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Cold Testing Through Full-Coverage Restorations

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Endodontic diagnosis often requires thermal testing through porcelain fused-to-metal (PFM) and all-ceramic restorations. The purpose of this study was to measure and compare the temperature change during thermal testing by three commonly used methods occurring at the pulp-dentin junction (PDJ) of nonrestored teeth and teeth restored with full coverage restorations made of PFM, all-porcelain, or gold. The methods used to produce a thermal change were (a) an ice stick, (b) 1,1,1,2-tetrafluoroethane (TFE), and (c) carbon dioxide snow. A thermocouple measured temperature changes occurring at the PDJ in 10 extracted premolars when thermal tested by each method over a period of 30 seconds. Temperature reduction was also measured for the same samples restored with full gold crowns, PFM, and Empress crowns. Results showed intact premolars and those restored with PFM or all-ceramic restorations to respond similarly to thermal testing. In these teeth, TFE produced a significantly greater temperature decrease than carbon dioxide snow between 10 and 25 seconds ($p < 0.05$). In conclusion, application of TFE on a saturated #2 cotton pellet was the most effective method for producing a temperature reduction at the PDJ of intact teeth and those restored with gold, PFM, and all-porcelain when testing for less than 15 seconds.

Porcelain fused-to-metal (PFM) crowns, and the more recently introduced all-ceramic crowns, are popular prosthodontic restorative options because of their desirable esthetic qualities and strength. Endodontic diagnosis routinely requires pulpal vitality testing of teeth on which full coverage restorations have been placed. Thermal and electrical stimuli are accepted methods of diagnostic testing to determine pulpal status. It has been shown that thermal testing with carbon dioxide (CO_2) snow does not jeopardize the health of the pulp (1) and that the sensory response to the application of CO_2 snow in vital pulps is very rapid, usually occurring in less than 2 seconds (2). Thermal stimuli provide a greater response when more extreme temperature changes occur, causing stronger and faster wave movement of the fluid within the dentinal tubules, stimulating receptors, and exciting pulpal A-delta fibers. Gradual temperature changes do not produce a rapid response but will eventually produce a response by stimulating pain receptor activity in the pulpal C-fibers (3, 4). CO_2 snow can be as cold as $-78°$ C, but, as it is used clinically, CO_2 snow can only produce a temperature of $-56°C$ (5). CO_2 snow has been determined to be safe for vitality testing (5). Application of CO_2 snow for as long as 2 minutes does not damage the enamel surface (5, 6), and no inflammatory or degenerative pulpal changes (6) occur even when it is applied for as long as 5 minutes (1). Thus, thermal testing agents such as CO_2 snow would appear to be a viable agent for thermal testing through full-coverage restorations.

Many thermal testing agents have been studied and found to be effective for endodontic diagnosis. White and Cooley (7) recommended skin refrigerant (dichlorotetrafluoroethane) as the most convenient cold test method, producing a more rapid and demonstrable thermal change than either ice water or an ice stick. Fuss et al. (2) determined that dichlorodifluoromethane (DDM), with a temperature of $-50°C$, and CO_2 snow produce a greater decrease in temperature than either ethyl chloride or ice. CO_2 snow was the most efficient method for testing multiple teeth without moving away from the mouth (2). The method in which an agent is used can also have a significant effect on its ability to produce a temperature change within the pulp chamber. DDM produces the greatest intrapulpal temperature reduction when applied via a saturated #2 cotton pellet rather than via a cotton tip applicator (8). The agents and methods used in previous studies would lead us to believe that CO_2 snow or refrigerant should be the best methods for thermal testing through full-coverage restorations.

Although the majority of thermal vitality testing research has been conducted on intact teeth, CO_2 snow was found to produce a significantly greater temperature decrease than refrigerant, of unspecified type, in both nonrestored teeth and teeth restored with full gold crowns after a 5 second application (9). In that study, two #0 cotton pellets were saturated with the skin refrigerant and applied with cotton pliers. CO_2 snow also produced the most consistent pulpal response when applied to teeth covered with stainless steel crowns when compared with ice (10). DDM has been reformulated because of environmental concerns and is commercially available as 1,1,1,2-tetrafluoroethane (TFE). An in vivo study by Jones et al. (11) determined that TFE was more likely to produce a pulpal response in a shorter time than CO_2 snow.

