# The Effect of Simulated Field Storage Conditions on Dental Restorative Materials for Military Field Use

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ABSTRACT Introduction: Dental readiness, one critical component of medical readiness, is adversely impacted by dental emergencies. Many dental emergencies require restorative materials such as glass ionomers, resins, and zinc oxide eugenols to remedy them. The Authorized Dental Allowance List (ADAL) and Authorized Medical Allowance List (AMAL) contain the equipment and materials used by Navy dentists to treat Sailors and Marines. These supplies are subjected to harsh storage conditions on deployments. Much is known about how materials behave when stored at room temperature, but less is known about how their properties are affected after exposure to high temperatures and humidity. We subjected five dental restorative materials to storage in aggravated conditions, and then tested them to determine which products are more robust. Materials and Methods: Unopened packages of Fuji Triage, Fuji IX GP (both GC America Inc., Alsip, Illinois), TPH Spectra ST Low Viscosity, Intermediate Restorative Material (both Dentsply Sirona, York, Pennsylvania), and Herculite XRV (Kerr Corporation, Orange, California) were exposed to 0, 5, or 10 days' storage at 30–60°C with 95% relative humidity. After storage in these aggravated conditions, we tested the compressive strength, hardness, elastic modulus, flexural strength, flexural modulus, sorption, and solubility of each material. Results: The physical properties of all materials were affected by storage in aggravated conditions, though the properties of some materials degraded more than others. Both glass ionomers, Fuji Triage (P = 0.0012) and Fuji IX GP (P = 0.0031), and the composite Herculite XRV (P = 0.0253) lost compressive strength after 5 or 10 days in aggravated conditions. The hardness values for all materials were affected (P < 0.05) by the aggravated conditions, though the elastic modulus of TPH Spectra was not affected (P > 0.05). None of the materials lost flexural strength (P > 0.05) or had changes in their flexural modulus (P > 0.05). The water sorption behavior of Fuji Triage (P = 0.0426) and Fuji IX GP (P = 0.0201) changed after 10 days of aggravated storage, and the solubility of all materials was altered by the harsh conditions. Conclusion: Some materials degrade more than others in aggravated conditions. Both resin composite materials were more resistant to high temperatures and humidity levels than the glass jonomers tested. These changes in physical characteristics should be considered when reviewing or optimizing the ADAL/AMAL for different projected operational environments.

## INTRODUCTION

Dental health is a critical component of readiness for active duty military personnel. Up to 170 dental emergencies occur per 1,000 personnel in combat per year, and more than 47.5% of these require dental restorative materials as part of the remedy<sup>1</sup>. Restorative materials, including glass ionomers, resin

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composites, and zinc oxide eugenols, must be robust enough to withstand the complex and challenging environment of the oral cavity<sup>2</sup>. Though esthetics play a role, the performance of these materials is chiefly dictated by their mechanical characteristics.

Much is known about how a material's physical properties are altered by differences in their design or usage, as well as how their physical properties change over time. Small variations in the amount of water in a material's mixture<sup>3</sup>, the inclusion of glass fibers or fillers<sup>4</sup>, and changes in delivery format or packaging<sup>2</sup> during the design phase are known to alter the physical properties. Material properties are also sensitive to sterilization<sup>5</sup>, curing<sup>6</sup>, and mixing or dispensing methods<sup>7</sup> during use. The most is known about how a material's properties will change over time after use<sup>8</sup>. This has been studied by mixing and setting samples and then storing them in either a buffered solution<sup>9</sup>, artificial saliva, Vaseline<sup>10</sup>, water<sup>11</sup>, with microbes<sup>12</sup>, with mechanical wear<sup>13</sup>, with bleaching agents<sup>14</sup>, with simulated foods<sup>15</sup>, with changes in moisture or humidity<sup>3,16</sup>, or with changes in temperature<sup>17</sup>.

