Temporary Dental Restorative Materials for Military Field Use

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New temporary dental restorative materials are an important military requirement. This study compares the critical properties of the currently used temporary material, reinforced zinc oxide-eugenol (ZOE), with those of a glass ionomer restorative material (GI), a high-viscosity modified glass ionomer material (MGI), and two resin-modified glass ionomer materials (RMGIs). Properties tested included compressive and tensile strength, rigidity, hardness, bond strength, working and setting times, and storage stability. Ranked results for compressive strength, rigidity, and hardness were MGI > GI > RMGI > ZOE; for tensile strength they were RMGI > MGI > GI > ZOE; and for storage stability they were ZOE > MGI > GI > RMGI. Working and setting times were all within reasonable clinical limits, and bond strength was heavily dependent on tooth surface preparation. Although none of the materials tested met all of the ideal requirements, the high-viscosity glass ionomer material offers the most promise for military field use.

Introduction

Dental emergencies, most often attributable to caries, are a significant problem during combat and field exercises and may be the cause of substantial lost duty time.[1-3] Temporary dental restorative materials used at present to treat such emergencies have disadvantages that may preclude their efficacious use and optimal longevity in the military field situation; new temporary dental restorative materials for field use are an important military requirement.[4] Table I lists the ideal biological, physical, mechanical, and chemical properties of temporary dental restorative materials. In addition, the materials should be inexpensive, easily obtained, and handle well under all environmental conditions. Temporary materials would be used primarily at the level of the dental aid bag,[5] but they could be used at every level of care.

The traditional temporary dental restorative material for military field use is a polymer-reinforced zinc oxide and eugenol material (ZOE).[6,7] The mechanical properties of reinforced ZOE are sufficient for short-term success, and the material is anti-inflammatory (inhibits prostaglandin synthesis), obtundent (inhibits sensory nerve activity),[8] and antibacterial.[9] Despite these benefits, ZOE solubility, thermal expansion, and shrinkage are high, and there is no bond to tooth structure.[10-13] Most importantly, hot, humid climates accelerate the setting reaction; this limits usefulness during certain military deployments.[14] Finally, eugenol may have detrimental effects on the dental pulp.[15]

Glass ionomer materials (GIs) offer advantages as temporary materials such as adhesion to tooth structure[16] and fluoride release.[17] However, glass ionomer materials set slowly, exhibit poor early mechanical properties, and are initially susceptible to moisture contamination or desiccation.[18] A varnish or gloss is necessary to protect the material during the setting reaction.[19] This varnish, as well as conditioners and primers necessary for optimal bond strength, may not always be available or practical in the military field situation. Finally, the GI liquid may become viscous over time or exposure to high temperatures, with consequential reduction in mechanical properties.[20]

Recently developed high-viscosity modified glass ionomer materials (MGIs) address the problems with traditional GIs mentioned above. The glass particles are treated with a surface agent to allow an increase in powder/liquid ratio, an improvement in cohesive strength, and to give the material a "packable" quality (R. Demke, personal communication). MGIs are reported to have an increased resistance to solubility, superior wear resistance compared with traditional GIs,[21] and yet retain bond strength.[22]

Resin-modified glass ionomer materials (RMGIs) are a further attempt to improve the immediate strength and resistance to desiccation and sorption properties of traditional GIs. These materials contain light-cured and/or self-cured polymerizable monomers to hasten the setting reaction. Resin polymerization allows rapid early development of strength and less susceptibility to moisture contamination, desiccation, and early solubility.[23] The traditional acid-base GI reaction should maintain the potential for adhesion and fluoride release.[24] The disadvantages of RMGIs compared with traditional GIs include a higher coefficient of thermal expansion,[24] and, although a bond to tooth structure is possible, a conditioner or primer may be needed to overcome polymerization shrinkage.

The purpose of the present research was to evaluate newly introduced high-viscosity modified glass ionomer materials and resin-modified glass ionomer materials for use as temporary dental restorative materials in the military field situation. Several critical mechanical and physical properties were measured and compared with those of a conventional glass ionomer material and the traditional temporary material, reinforced zinc oxide and eugenol.