Thermal testing with refrigerant had no apparent effect on castable ceramic Dicor crowns (12), but CO_2 snow may potentially reduce temperatures rapidly enough to damage ceramic restorations. However, to date, no studies have specifically investigated thermal testing of teeth restored with PFM or all-porcelain crowns using CO_2 snow or TFE, with a temperature of −26°C.

A recent survey of 900 practitioners identified Empress (IPS Empress, Ivoclar, Liechtenstein) as the most popular all-ceramic system used by prosthodontists (42% of the time) and general dentists (38% of the time) (13). The survey also found that practitioners believe many teeth restored with full-coverage restorations require endodontic treatment within 5 to 10 years of placement (14). Whether or not these perceptions are correct, it is safe to say that with the extensive use of PFM and all-ceramic restorations, it is possible that some of these restored teeth will require endodontic therapy after placement. This necessitates a safe and reliable method to test pulpal vitality through these restorative systems.

It would be clinically relevant to determine (a) whether current thermal testing methods decrease the temperature at the pulp-dentin junction (PDJ) of teeth restored with PFM or all-ceramic restorations, (b) the amount of thermal reduction each method can produce through these restorations at the PDJ, and (c) whether there is a significant difference between methods when testing for clinically relevant periods to determine the most efficient and reliable method.

The purpose of this study was to measure the temperature change occurring at the PDJ of extracted premolars restored with PFM or all-porcelain full-coverage restorations compared with nonrestored premolars or those restored with full gold crowns during thermal testing with (a) an ice stick, (b) TFE, or (c) CO_2 snow.

MATERIALS AND METHODS

Ten extracted human premolars (five maxillary and five mandibular), which had been stored in 0.2% sodium azide solution, were selected as test samples. Radiographs verified that adequate pulp chamber space existed to allow appropriate placement of a thermocouple within the pulp chamber and that there was uniform enamel-dentin thickness on the facial surface of all samples. The roots were sectioned 5 mm below the cementoenamel junction, and all pulpal contents were removed using barbed broaches. Samples were mounted with the apical extent of each root secured in a 3-mm–thick acrylic base while maintaining apical access into the root canal system. A thermal conductive medium (Omegatherm "201" High Temperature High Thermal Conductivity Paste, Omega Engineering, Stamford, CT) was placed into the pulp chamber using a 1-ml syringe (Excelint International, Los Angeles, CA) and a Lentulo spiral filling instrument (Star Dental, Philadelphia, PA) before placement of the thermocouple (Type T, Omega Engineering). The thermocouple was secured within the tooth using sticky wax. Adequate thermocouple placement within the pulp chamber against the most coronal extent of the pulp-dentin surface opposite the facial testing surface was confirmed with radiographs. Thermal testing was completed at room temperature using a bench-top apparatus to secure the acrylic base and sample. An adjacent water bath at 37°C allowed samples to return to the baseline temperature between thermal testing cycles.

Thermal testing was first completed on the intact crowns of the 10 samples (before preparation for artificial crowns) using three thermal testing methods: (a) ice stick with a 7-mm–diameter surface, (b) TFE (Endo Ice, Hygenic Corp., Akron, OH) using a saturated #2 cotton pellet (Richmond Dental, Charlotte, NC) held in Kelly straight hemostats (Hu-Friedy, Chicago, IL), and (c) CO_2 snow (Odontotest, Moyco Union Broach, York, PA) using a 3.5-mm–diameter pencil-shaped piece of CO_2 snow. All thermal testing agents were applied to the middle third of the facial surface for 30 seconds, and the intrapulpal temperature change was measured at 5-second intervals with a logging thermometer (HH2002AL, Omega Engineering). Three thermal test cycles were completed on each sample using each testing method. Three tests were completed on each tooth-restoration sample during each cycle to obtain a mean temperature measurement for each sample. One randomly selected sample was thermal-tested using each testing agent for 2 minutes with temperature change recorded at 5-second intervals. The 2-minute cycle was completed to evaluate the response of the sample to the effects of each thermal testing agent over an extended time range.