Comparably less is known about how changes in storage conditions before mixing can alter a dental material's physical properties and reliability. Most vendors recommend their materials be stored at room temperature or cooler, in

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Product	Manufacturer	Category	Storage	Notes
Fuji Triage	GC America Inc., Alsip, Illinois	Glass ionomer	$23 \pm 1^{\circ}$ C, $50 \pm 5\%$ RH	Keep receptacle tightly sealed
Fuji IX GP	GC America Inc., Alsip, Illinois	Glass ionomer	$\begin{array}{c} 23\pm1^{\circ}\text{C},50\pm5\%\\ \text{RH} \end{array}$	Keep receptacle tightly sealed
TPH Spectra ST Low Viscosity	Dentsply Sirona, York, Pennsylvania	Nanohybrid composite	2–24°C	Keep package tightly sealed, protect from ambient light, keep out of direct sunlight, store in well-ventilated area, protect from moisture, do not freeze
Herculite XRV	Kerr Corporation, Orange, California	Microhybrid composite	Ambient temperature	Protect from visible light, keep out of direct sunlight, store in a dry, cool, and well-ventilated area, keep container tightly closed
Intermediate Restorative Material (IRM)	Dentsply Sirona, York, Pennsylvania	Reinforced zinc oxide eugenol	10–24°C	Increased temperature or humidity reduces working time, store in well-ventilated area, do not store with (meth)acrylate resin components, keep package tightly sealed, protect from heat and direct sunlight, store in a dry area

TABLE I.	Recommended	Storage	Conditions
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dry places, and away from direct sunlight (Table I). These storage conditions are met easily enough in climate-controlled dental clinics but often are not met during deployed storage and transit. This consideration has historically been ignored, but conditions during military deployment or in developing nations are much more austere. If small variations in water content<sup>3</sup> or packaging<sup>2</sup> have large effects on a material's properties, prolonged exposure or storage in conditions outside the recommended temperatures will surely affect them too.

There is a need for understanding how preuse storage conditions can affect a dental material's physical properties, especially if adverse conditions are anticipated, as in the storage conditions in operational areas, with limited power supply, or in developing nations. We selected five materials from the U.S. Navy's Marine Authorized Dental Allowance List (ADAL) or fleet Authorized Medical Allowance List (AMAL) for testing. The ADAL contains supplies and equipment for dental procedures to stabilize and treat 200 patients with major injuries before evacuation to a higher level of care<sup>18,19</sup>. ADAL assemblages typically deploy with Marines and Navy dentists, while AMAL assemblages remain on their ships. We tested these five materials to determine which are most susceptible to degradation in high temperatures and relative humidity levels (RH). Our hypothesis was that some materials, or types of materials, would be more robust than others, making them more suited to use on deployments where high temperature and humidity levels are anticipated.

## MATERIALS AND METHODS

Fuji Triage capsules (glass ionomer, GC America model no. 002269), Fuji IX GP capsules (glass ionomer, GC America model no. 425081), TPH Spectra ST Universal Composite LV (low viscosity) compules (nanohybrid resin, Dentsply Sirona model no. 642221), Herculite XRV Microhybrid Dental Composite unidose capsules (microhybrid resin, Kerr Corp. model no. 29836), and IRM Intermediate Restorative Material cap-

sules (zinc oxide eugenol, Dentsply Sirona model no. 610200) were purchased from multiple vendors. Shade A2 was used when materials were available in different shades. All dental materials were kept at room temperature (approximately 22°C, 60% RH) before simulated field storage and while awaiting testing after simulated field storage.

## Simulated Field Storage

Simulated field storage was conducted in a panelized, aircooled, 5.805 cubic meter walk-in temperature and humidity chamber with SCP-220 control instrumentation (model no. EWPH205-CCA, Espec, Hudsonville, Michigan). Only unopened packages of dental materials were used, and all packages were placed in the chamber together, approximately 2 ft off the floor near the center of the chamber. The unopened materials were subjected to short periods of storage in high temperature and RH levels before mixing. After the appropriate storage, samples of each material were made according to the manufacturers' instructions and tested for changes in compressive strength, hardness, elastic modulus, flexural strength and modulus, sorption, or solubility. Simulated storage conditions were derived from the Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, MIL-STD-810G w/Change  $1^{20}$ . These conditions consisted of 6 hours at 60°C, an 8-hour ramp down to 30°C, 8 hours at 30°C, and a 2-hour ramp-up back to 60°C. RH was held constant at 95  $\pm$  4%, though, during temperature ramp downs, drops to as low as 85% RH were permitted (Fig. 1A). Intact packages of each dental restorative material were first exposed to an aggravated testing cycle for 5 days. Each package contains many individual capsules, compules, unidose tips, or caps. We placed at least four packages of each material in each batch of simulated field storage, giving us excess capsules, compules, unidose tips, or caps to conduct the required testing. After five 24-hour