Materials and Methods

Table II lists materials; test methods are listed below. Light-curing was accomplished with a hand-held curing light (Prismatics, Caulk/Dentsply, Milford, Delaware) on each side of the test molds according to the manufacturer's directions. The RMGIs were tested after both light-curing and self-curing to simulate those situations in which a light-curing unit may not be available in the field. Similarly, some specimens were tested after application of a varnish or gloss and some were tested without varnish or gloss in an attempt to simulate the field situation in which a varnish or gloss, especially if light-cured, may not be available to the provider.

Ultimate compressive strength (MPa) was determined according to American Dental Association specification number 96 for dental water-based cements, using cylindrical specimens (5.5 × 2.5 mm) and a universal testing machine (model 1011, Instron Corp., Canton, Massachusetts) at a crosshead speed of 1 mm per minute. Specimens were tested after setting for 1 hour in the

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TABLE I

OPTIMAL PROPERTIES OF A TEMPORARY DENTAL RESTORATIVE MATERIAL FOR MILITARY FIELD USE

Biological:	Compatible with vital tissue
Physical:	Maintain adequate seal at restoration-tooth margin
	Thermal expansion coefficient similar to tooth structure
	Potential for adhesion to enamel and dentin
	Stable under extremes of age and environment
Mechanical:	Sufficient early strength, hardness, and rigidity to resist occlusal forces (6–24 months)
Chemical:	Releases therapeutic amounts of fluoride and is rechargeable

TABLE II

MATERIALS, CLASSIFICATION, MANUFACTURERS, AND BATCH NUMBERS

Material	Classification	Code	Manufacturer	Batch numbers
Vitremer	Resin-modified glass ionomer	RMGI	3M Dental (St. Paul, Minnesota)	19930622 19930424 19941222
Fuji II LC	Resin-modified glass ionomer	RMGI	GC Corp. (Tokyo, Japan)	041034 081132 150734 180523
Fuji IX	High-viscosity modified glass ionomer	MGI	GC Corp. (Tokyo, Japan)	081251 260451
Fuji II	Glass ionomer restorative material	GI	GC Corp. (Tokyo, Japan)	931209C 940202A 940302A
Intermediate Restorative Material (IRM)	Polymer-modified zinc oxide-eugenol	ZOE	Caulk (Milford, Delaware)	931006 931217 930514

mold at 37 ± 2°C and 95 ± 5% humidity and after 24 hours in a distilled water bath at 37 ± 2°C.

Rigidity (elastic modulus) (GPa) was calculated as the ratio of stress to stain along the straight-line portion of the 24-hour compressive strength graph.

Diametral tensile strength (MPa) at 1 and 24 hours was determined according to specification number 96 using a cylindrical mold (3 × 6 mm) and a crosshead speed of 1 mm per minute.

Working and setting times (seconds) for the self-cured materials were determined using an oscillating rheometer (Sabri Enterprises, Lombard, Illinois) at 37°C.[25]

Hardness (Knoop hardness number) at 1 and 24 hours was determined (Tukon model 300, Wilson Instruments, Binghampton, Massachusetts) using the diametral specimens and a 600-g load.

In vitro bond strength to enamel (MPa) was determined using human enamel specimens prepared to 600 grit. Bonding of each material was accomplished using a cylindrical mold 3.75 mm in diameter. After setting for 1 hour in the mold at 37 ± 2°C and 95 ± 5% relative humidity and thermocycling for 500 cycles at 5 and 55°C, specimens were immediately tested in shear on the universal testing machine at 1 mm per minute. One RMGI (Vitremer) was tested both with and without the "primer" (poly (acrylic acid)/hydroxyethyl methacrylate copolymer) that comes with the kit. The other RMGI (Fuji II LC) was bonded without a "conditioner," although the manufacturer recommended its use, because a separate product was not included in the kit.