Standardized full crown preparations were then completed on all 10 samples using a parallel prepping device. Impressions were taken with a polyvinyl siloxate impression material (Express, 3M Dental Products, St. Paul, MN), and three sets of casts were made for each sample (Die-Keen, Heraeus Kulzer, South Bend, IN). Sets of three uniform full-coverage coronal restorations were fabricated for each tooth. These crowns included one full gold crown (Firmilay II Type III-hard, Jelenko, Armonk, NY), one PFM crown (Rexillium III metal, Jeneric/Pentron, Wallingford, CT and Vita Porcelain, Vident, Brea, CA), and one all-porcelain crown (IPS Empress).

Three 30-second thermal testing cycles, using the same three thermal tests and methods previously described, were completed on all samples, with each restoration fully seated with thermal conductive medium placed in the tooth-restoration interface. One sample was thermal-tested with all three restorative systems using each thermal testing method for 2 minutes, with temperature changes recorded at 5-second intervals to evaluate the response of each restorative system to the effects of each thermal testing agent over an extended time range. Three 30-second thermal testing cycles using the same three thermal tests were then conducted on the Empress porcelain crowns permanently bonded with a dual cure resin (Calibra, Dentsply Caulk, Milford, DE) as per manufacturer's recommendations.

Means and SDs were calculated for each crown type and test method at each time interval. Data was analyzed with a two-way analysis of variance for restorative systems and thermal testing agents at each time interval. Pair-wise comparisons were made with the Tukey honestly significant differences test. Additionally, one-way analysis of variance with Bonferroni significant difference tests was completed for each restorative system and thermal testing agent for each time interval. A confidence level of $p < 0.05$ was used for all tests.

RESULTS

Comparisons of the effects of thermal testing agents on each restoration type are indicated in Table 1. Comparison of thermal testing methods found no significant difference between thermal testing methods at 5 seconds for all restoration types ($p < 0.05$). When compared with ice or CO_2 snow, application of TFE to unprepared teeth or PFM crowns produced a significant decrease in temperature at the PDJ from 10 seconds through 30 seconds. Similarly, but over a shorter period, TFE produced a significant decrease in temperature at the PDJ from 15 seconds through 25 seconds ($p < 0.05$) when applied to all-ceramic crowns and bonded all-ceramic crowns. CO_2 snow produced a significant temperature decrease compared with ice or TFE from 15 seconds onward when applied to FGCs ($p < 0.05$). Overall, Table 1 demonstrates that TFE produced a significant temperature decrease compared with either ice or CO_2 snow between 10 and 30 seconds in all restoration types tested except FGCs ($p < 0.05$).

Comparison of the various restoration methods in response to each thermal testing agent is indicated in Table 2. At 5 seconds, there was no significant difference in temperature reduction between any restoration types ($p > 0.05$). FGCs allowed a significant decrease in temperature throughout the entire remaining test period when compared with all other restoration types ($p < 0.05$). The temperature reduction that occurred in unprepared teeth to TFE application was significant at 20 and 25 seconds when compared with bonded all-ceramic crowns and at 25 and 30 seconds when compared with nonbonded all-ceramic crowns ($p < 0.05$). The only other significant difference occurred in PFM crowns with the application of ice at 30 seconds when compared with bonded all-ceramic crowns ($p < 0.05$). Table 2 demonstrates with a few exceptions that unprepared teeth, teeth restored with PFMs, and teeth restored with either bonded or nonbonded Empress crowns respond similarly to each individual testing agent at clinically relevant test times.

Mean temperature changes at each 5-second interval were charted for each restoration system comparing each thermal testing agent. This was completed to demonstrate graphically the temperature reduction occurring with application time and allows visual comparison of the effects of each restoration system to the three thermal testing agents. At the initial 5-second application time, very little temperature change occurred. An important finding was that TFE produced the most rapid temperature reduction, approaching 7°C in all samples tested. Charting of the thermal responses of unprepared teeth and teeth restored with PFM restorations, all-ceramic restorations, and bonded all-ceramic restorations all produced similar relationships among the three testing agents. For example, the chart for teeth restored with nonbonded Empress restorations (Fig. 1) shows TFE initially producing the most rapid temperature reduction from the 10-second to 25-second application time. The samples tested for 2 minutes (Fig. 3G) demonstrated that CO_2 snow surpassed TFE after the 30-second application time.