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**FIGURE 1.** Mechanical properties before and after storage in aggravated conditions. Samples were stored in aggravated environmental conditions (A) of high temperature (°C) and percent RH for 0, 5, or 10 days. All samples were then tested for compressive strength (B, n = 8-18), surface hardness (C, n = 71-100), elastic modulus (D, n = 71-100), flexural strength (E, n = 3-15), or flexural modulus (F, n = 3-15). Black bars indicate significant differences between two groups of data; asterisks indicate the level of significance: \* $P \le 0.05$ , \*\* $P \le 0.001$ , \*\*\*\* $P \le 0.0001$ .

aggravated storage cycles, packages of each dental material were removed, the materials were mixed and set per the manufacturer's instructions, and then their physical properties were analyzed. Remaining unopened packages were placed back into the chamber for an additional five 24-hour aggravated storage cycles and then tested. Aggravated storage conditions were intended to reveal defects that may emerge after prolonged storage in the conditions typical of deployed transit and storage.

All materials were prepared according to their manufacturers' instructions. Fuji Triage and Fuji IX capsules were triturated at 4,800 rpm for 10 seconds (OptiMix, Kerr Corporation). IRM capsules were triturated at 4,000 rpm for 30 seconds. Molds were prepared with a thin layer of petroleum jelly, applied using a microbrush, to serve as a mold release agent. After placement in the appropriate mold, Fuji Triage, Fuji IX, and IRM were allowed to set for at least 20 minutes before samples were removed from their molds. TPH Spectra and Herculite XRV were both cured for 20 seconds on each side with a SmartLite Focus (Dentsply Sirona) or Demi Ultra (Kerr Corporation) curing light, respectively. This was repeated in overlapping segments until the whole length of the samples were cured from above and below the mold. Samples were removed from their molds and visually inspected without magnification. Any specimens with surface defects or air inclusions were rejected. The non-defective samples were placed in water and incubated at 37°C for 24 hours to continue curing. After 24 hours, the samples were stored at room temperature in small, sealed glass bottles with wet paper towels under the bottle caps until mechanical testing. All means are reported plus or minus the standard error of the mean.

# Mechanical Testing

## **Compressive Strength**

Samples were prepared in cylindrical split molds with internal dimensions of 4 mm diameter and 6 mm tall (Bisco Dental Products, Schaumburg, Illinois). Samples were covered with Mylar strips and pressed between glass bricks with Mylar strips to prepare smooth surfaces at the top and bottom edges of the mold. Specimens were removed from the mold and their surfaces were checked visually for air voids or chipped edges. Compressive strength tests were conducted according to the International Organization for Standardization (ISO) 9917-1<sup>21</sup>. Samples (n = 7-18) were placed between the platens of an Alliance RT/5 testing machine (MTS, Eden Prairie, Minnesota), and a compressive load along the long axis of the specimen was applied using a 5 kN load cell (model 4501029, MTS) and MTS TestSuite TW Elite software (MTS). Peak load immediately before failure, using a 0.5 mm per minute crosshead speed, was recorded, and peak compressive strength was calculated by  $\frac{4p}{\pi d^2}$ . Flexural strength is measured in megapascals (MPa), where p equals the peak load (in N) and d is the diameter of the specimen (4 mm).