Comparative storage stability (shelf life) was determined by subjecting the material liquids to temperatures of 50°C for prolonged periods (U.S. Army Dental Research Detachment Shelf Life Study, unpublished data). Viscosity (centipoise [cp] at 27°C) was measured (model DV-II, Brookfield Engineering, Inc., Stoughton, Massachusetts) at baseline and at intervals until it passed an arbitrary 2,000 cp, which is two to four times baseline for the polymer-based materials.

Statistical analysis included two-way and one-way analysis of variance (ANOVA), Scheffe's test ($p \leq 0.05$) for multiple comparisons, and Kruskal-Wallis and Mann-Whitney pairwise comparisons for nonparametric data. Sample size was eight for each mechanical test, five for working and setting times, six for bond strength tests, and three for each viscosity interval.

Results

Results are summarized in Table III; graphic representation of statistical multiple comparisons is given in Table IV. Two-way ANOVA revealed a significant difference between materials ($p \leq 0.0001$) and times ($p \leq 0.0001$) for ultimate compressive strength, a significant difference between materials ($p \leq 0.0001$) and times ($p \leq 0.0001$) for hardness, a significant difference between varnished and unvarnished hardness samples ($p \leq 0.0001$), and a significant difference for material rigidity ($p \leq 0.0001$). Compressive strengths at 1 and 24 hours, rigidity at 24 hours, and hardness at 1 and 24 hours seemed to follow the same general trend: MGI > GI > RMGI > ZOE. When the RMGIs were self-cured only, the strength and hardness were often close to those of samples that had the advantage of a light-cure. Varnish did not necessarily improve or maintain microhardness after 24 hours of water exposure.

For diametral tensile strength, two-way ANOVA revealed a

TABLE III

RESULTS, MEANS (SD)

Material	Compressive Strength 1 hour (MPa)	Compressive Strength 24 hours (MPa)	Tensile Strength 1 hour (MPa)	Tensile Strength 24 hours (MPa)	Rigidity at 24 hrs (GPa)	Hardness 1 hour (KHN)	Hardness 24 hours (KHN)	Bond Strength Enamel (MPa)	Bond Strength Enamel (range)	Working Time (seconds)	Setting Time (seconds)
Vitremer											
Light-cured								4.4 (1.7)	3.2–8.5		
No gloss	62.6 (15.2)	101.1 (13.0)	27.8 (4.6)	32.2 (6.8)	2.09 (0.29)	25.0 (5.5)	38.6 (5.9)				
Glossed				38.8 (9.7)			29.0 (4.2)				
No primer								1.8 (1.2)	0.3–4.2		
Self-cured								4.4 (1.3)	4.0–7.8	115 (15)	200 (28)
No gloss	54.0 (12.6)	86.3 (12.7)	23.3 (3.8)	33.5 (3.2)	2.21 (0.21)	20.3 (2.7)	30.4 (6.0)				
Fuji II LC											
Light-cured								1.0 (1.2)	0–3.5		
No varnish	92.8 (8.1)	113.5 (8.2)	26.7 (5.7)	22.6 (6.7)	2.44 (0.25)	31.0 (1.9)	27.2 (4.2)				
Varnished				32.3 (5.4)			19.9 (4.5)				
Self-cured								0.1 (0.2)	0–0.6	126 (9)	289 (27)
No varnish	92.6 (11.3)	127.6 (13.4)	19.5 (3.8)	21.1 (4.2)	2.34 (0.91)	33.3 (2.3)	30.3 (6.1)				
Varnished				27.0 (5.1)			22.2 (4.7)				
Fuji IX								1.9 (1.5)	0.6–4.9	97 (7)	145 (8)
No varnish	137.4 (22.9)	139.9 (18.8)	16.1 (4.7)	15.4 (4.9)	3.53 (0.20)	51.4 (7.3)	57.1 (10.9)				
Varnished				21.2 (3.1)			58.4 (13.3)				
Fuji II								2.2 (0.9)	0.9–4.2	93 (9)	160 (25)
No varnish	112.6 (27.0)	142.0 (35.1)	16.1 (4.5)	7.7 (1.6)	2.80 (0.55)	33.0 (7.5)	42.2 (8.3)				
Varnished				17.1 (3.7)			34.3 (3.2)				
IRM	50.3 (10.0)	55.7 (12.5)	7.9 (1.4)	8.5 (2.1)	1.19 (0.28)	11.3 (2.8)	14.9 (2.6)	0		105 (24)	237 (27)

