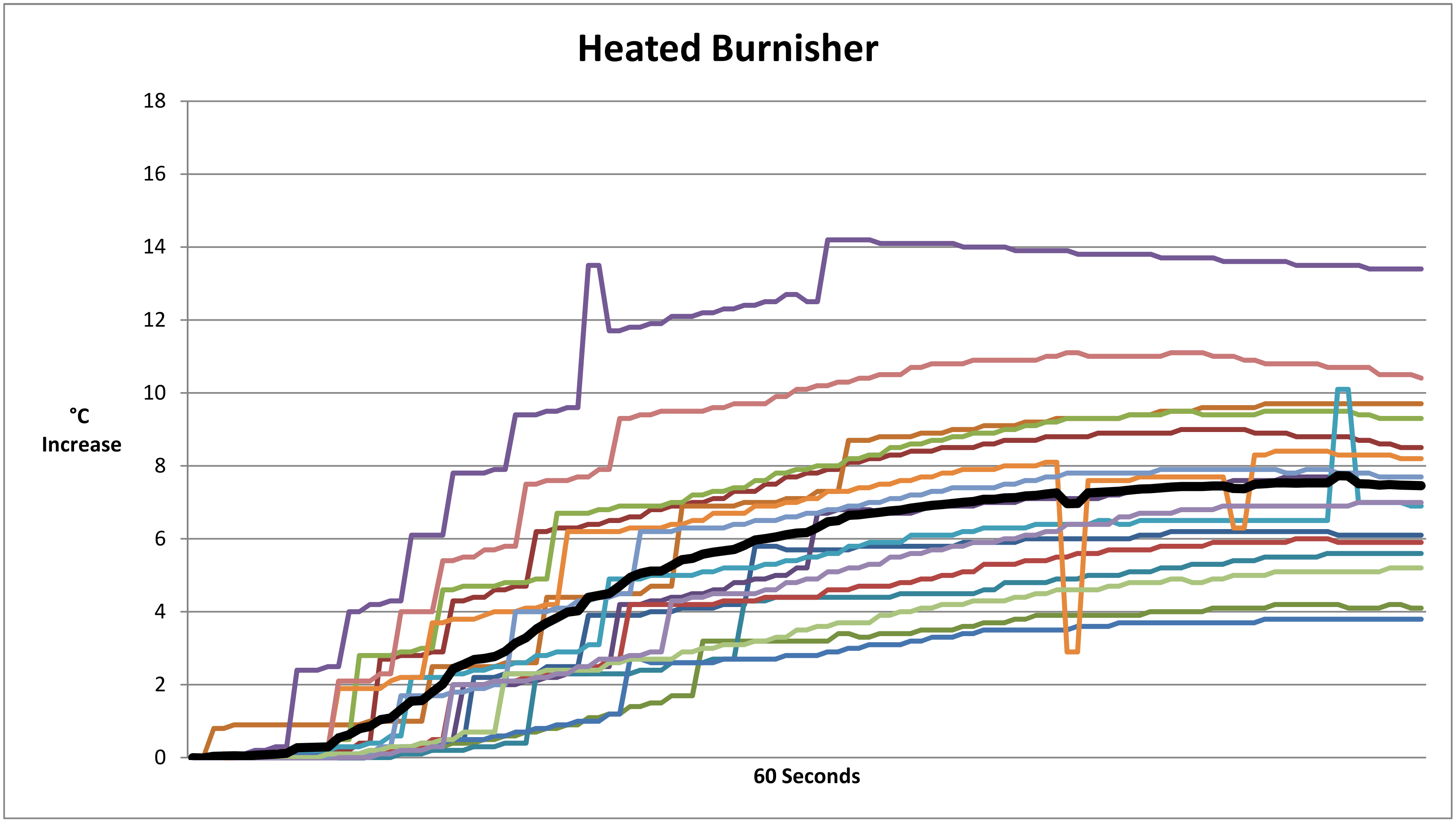

Figure 2. Heated Ball Burnisher Recorded Data

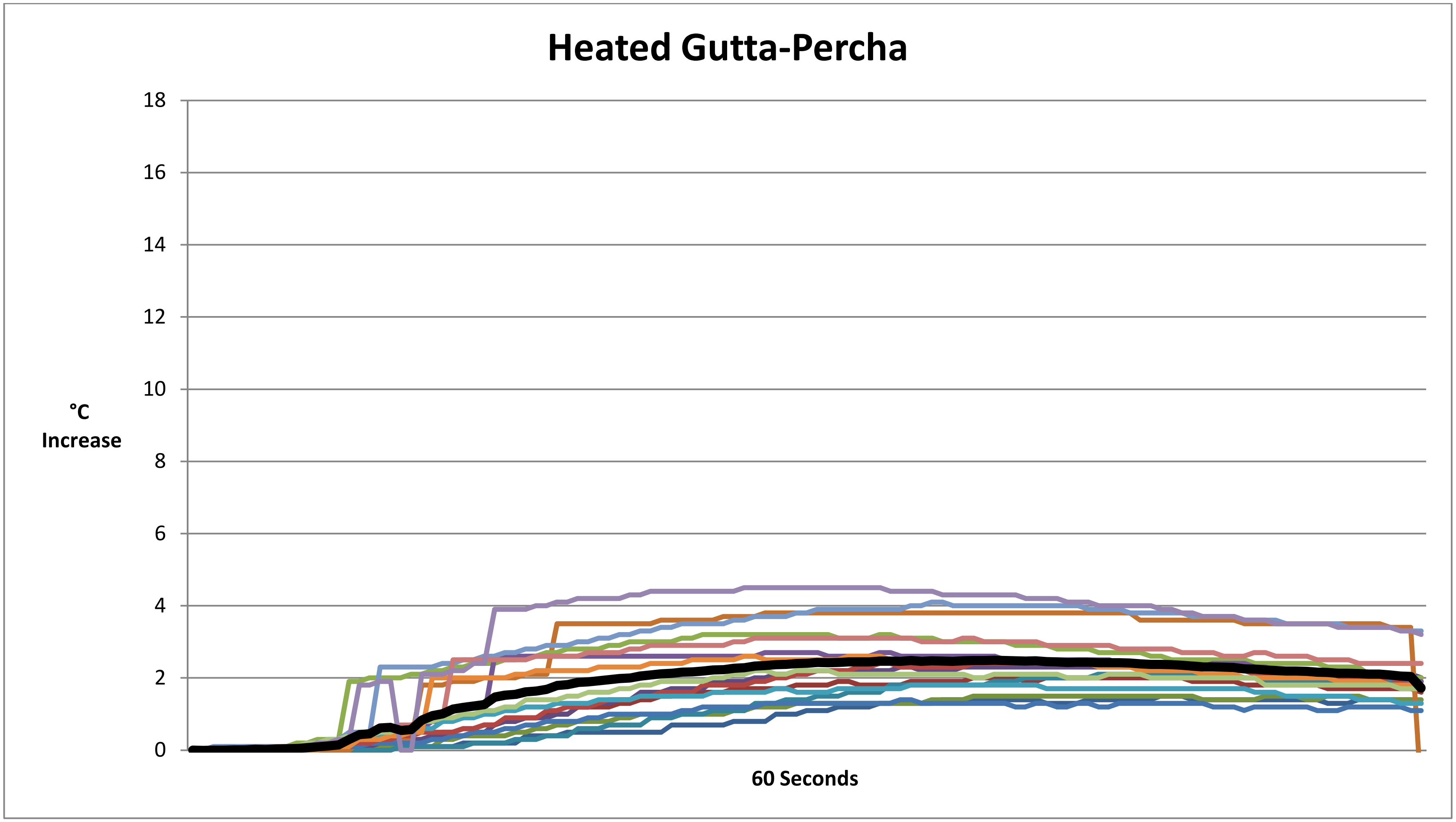

Figure 3. Gutta-Percha Recorded Data

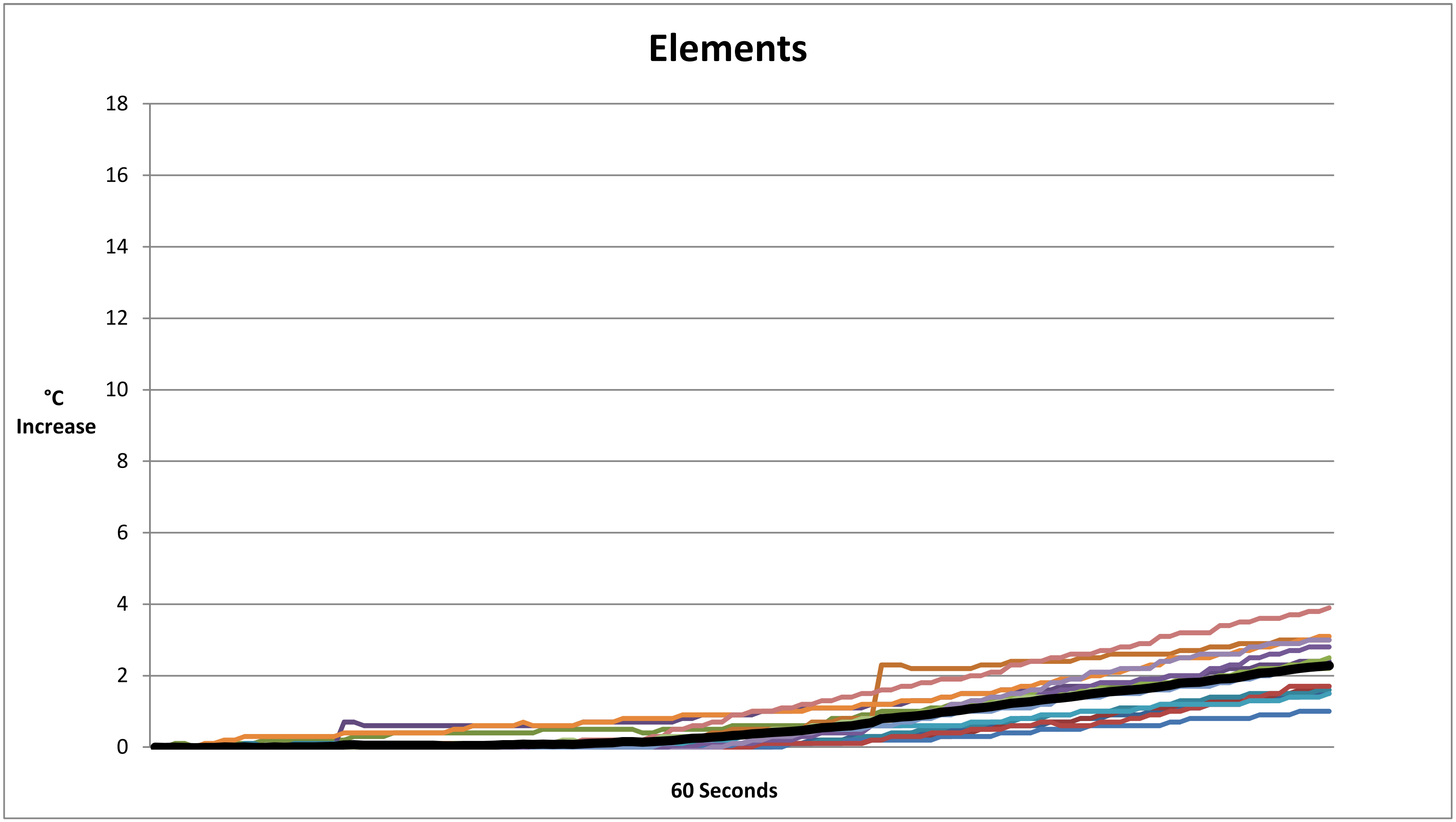

Figure 4. Elements Unit Recorded Data

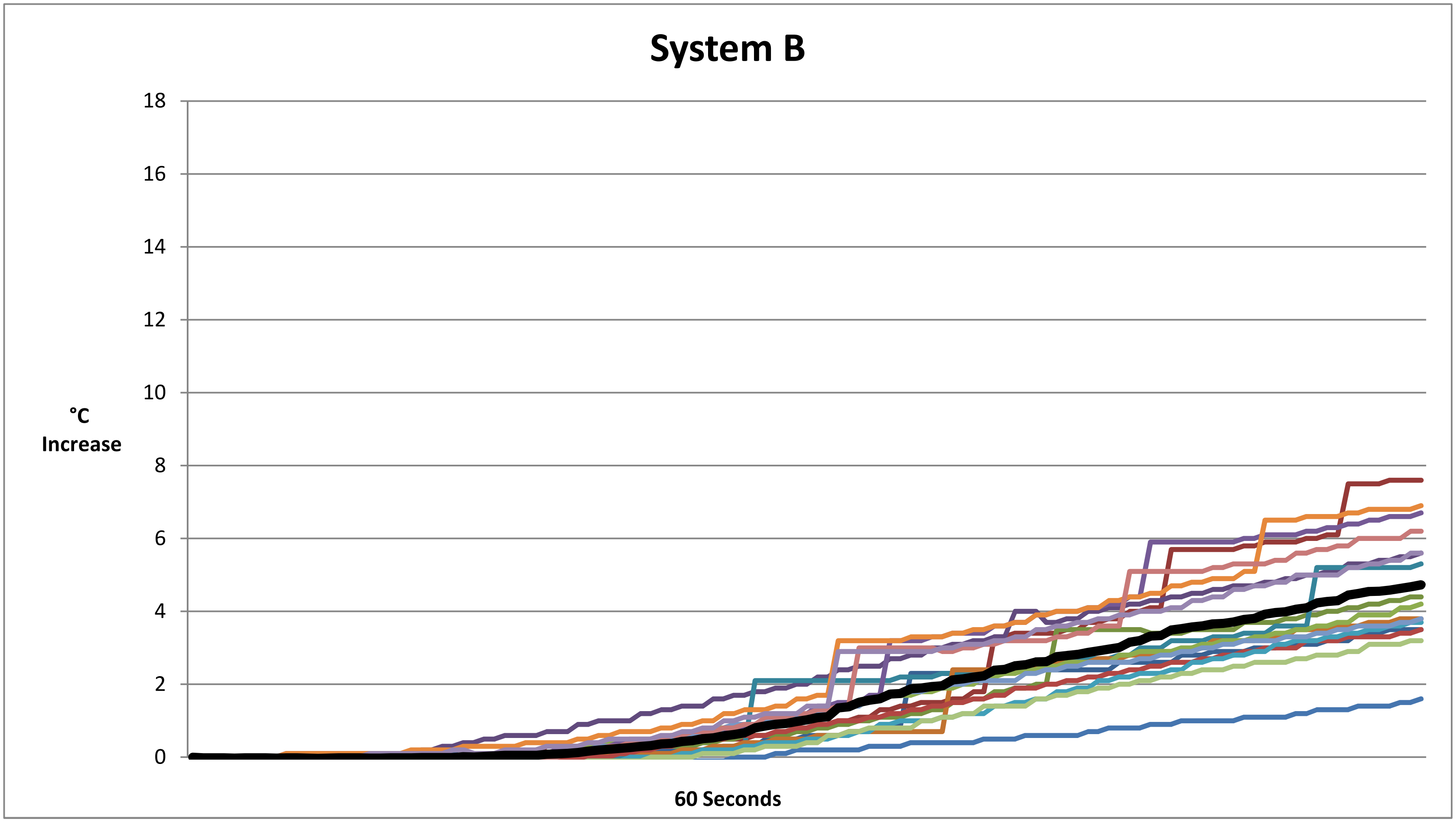

Figure 5. System B Unit Recorded Data

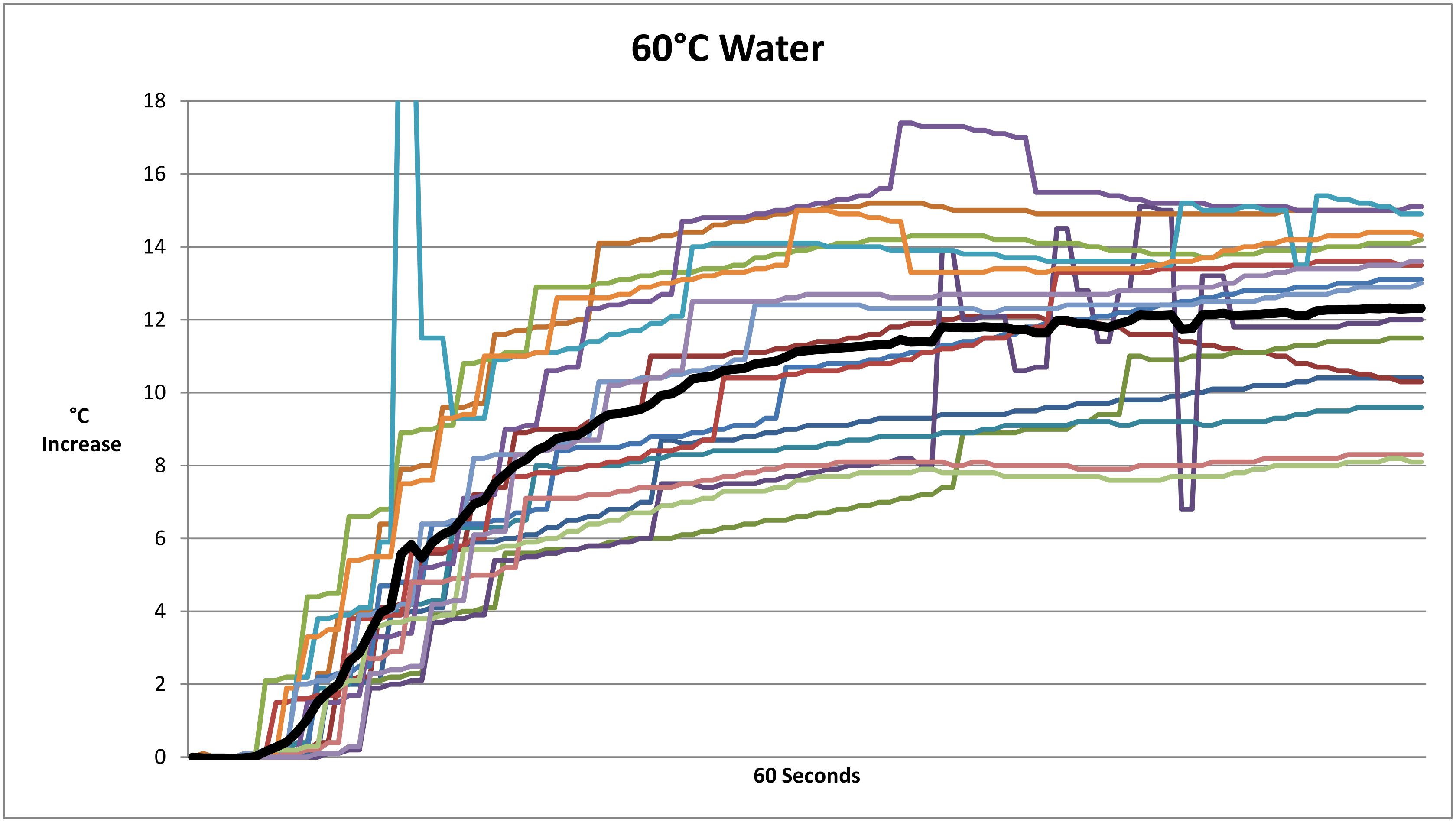