### Hardness and Elastic Modulus

Hardness testing was performed after one surface on each sample was made smooth by sanding with progressively finer grit papers, followed by polishing with progressively smaller alumina particles. Samples were set in resin (EpoxiCure, Buehler, Lake Bluff, Illinois), and smooth surfaces were prepared by sanding with 180, 400, 600, 800, and 1,200 grit grinding papers (CarbiMet, Buehler) and then polishing with 1.0, 0.3, and 0.05 µm alumina particles (MicroPolish II, Buehler) on an Ecomet 6 grinder/polisher with Automet 3 power head (Buehler). Epoxy pucks with prepared sample surfaces exposed were mounted in a Nano Indentation System (Nanomechanics, Inc., Oak Ridge, Tennessee) and tested with a pyramidal indenter and a 10 mN target load. Five samples were tested for each combination of material and conditions, each test consisted of a 20-by-20 grid of 400 nanoindentations. Values for each column of 20 separate indents were averaged such that there were up to 20 data points for each sample, rather than 400 (n = 80-100). Outliers in hardness value data were identified with an iterative Grubbs test (alpha 0.05, Prism 6, GraphPad Software, San Diego, California) and were discarded before any analysis.

### **Flexural Strength and Modulus**

Flexural strength was measured according to ISO 9917-2<sup>21</sup>. Samples were tested on a 20 mm span with 1 mm per minute crosshead speed using an E3000 testing machine with 5 kN Dynacell load cell and Blue Hill testing software (Instron, Norwood, Massachusetts). Peak flexural strength was calculated by  $\frac{3FL}{2bd^2}$ . Flexural strength is measured in MPa, where F equals the peak load (in N), L is the length of span (in mm), b is the width of the sample (in mm), and d is the depth of the sample through the axis to which the load is applied (in mm). Samples (n = 3-15) were prepared in 2 by 2 by 25 mm beamshaped molds (Bisco Dental Products) and tested by applying a load to the center of a 20 mm span. Flexural modulus was calculated by  $\frac{L^3m}{4bd^3}$  where L is the length of span (in mm), m is the slope of the linear portion of the N/mm curve generated during testing, b is the width of the sample (in mm), and d is the depth of the sample through the axis to which the load is applied (in mm). Broken pieces were recycled for use in hardness tests.

## Sorption

Samples were prepared in the molds used for compressive strength testing, but rather than continuing to cure in  $37^{\circ}$ C water, samples were incubated at room temperature in a desiccator and their mass recorded for 12 consecutive week-days. Once all samples (n = 5-6) reached constant mass for three consecutive measurements within  $\pm 0.5\%$  of the first

measurement, each was immersed in 1 mL deionized water and incubated at 37°C. After 24 hours, each sample was removed and blotted dry on paper towels before its mass was recorded. Any gain in mass was attributed to water sorption, and the degree of sorption for each sample was inferred from its percent change in mass after the 24-hour soak.

#### Solubility

Samples were prepared using the compressive strength mold, as described above, and incubated individually in amber glass bottles with 0.5 mL water at  $37^{\circ}C$  (n = 1). After 24 hours, the dental materials were removed and the water retained for analysis by liquid chromatography with tandem mass spectrometry (LC-MS/MS). Liquid chromatography was performed on an Acquity UPLC M-Class system (Waters Corporation, Milford, Massachusetts) with a 10-minute, 3-80% solvent B gradient (solvent A was 0.1% formic acid in water, solvent B was 0.1% formic acid in acetonitrile). The flow rate was 0.3 µL per minute. A 2.5 µL aliquot of each sample was injected into a nanoEase M/Z HSS T3 column (100 Å, 1.8  $\mu$ m, 75  $\mu$ m  $\times$  100 mm, Waters Corporation) held at 35°C. Mass spectrometric analysis was performed on a Xevo G2-XS QToF mass spectrometer (Waters Corporation) with nano electrospray ionization interface (nanoESI) and quadrupole time-of-flight mass analyzer.

#### **Statistical Analysis**

Raw data, unless otherwise noted, were compared pair-wise between treatments within each material by one-tail *t*-test. Differences with *P* values below 0.05 were considered significant.