significant difference between materials ($p \leq 0.0001$) but not between times ($p \leq 0.49$). Tensile strength at 1 and 24 hours did not follow the same trend as compressive strength/hardness/rigidity, but was as follows: RMGI > MGI > GI > ZOE. One RMGI (Vitremer) appeared to be superior or equal to the other RMGI (Fuji II LC) in tension but not in compression. For the RMGIs, varnish or gloss allowed tensile strength to increase over 24 hours after water exposure, whether the material was light-cured or self-cured only. Even without varnish protection, the RMGI had greater tensile strength than the MGI or the GI. Varnish was critical to maintaining or improving tensile strength after water exposure for both GI and MGI. ANOVA revealed significant differences between material working times ($p = 0.04$) and setting times ($p = 0.0001$).

Statistical analysis for bond strength data was nonparametric, because data were not normally distributed, and revealed a significant difference between materials ($p = 0.0001$). Bond strengths for MGI and GI were typical for traditional GI to untreated enamel; light-cured bond strength and self-cured bond strength for one RMGI (Vitremer) were typical for traditional GI when a surface conditioner is used.[16,26] Without conditioner, the bond strength of one RMGI (Vitremer) decreased to the level of the bond strength of the MGI and GI. Light-curing was necessary to achieve any degree of bond strength for the other RMGI (Fuji II LC).

Baseline viscosity ranged from 400 to 800 cp for new, polymer-based liquids and was approximately 8 cp for ZOE. Accelerated aging results were variable even for different batches of the same material; one batch of RMGI (Vitremer) measured greater than 2,000 cp at baseline within the manufacturer's designated shelf life. Overall, the viscosity of the two RMGIs exceeded 2,000 cp at approximately 30 to 35 days of exposure at 50°C; the GI passed that point at 40 days, whereas the viscosity of MGI remained less than 2,000 cp past 60 days. The viscosity of ZOE liquid remained at the baseline level past 80 days.

Discussion

The MGI and GI generally exhibited greater compressive strength, hardness, and rigidity at 1 hour than the RMGIs despite the purported faster set of the RMGIs. Conversely, the tensile strength of the RMGIs is markedly superior to that of GI and MGI, with or without varnish application. The difference may be attributable to the resin component of the RMGI, and, because brittle materials characteristically fracture in tension,[27] this may be a critical advantage of the RMGIs. The RMGI samples that were self-cured reached only approximately 80% or more of the mechanical properties of the light-cured samples. This implies that these materials may be used successfully as temporary restorative materials even if no light-curing capability is available in the field.

Varnish and/or gloss application was essential to improve or maintain tensile strength for the GIs and MGIs after water exposure. This may obviate the use of the conventional GIs in the field. The resin component of the RMGI apparently allows superior resistance to moisture degradation of tensile strength. Curiously, varnish application does not necessarily improve or maintain hardness after 23 hours of water exposure. This may be a function of the test method; application of a surface coating may impede accurate determination of bulk microhardness by surface indentation.

Although wear is a complex combination of mechanical, compositional, and physical properties,[28–30] data indicate that both

TABLE IV

MULTIPLE COMPARISONS (THOSE MATERIALS NOT STATISTICALLY DIFFERENT [$P < 0.05$] WITHIN EACH TEST GROUP ARE JOINED BY SOLID LINES)