Figure 6. Hot Water Recorded Data

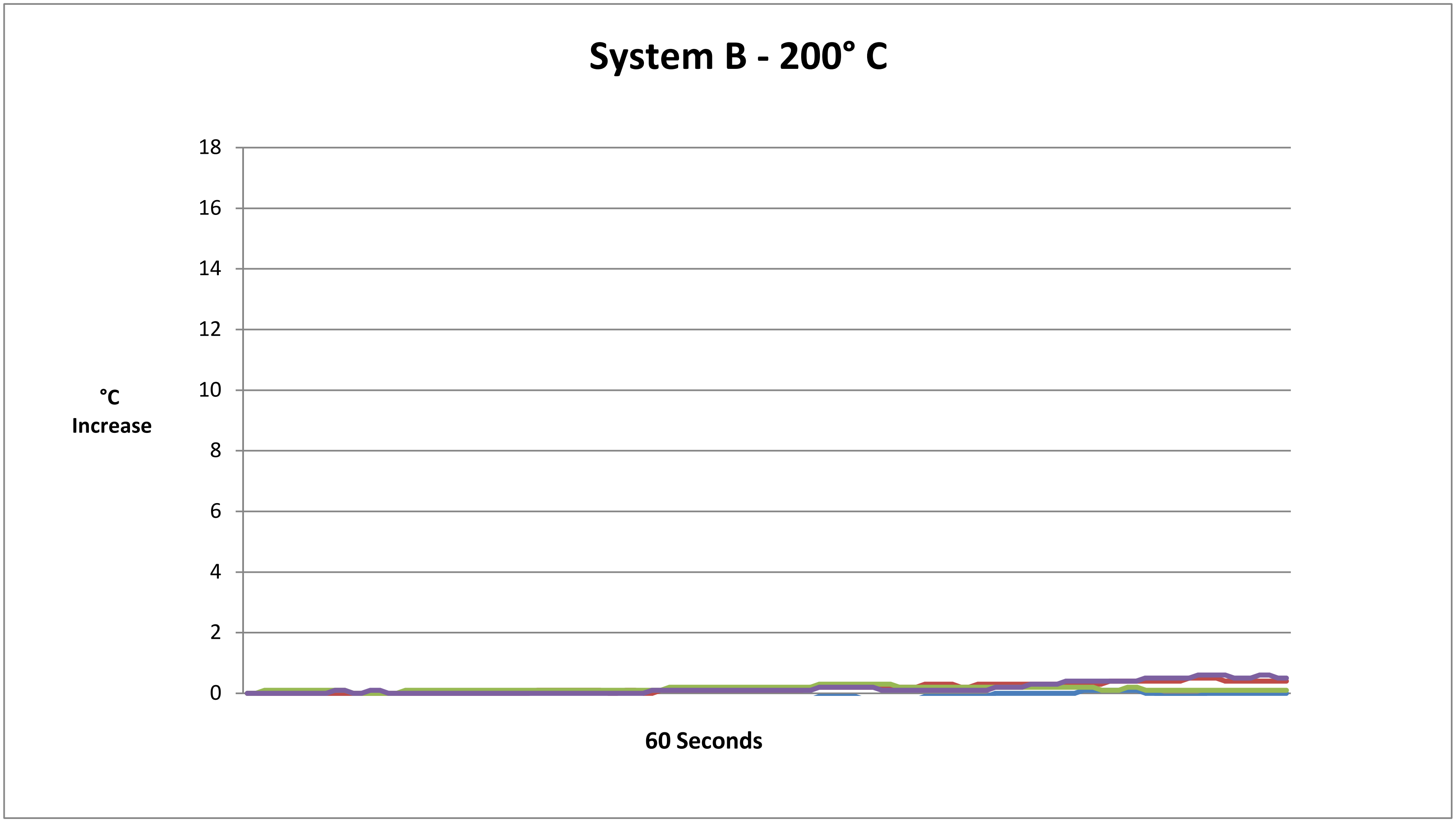

Figure 7. System B Unit Recorded Data. Instrument Set at 200°C

As seen in Figures 2-6 above, there were occasional errors on the part of the thermocouple. Of the 80 trials, only three such instances could be identified, each lasting for less than two seconds, thus no attempt was made to re-test those trials and the raw data was used exactly as it was recorded.

Data Analysis

All data analysis from this repeated measures experiment was performed using PROC MIXED in SAS v9.1.3 (SAS Institute, Cary, NC) software. To evaluate the consistency of each method, the intraclass correlation coefficient was calculated for all of the data in each group. The correlation structure of the repeated temperature measures within each operator-tooth combination was modeled with a first-order autoregressive covariance matrix. The following results were obtained where the numbers closer to 1 indicate the highest level of consistency:

Negative Control: (System B™ Unit set at 200°C)	0.99
Elements™ Unit:	0.79
Heated Gutta-Percha:	0.55
System B™ Unit:	0.53
Heated Ball Burnisher:	0.38
Hot Water:	0.12

The standard deviation was calculated for each method at each time point. The analysis also demonstrated that the hot water and heated ball burnisher are less consistent than the electronic probe and heated gutta-percha (Fig. 8). The spike in the standard deviation of the hot water near the 10 second time point is due to the erroneous data acquired in that test.