#### RESULTS

#### **Compressive Strength**

After 0, 5, or 10 days of storage in aggravated conditions (Fig. 1A), samples of each material were cast into 4 mm diameter, 6 mm tall cylindrical molds for compressive strength testing. A sample's compressive strength is inferred from its peak stress, which is calculated from its dimensions and the peak load it tolerates without breaking. Materials with a higher compressive strength support more load per unit area than materials with lower compressive strength. TPH Spectra ST LV's compressive strength was unaffected by storage in aggravated conditions (192.0  $\pm$  90.0 MPa n = 12,  $208.8 \pm 22.1$  MPa n = 18, and  $185.0 \pm 28.3$  MPa n = 8, for 0, 5, and 10 days of aggravated storage, respectively, see Fig. 1B). Herculite XRV was not adversely affected by the first 5 days of aggravated storage (145.8  $\pm$  14.6 versus 147.5  $\pm$  23.9 MPa P = 0.4753) but did lose approximately 35.7% of its compressive strength after the second 5-day period (93.7  $\pm$  9.4 MPa P = 0.0253, Fig. 1B). Both glass ionomers, Fuji Triage and Fuji IX, lost compressive strength after the first 5-day period of storage in aggravated conditions (48%, from 46.9 ± 4.6 to 24.4 ± 1.3 MPa, P = 0.0012 for Fuji Triage; 55%, from 116.9 ± 19.7 to 53.1 ± 6.4 MPa, P = 0.0031 for Fuji IX) but did not continue to lose strength during the second 5-day period (31.0 ± 5.0 MPa P > 0.05for Fuji Triage, 36.5 ± 7.6 MPa P > 0.05 for Fuji IX, Fig. 1B). IRM's compressive strength fluctuated with storage in aggravated conditions, but its compressive strength after 0 (39.3 ± 4.6 MPa) and 10 (40.0 ± 1.8 MPa) days of aggravated storage was not significantly different (Fig. 1B).

#### Hardness and Elastic Modulus

Hardness defines how difficult a material is to permanently deform. Harder samples resist changing shape better than less hard samples do. Though there were significant differences in mean hardness of samples at 0 and 5 ( $P = 2.0 \times 10^{-18}$ ) and 0 and 10 ( $P = 7.6 \times 10^{-11}$ ) days of aggravated storage, both resins tolerated the aggravated conditions well. Such low P values can be attributed to the large number of data points (up to 20) for each individual sample. TPH Spectra's mean hardness was stable at just over 1 GPa ( $1.0 \pm 0.0$  GPa for 0 days,  $1.1 \pm 0.0$  GPa for 5 days, and  $1.1 \pm 0.0$  GPa for 10 days of aggravated storage, Fig. 1C). Herculite XRV's mean hardness was similarly stable (1.25 GPa for 0 days, 1.3 GPa for 5 days, and 1.4 GPa for 10 days of storage in aggravated conditions, Fig. 1C). Samples of both glass ionomers were harder when the materials were stored in aggravated conditions for 5 (3.4  $\pm$  0.3 GPa  $P = 4.8 \times 10^{-7}$ for Fuji Triage,  $2.8 \pm 0.1$  GPa P = 0.0003 for Fuji IX) or 10  $(2.3 \pm 0.1 \text{ GPa } P = 0.0006 \text{ for Fuji Triage}, 2.7 \pm 0.1 \text{ GPa}$ P = 0.0030 for Fuji IX) days than materials kept at room temperature (1.9  $\pm$  0.1 GPa for Fuji Triage, 2.5  $\pm$  0.1 GPa for Fuji IX, Fig. 1C). IRM had the greatest decrease in hardness from 0 (2.2  $\pm$  0.3 GPa) to 0 (0.3  $\pm$  0.0 GPa  $P = 4 \times 10^{-7}$ ) days of aggravated storage (Fig. 1C).

We observed many of the same trends when we compared mean elastic modulus, rather than hardness. A material's elastic modulus quantifies how difficult that material is to reversibly deform. Stiff materials have high elastic moduli. Only TPH Spectra's mean elastic modulus did not change (14.4  $\pm$  0.0 GPa for 0 days, 14.4  $\pm$  0.0 GPa for 5 days, 14.4  $\pm$  0.0 GPa for 10 days) with storage in aggravated conditions (Fig. 1D).