The chart for teeth restored with FGCs (Fig. 2) demonstrates a similar relationship between testing agents over a much shorter application time to a temperature reduction of 8°C. CO_2 snow continued to produce the most temperature change after 12 seconds of application.

Mean temperature changes at each 5-second interval were also charted for each thermal testing agent comparing unprepared teeth and each restoration type. This allows visual comparison of the effects of restorations to each individual thermal testing agent. All three charts demonstrate a similar relationship between restoration types. For example, the chart for TFE (Fig. 3A) shows that there was no significant difference at all time intervals between all groups except FGCs, as demonstrated by the tight grouping of the four restoration types, with FGCs showing a significant reduction after 5 seconds of application.

Evaluation of the results from the 2-minute test samples (Fig. 3G) demonstrated that ice and CO_2 snow continued to produce a thermal change with as long as 1 minute of application, at which time the temperature remained constant. However, TFE ceased reducing the temperature within the sample by 1 minute of application, and the intrapulpal temperature began to return to the baseline temperature.

DISCUSSION

The results of this study indicate that TFE sprayed onto a #2 cotton pellet, as described by Jones (8), provides a more rapid and effective initial temperature reduction than either ice or CO_2 snow when testing nonrestored or crowned teeth. The results also support the findings of Jones et al. (11) that TFE produced a faster response in vivo than CO_2 snow. They also agree with Fuss et al. (2), who found refrigerant to evoke an immediate response and CO_2 snow to take somewhat longer to elicit a response when thermally testing unprepared premolars. The results contrast with the conclusion of Augsburger and Peters (9), who found CO_2 snow

TABLE 1. Comparison of effects of thermal testing agents on each restoration type (*n* = 10)

	5 s			10 s			15 s			20 s			25 s			30 s		
	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2
Unprepared teeth	NSD	NSD	NSD		I C			I C	I		I C	I		I C	I		I C	I
Full gold crowns	NSD	NSD	NSD		I C	I		I	I T		I	I T		I	I T			I T
PFM crowns	NSD	NSD	NSD		I C	I		I C	I		I C	I		I C	I		I C	I
All-ceramic crowns	NSD	NSD	NSD		I			I C	I		I C	I		I C	I		I	I
Bonded all-ceramic crowns	NSD	NSD	NSD		I			I C	I		I C	I		I C	I		I	I

NSD = no significant difference in temperature decrease between testing methods; I = produced a significant temperature decrease when compared to ice at $p < 0.05$; T = produced a significant temperature decrease when compared to TFE at $p < 0.05$; C = produced a significant temperature decrease when compared to CO_2 at $p < 0.05$.

TABLE 2. Comparison of restoration type to each thermal testing agent (*n* = 10)

	5 s			10 s			15 s			20 s			25 s			30 s		
	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2	Ice	TFE	CO_2
Unprepared teeth	NSD	NSD	NSD								B			A B			A	
Full gold crowns	NSD	NSD	NSD	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
PFM crowns	NSD	NSD	NSD													B		
All-ceramic crowns	NSD	NSD	NSD															
Bonded all-ceramic crowns	NSD	NSD	NSD															

NSD = no significant difference in temperature reduction between restoration types; F = temperature reduction significant when compared to other restoration types at $p < 0.05$; A = temperature reduction significant when compared to all-ceramic crowns at $p < 0.05$; B = temperature reduction significant when compared to bonded all-ceramic crowns at $p < 0.05$.