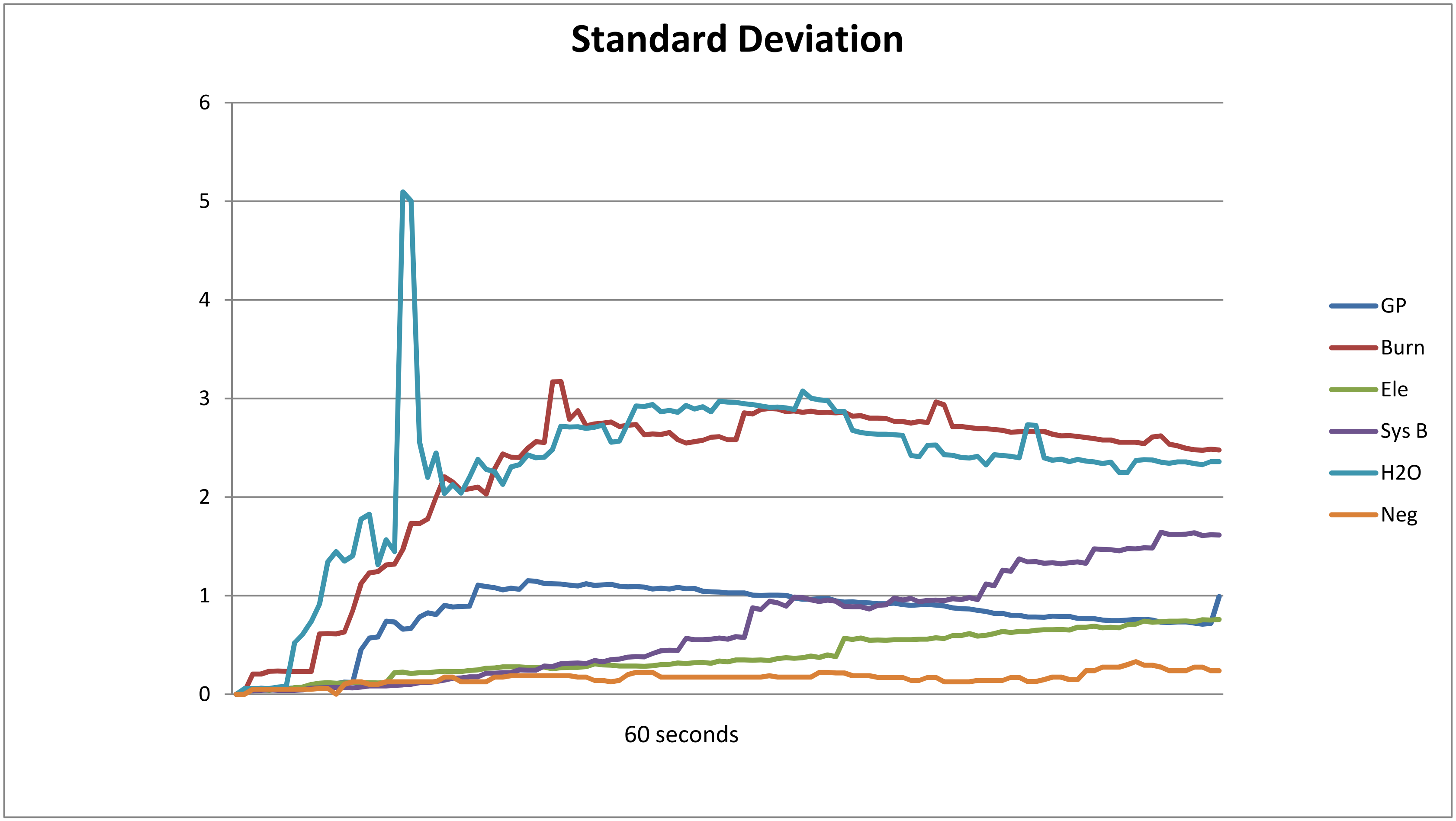

Figure 8. Standard Deviation of Heat Testing Data

To further investigate consistency between methods, average temperature change over time was analyzed. A repeated measures model with method, operator, and their interaction as covariates was used to compare the mean outcome between methods. A compound symmetric correlation structure was used to model within tooth measurements. A post-hoc t-test was performed as part of these calculations to establish which groups had significant differences. P-values less than 0.05 were deemed statistically significant. There was a significant interaction between method and operator (Table 1), indicating that the relationship between the operators and the mean average temperature change over time differed between methods. As seen in table 2, there were significant differences seen between operators using the heated ball burnisher, hot water, and heated gutta-percha methods. No significant differences were found between the individual teeth.

Table 1. Type 3 Tests

	F-Value	P-value
Method	250.08	<0.0001
OP	11.13	0.0022
Method*OP Interaction	4.24	0.0004

Table 2. Least Square Means within Operator

Method (OP)	Mean*	Significant Differences
GP		
1	1.17	4**
2	1.60	
3	1.86	
4	2.51	1
Heated Burnisher		
1	4.36	3
2	3.85	3, 4
3	6.87	1,2,4
4	5.13	3
Elements		
1	0.65	
2	0.51	
3	0.76	
4	0.82	
System B		
1	1.81	
2	1.12	
3	1.86	
4	1.66	
H20		
1	7.62	2,3
2	9.30	1,3,4
3	11.52	1,2,4
4	7.90	2,3

*Standard error for each mean is 0.52

** The mean for operator 4 is significantly different than the mean for operator 1 (p-value < 0.05).

The following values demonstrate the maximum temperature increase and mean temperature increase for each method:

	Max Increase	Mean Increase
Gutta-Percha:	4.5°C	2.6°C
Burnisher:	14.2°C	7.9°C
Elements™ Unit:	3.9°C	2.8°C
System B™ Unit:	7.6°C	4.7°C
Hot Water:	17.4°C*	13.3°C
Negative Control:	0.6°C	0.4°C

* The erroneous reading of 23.1°C from trial #11 was not used in the calculation of this maximum.

Discussion

The main focus of this study was to evaluate the consistency of the heat testing methods which were investigated. The intraclass correlation coefficient demonstrated that the Elements™ Unit, heated gutta-percha, and System B™ were the most consistent methods of heating the test teeth. By utilizing a device that applies the same stimulus to every tooth, an operator will have a better opportunity to distinguish between a normal pulpal response and that which is hypersensitive. As the graphic data demonstrates, the Elements™ Unit produced very similar warming curves each time it was used. Thus, if a patient reported severe pain from only one tooth out of several which are tested, then the operator would have some level of confidence that the more sensitive tooth is responsible for the patient's chief complaint of heat sensitivity. By contrast, with the recorded warming provided from the hot water and heated ball burnisher, it is easy to appreciate the wide range of temperatures recorded and realize how a hypersensitive response could occur on a normal tooth which could potentially mislead or confuse the operator. Thus, on the basis of consistency, one would prefer to use the electronic heat testing tip or heated gutta-percha to achieve more reliable results.