## Flexural Strength and Flexural Modulus

When the materials were tested with a three-point bending test for flexural strength (Fig. 1E), we did not observe any significant differences because of the storage in aggravated conditions. Flexural strength for a sample was inferred from the calculated peak flexural stress the sample tolerated before breaking. Herculite XRV was the material with the greatest mean peak flexural stress (for all samples combined) of 118.9  $\pm$  3.3 MPa. TPH Spectra was the next greatest, with a combined mean peak stress of 86.1  $\pm$  5.0 MPa. Combined mean peak flexural stress values for Fuji IX, IRM, and Fuji

Triage were  $18.5 \pm 1.5$ ,  $11.7 \pm 0.7$ , and  $11.3 \pm 1.0$  MPa, respectively. Fuji IX had the greatest combined mean flexural modulus (22.6  $\pm$  1.6 MPa), followed by Herculite XRV ( $15.4 \pm 0.2$  MPa), Fuji Triage ( $14.7 \pm 1.2$  MPa), TPH Spectra ( $10.3 \pm 0.5$  MPa), and IRM ( $6.6 \pm 0.2$  MPa). A sample's flexural modulus, which describes how well a sample resists being bent, was calculated from its dimensions and the slope of the linear portion of its load versus displacement curve (N/mm). As with flexural strength (Fig. 1E), we did not observe any significant differences because of the storage in aggravated conditions (Fig. 1F).

#### Water Sorption and Solubility

Water sorption was inferred and quantified from the percent mass gain after desiccated samples were soaked in water for 24 hours. For all materials, including the glass ionomers, sorption was unaffected by 5 days in aggravated conditions (Fig. 2A). The only significant differences (P = 0.0426 for Fuji Triage, P = 0.0201 for Fuji IX) we observed were for glass ionomers after 10 days of storage in aggravated conditions versus 5 and 0 days. Fuji Triage's water sorption decreased from a mean percent mass gain of  $5.3 \pm 0.2\%$  at 0 days and  $5.3 \pm 0.1\%$  at 5 days to  $4.6 \pm 0.1\%$  at 10 days, while Fuji IX's water sorption displayed a similar decrease from  $4.1 \pm 0.1\%$  and  $4.2 \pm 0.2\%$  to  $3.7 \pm 0.1\%$  (Fig. 2A).

LC-MS/MS chromatograms from solubility testing show multiple changing peaks for all materials, both by total ion count (TIC, see Supplemental Figs S1–S5A–C) and base peak intensity (see Supplemental Figs S1–S5D–F). When the TIC values for all peaks were combined for each material after 0, 5, or 10 days of aggravated storage, bulk changes in solubility were revealed (Fig. 2B). Both glass ionomers decreased in solubility from 0 to 5 days of aggravated storage and then increased after 10 days of storage. Herculite XRV's solubility decreased with subsequent periods of aggravated storage, while the solubility of TPH Spectra and IRM remained relatively stable (Fig. 2B).

#### DISCUSSION

Multiple factors make direct comparisons between different dental materials difficult. The first of these is the difference in packaging. Because we were interested in how new, intact, and unopened packages held up to the aggravated environmental conditions, rather than unsealed individual capsules, compules, unidose tips, or caps, we cannot exclude differences in packaging from our analysis. TPH Spectra's packaging may give it the most protection from environmental conditions; several compules are sealed in a foil pouch, and several foil pouches are sealed in a plastic pouch. Only Herculite XRV had a comparable double layer of protection from the environment; several of its unidose tips are shipped in a small plastic box sealed with a sticker, and two of these boxes are then sealed in a plastic bag. The pouch within a pouch



**FIGURE 2.** Sorption and solubility before and after storage in aggravated conditions. Samples were stored in aggravated environmental conditions for 0, 5, or 10 days. Samples were tested for changes in water sorption, inferred from % mass gained (A, n = 5-6) or solubility, inferred from TIC by LC-MS/MS (B, n = 1). Bars in A indicate significant differences between two groups of data; asterisks indicate the level of significance:  $*P \le 0.05$ ,  $**P \le 0.01$ ,  $***P \le 0.001$ .