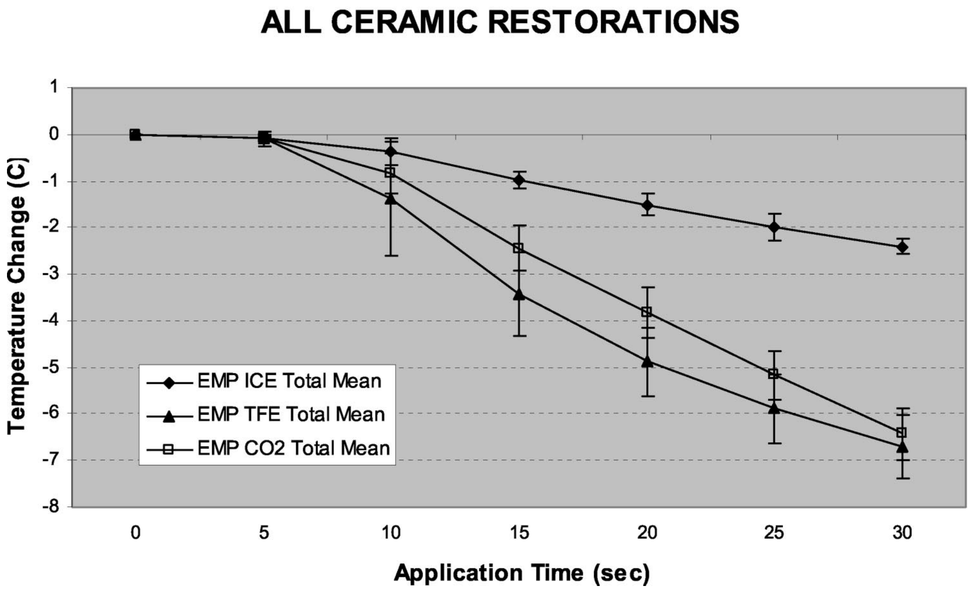

FIG. 1. Teeth restored with nonbonded Empress restorations.

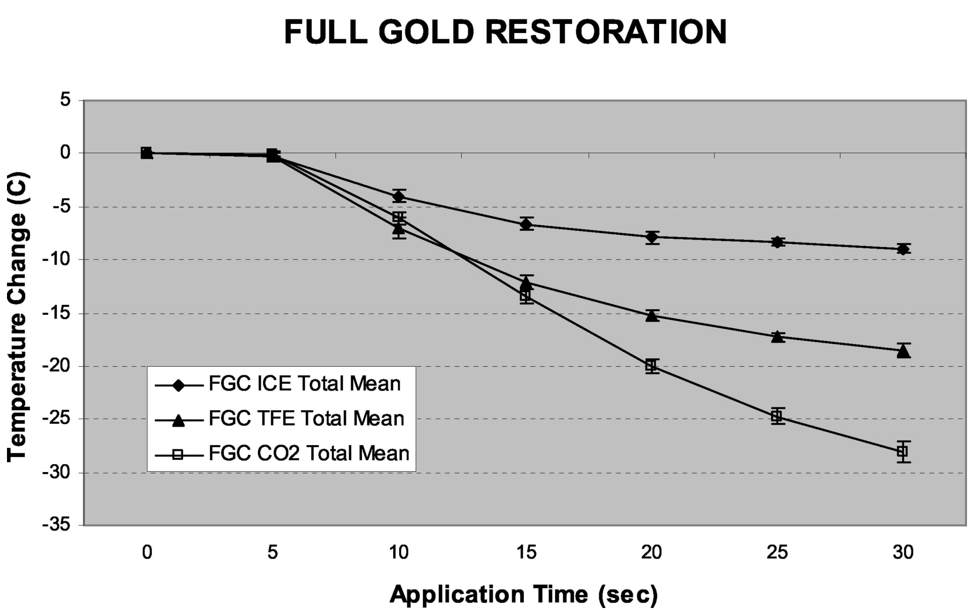

FIG. 2. Teeth restored with FGCs.

to be superior to ice or skin refrigerant when placed for 5 seconds. Bender (4) states that thermal stimuli, such as heat and cold, give superior pain reactions when more extreme differences in temperature are applied to the crown of the tooth. Although CO_2 snow may have a more extreme temperature at the tip of the application pencil of CO_2, the method of applying TFE with a saturated #2 cotton pellet appears to produce a more extreme temperature on application. This temperature diffuses through enamel or restorative material and dentin to the PDJ more rapidly than the diffusion produced by CO_2 snow on application. Thus, TFE appears to be the most desirable agent for producing an extreme temperature change when applied to the tooth. The results indicate that TFE, used as described, can produce a more extreme and thus desirable thermal change within the pulp chamber of nonrestored teeth or those restored with gold, PFM, or all-porcelain crown systems.