Another evaluation of the consistency between the methods can be found when comparing the results from the different operators. Here as well, the electric heat testing tip and heated gutta-percha demonstrated very little variability between the four different operators. Conversely, the hot water and heated instrument did show significant differences in pulpal temperature rise between the different operators. Thus, despite receiving the exact same instructions for a technique, there still remains the potential for individual differences when implementing the hot water and heated ball burnisher.

Consistency, however, does not make up the sole basis for choosing a particular method when performing a heat test. When an individual patient presents with a chief complaint of heat sensitivity, the intensity and triggers of that pain will likely determine which method would be most useful. If a patient complains that extremely hot coffee produces mild discomfort, then it may take a stronger stimulus than the electric heat-testing tip to reproduce this discomfort. In other cases, an extremely sensitive patient may be overwhelmed by some of the methods studied. For example, if a patient's own body heat triggers the pain, then placing hot water on the offending tooth would be unwise. However, by applying cold to one tooth at a time, relief of the pain may accurately locate the source of the chief complaint. A clinical description of creative problem solving has been published in a case study using warm water to elicit pain, with cold application to one tooth at a time until the pain is relieved and thereby locate the offending tooth (Selden, 2000). A clinician should also be mindful of what type of neurologic response he or she intends to induce. A strong, quick change in pulp temperature could be expected to activate mechanosensitive receptors in the pulp via hydrodynamic fluid movement and may establish a response from the Aδ nerve fibers. A hot water test could provide such a stimulus. Conversely, a very slow, gradual heating may avoid such a response and may instead allow the heat to reach the C-fibers within the pulp and thereby establish their sensitivity.

Another consideration for selecting a heat testing method is safety for normal, healthy tissues. Obviously, when testing control teeth on a patient, an operator does not want to cause damage to pulp or periradicular tissues which are intended to be preserved in good health. In the data given above, it is evident that both the hot water and heated ball burnisher, if applied for a long enough time, can raise the pulp temperature above the 42°C threshold where pulpal damage begins (Pohto, Scheinin, 1958). Thus, if an operator decides to use one of these methods, they must be mindful of the duration of the testing so as not to damage normal tissues.

With respect to ease of use, each method has its own strengths and weaknesses. As mentioned in earlier studies, any technique that does not require an external heat source is easier to implement (White, Cooley, 1977). One of the disadvantages of the heated gutta-percha and heated ball burnisher is that a flame is required. Hot water must also be acquired and its temperature verified before its use. By contrast, the electronic heat tip can quickly be removed from storage, placed in a power source and heat can be immediately applied. However, this does require an appropriate power source such as a System B™ or Elements™ unit. On the basis of cost, the heated instrument, gutta-percha, and hot water have the advantage of economy, but the electronic units are more expensive.

Several practical clinical suggestions resulted from this study:

1. Make certain the depression at the end of the electronic heat-testing tip is filled with gutta-percha. This provides adequate contact between the tip and the tooth to allow thorough transfer of the.
2. Properly set the System B™ unit for use. While the Elements™ unit has a preset to allow proper power delivery, the System B™ functions best when turned to the highest power (10) and highest temperature (599°C) settings.
3. The operator should expect a longer application of heat from the electronic heat tip due to the slow, gradual increase in pulpal

temperature. While hot water could elicit a response within a few seconds, the electronic tip may take 15 seconds or more to cause enough warming to trigger a neurologic response.

Additional studies on this topic could help refine the process of heat testing further. While this *in vitro* study established which methods are the most consistent, established relative safety, and determined a characterization of their warming trends, the information should be correlated to clinical performance. Since the consistency of the techniques was very different in the laboratory and the temperature rises were significantly different between some operators among the techniques, clinical application remains a challenge. In the clinical setting, effective use of the techniques to accurately reproduce the patient's chief complaint would be extremely useful. If the results of this study transfer well to the clinic, then these newer heat testing techniques would be an improvement for endodontic diagnosis.

Conclusion

The present study evaluated the new electronic heat testing tip in comparison to some traditional techniques and found that this instrument can warm teeth with greater consistency than using hot water or a heated instrument. Additionally, the electronic tip and heated gutta-percha were found to be the safest in terms of preventing heat damage to healthy tissues. Hot water and a heated ball burnisher proved to provide the fastest and most potent warming of teeth and may be useful for eliciting a response from teeth which do not respond to more mild stimuli. Additional clinical research will help refine the application of these techniques.

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