packaging may be a more effective strategy than the single barrier (individually wrapped pouches or unwrapped capsules in a cardboard box) used by both glass ionomers and the zinc oxide eugenol tested. The pouch-in-a-pouch format that TPH Spectra compules ship is may be responsible for that material's ability to withstand 5 and 10 days of storage in aggravated conditions without suffering significant losses in compressive strength (Fig. 1B) or elastic modulus (Fig. 1D). Herculite XRV was less robust; it also tolerated 5 days, but not 10 days, storage in these conditions without effects on its compressive strength (Fig. 1B) and elastic modulus (Fig. 1D).

A second factor that makes direct comparison between materials difficult is that the same physical properties are not equally important for all dental materials. For example, a buccal restoration will not be exposed to the same compressive stresses as one on the occlusal tooth surface. A material's ability to absorb and release fluoride<sup>22-24</sup>, coupled with the ability to tightly seal or bond with the tooth structure<sup>2</sup>, can give this material an advantage in clinical situations where those properties are called for. In this case, decreases in hardness or compressive strength may be less impactful for glass ionomers than for resins. In all cases, however, it is important that the material selected for a restoration behave predictably. Our solubility results (Figs. 2B, S1-S5) indicate that, for all materials tested, at least one component is degrading or reacting over time in aggravated conditions. When we tested sorption (Fig. 2A), we found that both glass ionomers were impacted by aggravated storage conditions. The water sorption and solubility of a material are critically important, as they dictate a restoration's shape change during curing and its structural integrity<sup>25</sup>, as well as restoration retention, tooth sensitivity, microleakage, and secondary caries formation<sup>26</sup>. Changes in the sorption or solubility of compounds in a material could impact any of these characteristics. Though determining the precise identity of all soluble compounds that are affected by aggravated storage is beyond the scope of this work, future LC-MS/MS studies could explain the changes in physical properties that we observed after aggravated storage. If the components involved in a material's curing reaction are affected, this could have compounding effects on solubility; not only will a less well-cured sample be more soluble than a well-cured one, but the changes in the relative abundance of monomers would also appear on LC-MS/MS chromatograms. If monomers are degrading, this could impact the physical properties of a material<sup>2,25,26</sup>. Future studies should investigate which components are particularly susceptible to degradation in harsh conditions, though as mentioned previously, packaging considerations must be taken into account. If a particular compound is known to degrade in high humidity environments, then it will be easy to exclude dental materials with this compound on their ingredients list. Since there are comparably few curing reactions<sup>2</sup>, prioritizing the components involved in these reactions may be the natural place to start.

It is the aim of military dentistry to support high military readiness and the rapid return to duty by restoring a service member's dentition to full form, functionally and esthetically, even in austere environments, when service members present with dental pain or injury. The dental materials available in the field and listed in the Marine ADAL should behave predictably, even in deployed settings and after storage in less than ideal conditions. Since changing storage methods for these materials on deployment may be impossible, an alternative may be to monitor new restorations closely for signs of failure. If follow-ups can be scheduled in advance to accommodate the patient's expected routine, failing restorations might be caught before the mission is impacted. Further follow-up, at the end of each deployment to evaluate and possibly redo restorations, may also prevent future failures of these restoration because of imperfect storage of the materials used on deployment. Finally, since resin-based restoratives appear to tolerate high temperatures and humidity levels better than glass ionomers, selecting resins for restorations on deployment may prevent later restoration failures.

The findings in this study indicate that many physical properties of several dental restorative materials commonly used in deployed settings are affected by extremes in temperature and RH and may affect the ultimate clinical performance of these materials. Therefore, further work on determining the clinical significance of these findings is warranted, and consideration should be made of the effects of storage conditions on different dental restorative materials when updating the ADAL or optimizing it for a projected operational environment.

#### SUPPLEMENTARY MATERIAL

Supplementary material is available at MILMED online.

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