Charting temperature reduction at the PDJ versus application time for natural teeth and each restorative system demonstrates several findings. All of the samples tested showed a very small yet similar reduction in temperature to each of the thermal testing agents in the initial 5 seconds. After 5 seconds, TFE caused the most rapid initial reduction in temperature for all samples, as demonstrated by the graphs. The temperature reduction caused by CO_2 snow eventually catches up to TFE as the refrigerant dissipates from the cotton pellet and the temperature reduction created by CO_2 snow is transmitted through the restoration and tooth structure. The application times at which CO_2 snow produces a greater temperature reduction than TFE depend on the restorative system. This occurred after 12 seconds of application to samples restored with full gold crowns, but only after the 30-second test cycle for all other sample groups. This would

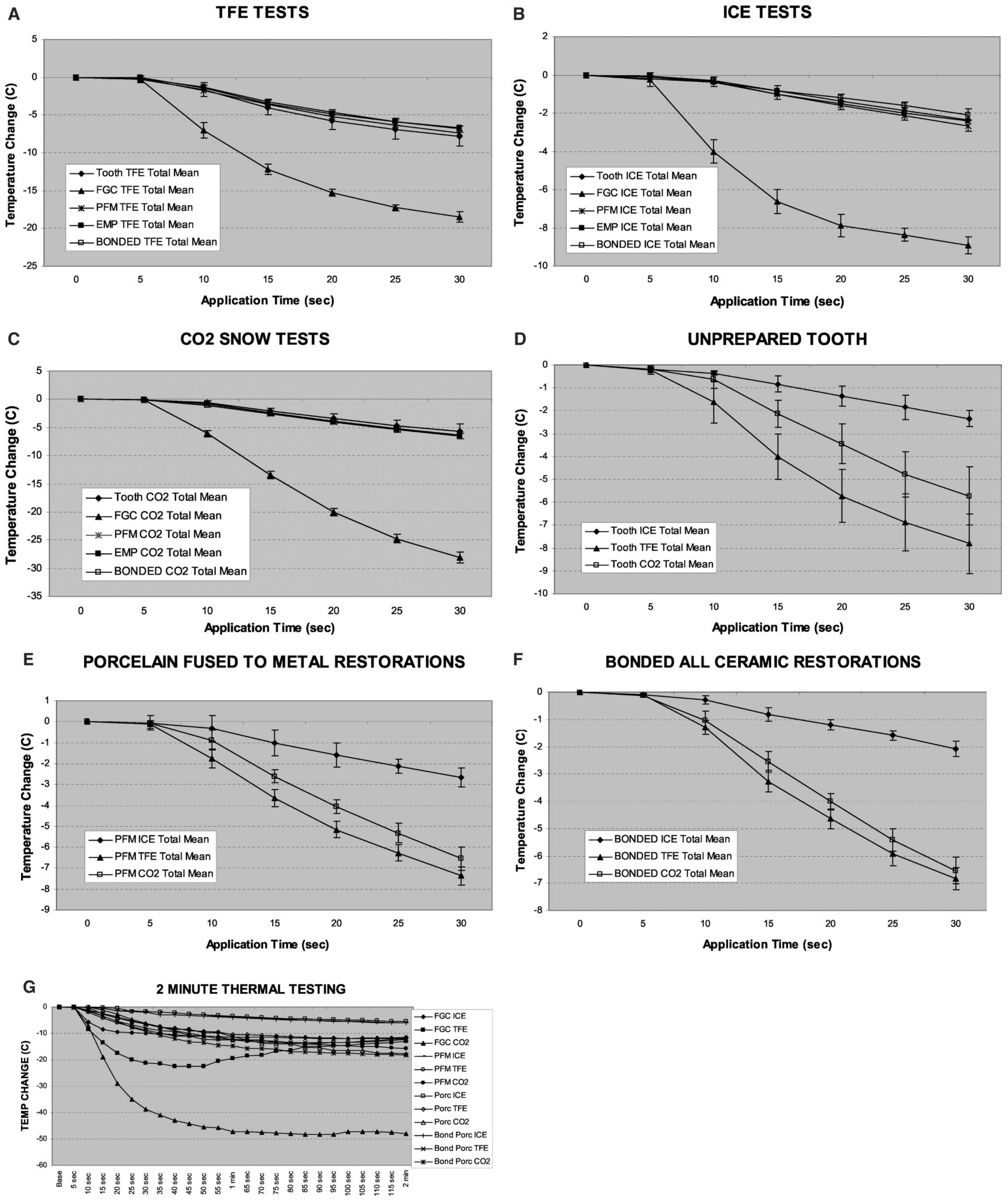

FIG. 3. Legend: (A) Response to TFE Testing; (B) Response to ICE Testing; (C) Response to CO_2 Testing; (D) Unprepared teeth; (E) Porcelain fused metal restorations; (F) Bonded all ceramic restorations; (G) 2 minute thermal testing.