Compressive Strength (1 hour)	Compressive Strength (24 hours)
Fuji IX	Fuji II
Fuji II	Fuji IX
Fuji II LC (LC)	Fuji II LC (CC)
Fuji II LC (CC)	Fuji II LC (LC)
Vitremer (LC)	Vitremer (LC)
Vitremer (CC)	Vitremer (CC)
IRM	IRM
Hardness (1 hour)	**Hardness (24 hours)**
Fuji IX	Fuji IX
Fuji II	Fuji II
Fuji II LC (CC)	Vitremer (LC)
Fuji II LC (LC)	Vitremer (CC)
Vitremer (LC)	Fuji II LC (CC)
Vitremer (CC)	Fuji II LC (LC)
IRM	IRM
Tensile Strength (1 hour)	**Tensile Strength (24 hours)**
Vitremer (LC)	Vitremer (CC)
Fuji II LC (LC)	Vitremer (LC)
Vitremer (CC)	Fuji II LC (LC)
Fuji II LC (CC)	Fuji II LC (CC)
Fuji II	Fuji IX
Fuji IX	IRM
IRM	Fuji II
Rigidity	**Bond Strength**
Fuji IX	Vitremer (LC)
Fuji II	Vitremer (CC)
Fuji II LC (LC)	Fuji II
Fuji II LC (CC)	Fuji IX
Vitremer (CC)	Fuji II LC (LC)
Vitremer (LC)	Fuji II LC (CC)
IRM	IRM
Working Time	**Setting Time**
Fuji II LC (CC)	Fuji II LC (CC)
Vitremer (CC)	IRM
IRM	Vitremer (CC)
Fuji IX	Fuji II
Fuji II	Fuji IX

MGI and RMGI are mechanically superior to the currently used ZOEs and should be more than adequate for temporary restorations.

Bond strength to enamel is relevant to restoration retention, and seal at the restoration-tooth interface is essential to even temporary clinical success. Although bond strengths were typical for traditional GI to untreated and treated enamel,[16,26] bond strength of the RMGI to enamel were lower than that reported in other laboratory studies.[22] This may be attributable to tooth-surface preparation and means of polymerization tested in this study. Although a conditioner or primer and a light source may improve bond strength, such material may not be available in the military field situation. The use of the glass ionomer-based material liquid (a weak acid) to remove pellicle and smear layer may be a practical alternative in an austere field environment.[31]

The MGI liquid resisted an increase in viscosity under accelerated aging conditions far better than the other polymer-based materials tested. Batch variation was an important factor with some materials, and the light-sensitive materials (RMGI) would be expected to be more storage-labile than the solely self-cured materials (GI and MGI).

Data revealed differences between the two RMGIs (Vitremer and Fuji II LC). Compressive strength and rigidity favored Fuji II LC; tensile and bond strength favored Vitremer; and moisture affected hardness and tensile strength of Fuji II LC more than Vitremer. Possible explanations for these differences are the resin/glass ionomer ratio and the monomer compositions in each product. There were also differences between the two glass ionomer materials. The high-viscosity modified glass ionomer (Fuji IX) was stronger, more rigid, harder, and not as affected by moisture contamination or extreme temperatures as the conventional glass ionomer (Fuji II). These differences are likely attributable to the compositional differences mentioned above and imply critical advantages for the MGI as a temporary restorative material.

Previous research has addressed two additional properties that may be critical to the success of temporary restorations. Fluoride release from MGIs and RMGIs is reportedly comparable with that from conventional GIs.[32] For RMGI, release is similar whether light-cured or self-cured only,[33] and all the glass ionomer-based materials can be recharged.[34] Research has also shown that thermal expansion of GI and MGI is matched to tooth structure[35] and that adding resin to the material (RMGI) raises expansion considerably.[24]

Temporary restorative materials may not be used at such quantities that even a comparatively high cost would prohibit military purchase. Nevertheless, cost is not trivial; the cost of GI is approximately two times the cost of ZOE, that of MGI is approximately five times that of ZOE, and that of RMGI is approximately six to nine times that of ZOE. Complex packaging (i.e., capsules) will double the cost.

Packaging for delivery in the military field environment is another critical issue. A self-mixing cartridge and pistol, or disposable individual squeeze packs with pad and sticks, could be easily handled in any field situation and would guarantee proper and consistent powder/liquid ratios. Such packaging should also solve most storage and stability problems for light- or air-sensitive materials.

Conclusions

When all mechanical, physical, chemical, handling, and cost factors are considered, the high-viscosity modified glass ionomer materials may prove to be the most suitable temporary restorative material for military field use.

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