possibly agree with the explanation by Fuss et al. (2) that the technique using TFE on a large cotton pellet provides a larger and more effective contact with the tooth or restoration surface when compared with CO_2 snow. Fuss et al. (2) hypothesized that during the application of CO_2 snow, a vapor layer may form and reduce thermal transfer to the tooth structure. Thus, TFE may affect a greater number of dentinal tubules and nerve fibers (2), thereby generating the potential for a more rapid pulpal response.

This study evaluated the difference in temperature change that occurs at the PDJ when the variables of either the restoration or testing method were altered. For this reason, no attempt was made to use a warm water bath to simulate the effects of oral environment on thermal testing as in previous studies (2, 15, 16). A simulated oral environment could potentially increase application times but would not be likely to alter the correlation between thermal testing agents and restorative materials.

The apical portion of each root was removed because it has been demonstrated that teeth without roots allow more accurate temperature measurements (16) and provide access for placement of the thermocouple and conduction medium into the pulp chamber. Similar to earlier studies, which used a silicone heat transfer agent in the pulp chamber (15, 16), this study used a commercially available thermally conductive silicone paste.

Trowbridge et al. (15) demonstrated that sensory response to thermal stimulation occurs before there is a temperature change in the area of the PDJ, where sensory nerve endings are located. The mean sensory response time was less than half the time required for initial temperature changes to occur at the PDJ. The mean sensory response time to cold testing was 1.49 seconds; therefore, the application time of 30 seconds was selected for each test cycle, which appeared to be more than adequate to be clinically relevant. Also, a more rapid response to thermal testing is seen clinically than the minimum of 10 seconds required for a significant difference to occur in this study. In vivo, the fluid movement within dentinal tubules excites pulpal A-delta fibers because of the rapid hydrodynamic response, and agents that evoke fluid movement are able to elicit positive responses from patients (17–19). While in vitro, a demonstrable temperature change at the PDJ occurs after thermal conduction through the complete thickness of restorative material and dentin.

As expected, gold conducted the cold far more rapidly than the other materials, and even ice, which was less effective than TFE and CO_2, produced temperatures on the full gold crowns after 15 to 20 seconds that were close to those produced by TFE and CO_2 on other materials after 25 to 30 seconds.

An unanticipated finding of this study was that thermal transfer through PFM and all ceramic crowns was similar to thermal transfer through nonrestored teeth. Instead of insulating the pulp, ceramics and ceramics bonded to metal appear to conduct cold temperature similar to enamel tooth structure.

Although statistically significant, the temperature reduction produced by TFE compared closely with that produced by CO_2. The temperature difference was often within 1 or 2°C and may not be clinically significant. Still, TFE would appear to be the agent of choice for thermal cold testing. It is convenient and may be less expensive than CO_2 snow. Supplied in an aerosol can, TFE is readily available when needed. The primary disadvantage of TFE, or any refrigerant agent, is dissipation from the saturated cotton pellet, which occurs after testing only 2 or 3 teeth for a few seconds each. Although the cotton pellet can be rapidly resaturated, this may be time-consuming when testing an entire quadrant. For some providers, CO_2 snow may be more convenient when testing more than three teeth consecutively, as previously stated by Fuss et al. (2)

CONCLUSION

The extensive use of PFM and all-ceramic restorations and the possibility that many of these restored teeth may require endodontic therapy after their placement necessitate a safe and reliable method to test pulpal vitality through these restorative systems. Thermal testing of PFM and all-ceramic restorative systems can produce rapid intrapulpal temperature reductions. TFE produces a significantly greater temperature decrease than CO_2 snow between 10 and 25 seconds of application in vitro. TFE, used in the method described, appears to be the best method for cold-testing nonrestored teeth and those restored with PFM or all-ceramic restorations for as long as 30 seconds, and for full gold crowns tested for less than 15 seconds. CO_2 appears to produce the greatest temperature reduction through full gold crowns at 15 seconds or longer, and for nonrestored teeth and other crown types that are tested for longer than 30 seconds.

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, the Department of Defense, or the US Government.

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