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Influence of ultrasonic excitation and heat application on the microleakage of glass ionomer cements

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ABSTRACT

Background: The aim of this study was to assess the influence of externally applied 'command set' methods on the microleakage of several glass ionomer cements (GICs).
Methods: Four different restorative GICs were cured using three different methods: standard curing (SC), ultrasonic excitation (UC) and by an external heat source (HC). Different conditioning agents (10% polyacrylic and 10% citric acid) were used. The sample comprised 180 teeth with 360 Class V restorations placed on the lingual and vestibular tooth surface. After thermocycling, the teeth were immersed in a dye solution for 24 hours, embedded in acrylic resin, sectioned and evaluated. Oberholtzer criteria were used for margin evaluation. Data were analysed using three-way ANOVA.
Results: The heat cured GIC showed statistically significant better marginal adaptation compared to the other tested groups (SC, UC) ($p < 0.001$). GICs in groups with HC and conditioned cavities had lower microleakage scores. The highly viscous material Fuji IX GP Fast in the HC and conditioned cavities group demonstrated the best marginal adaptation. The other three products reacted similarly to heating treatment. Leakage at the enamel margins was significantly lower than the cementum/dentine margins ($p < 0.001$).
Conclusions: Heating the GIC during setting decreased microleakage, improved marginal adaptation of the GIC restoration and is suitable for clinical practice.

Keywords: Glass ionomer, heat curing, microleakage, ultrasonic curing.

Abbreviations and acronyms: GIC = glass ionomer cement; HC = heat source; PMMA = polymethylmethacrylate; SC = standard curing; UC = ultrasonic excitation.

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INTRODUCTION

Glass ionomer cements are currently used for various dental applications and have a number of advantages over polymethylmethacrylate (PMMA) cements. These include good adhesion to tooth enamel and dentine, long-term fluoride release and less toxic to dental pulp. They also have potential to inhibit caries and exhibit antibacterial activity generally by a low setting pH.[1] These acid-base reaction cements can be regarded as bioactive and therapeutic.[2] Clinical observation has led to the conclusion that GICs both reduce the tendency to demineralization and enhance the remineralization of enamel and dentine that has been subjected to caries attack.[3] The coefficient of thermal expansion of GIC is similar to that of tooth structure, but their capacity to prevent microleakage is disputed.[4,5] Glass ionomers are also subjected to microleakage that allows oral microorganisms and chemical substances to migrate through the tooth-estoration interface.[6] Reducing or eliminating microleakage around the restoration is an important objective in clinical practice and has resulted in numerous investigations performed on direct restorations with adhesive materials.[7] However, there are no studies on the potential of GICs to reduce microleakage after heating or ultrasonic curing. Prior to maturation and during the period of initial hardening, the material is susceptible to moisture contamination. Recent research has suggested that a fast or perceived 'command set' of conventional GICs can be achieved using an external energy source such as ultrasonic excitation[8,9] or heat application.[10–14] Rapid setting allows for shorter chair time and an improved clinical technique. The aim of this study was to assess the influence of ultrasonic excitation and heating as externally applied 'command set' methods on the microleakage of several conventional GICs.

MATERIALS AND METHODS

Experimental design

The microleakage test was carried out to evaluate the interface between enamel/dentine prepared with different conditioning agents and restored with glass ionomer cements cured in three different ways (conventional, heat and ultrasound).

Sample preparation

A sample comprised of 180 teeth with 360 Class V restorations placed on the lingual and buccal surface of each tooth was used. Sound and recently extracted human premolars and molars were thoroughly cleaned and stored in demineralized water until ready for use. Each material was divided into three groups according to cavity preparation (without conditioning, conditioning with 10% polyacrylic acid and conditioning with 10% citric acid). In each of these groups, 10 glass ionomer fillings were heated, 10 were cured ultrasonically and 10 were chemically cured as a control group.

Cavity preparation

Class V cavities were prepared on both the buccal and lingual surfaces of each tooth with the occlusal margins in enamel and the cervical margins surrounded by cementum/dentine. Class V cavity dimensions were standardized using a template of 3.0 mm width and 2.0 mm height. The depth of the cavity was approximately 1.5 mm which was measured and controlled for depth by a marked periodontal probe.

Restoration placement

Four different restorative glass ionomer cements (Ionofil Molar AC, VOCO, Lot 540795; Fuji VII, GC, Lot 0410251; Fuji IX GP Fast, GC, Lot 0605021; Megacem, Megadenta, Lot 870462) were used in this study. The chemical compositions of these materials are listed in Table 1. Materials were cured using three different methods: standard curing (SC), ultrasonic excitation (UC) and by an external heat source (HC) for 40 seconds (Elipar^{TM} Highlight, 3M ESPE Dental Products, Seefeld, Germany). The materials were mixed according to their manufacturers' instructions and inserted into the cavity. The surface of the cavity was covered with the clear celluloid strip to prevent the ultrasonic tip from pulling out the GIC restoration. Slight pressure was applied and the bulk of the extruded excess cement was removed. An ultrasonic tip (SONICflex scaler tip no. 7) was then placed on top of the filled cavity. The ultrasonic excitation was applied using the KaVo SONICflex 2000N (KaVo, Biberach, Germany) with a frequency of 5 kHz for 40 seconds. The glass ionomer restoration was heated with a conventional polymerization unit Elipar^{TM} Highlight (3M ESPE Dental Products, Seefeld, Germany) in standard mode. The polymerization tip was placed as close as possible to each cement filling. Different conditioning agents were also used: 10% polyacrylic acid (GC Dentin Conditioner, Lot #0507291, GC Corporation, Tokyo, Japan) and 10% citric acid. The sample comprised 180 teeth with 360 Class V restorations placed on the lingual and buccal surface of each tooth. The restorations were contoured and polished with moist Sof-Lex^{TM} discs (3M ESPE). A finishing gloss (Final Varnish LC, VOCO, Cuxhaven, Germany, Lot 540578) was applied immediately after and light cured for 20 seconds. The root apices were sealed with composite and all tooth surfaces were sealed with nail varnish, with the exception of a 1 mm band around the

Table 1. List of materials investigated in this study

Material	Composition	Manufacturer	Lot	Ratio powder/liquid
Megacem	Calcium/sodium fluorides, aluminium oxides/phosphates and silicates, iron oxide pigments, polyacrylic acid	Megadenta, Radeberg, Germany	#870462	P: 3.5 g L: 1 g
Fuji VII	Alumino-silicate glass iron (III) oxide <0.1	GC Corporation, Tokyo, Japan	#0410251	P: 0.3 g L: 0.15 g
Fuji IX GP Fast	Water, carboxylic acid, polyacrylic acid, polybasic aluminofluorosilicate glass	GC Corporation, Tokyo, Japan	#0605021	P: 0.36 g L: 0.10 g
VOCO Ionofil Molar AC	Water, pure polyacrylic acid, (+)-tartaric acid, aluminofluorosilicate glass and pigments	VOCO, Cuxhaven, Germany	#540795	P: 0.43 g L: 0.125 g

P = powder; L = liquid.

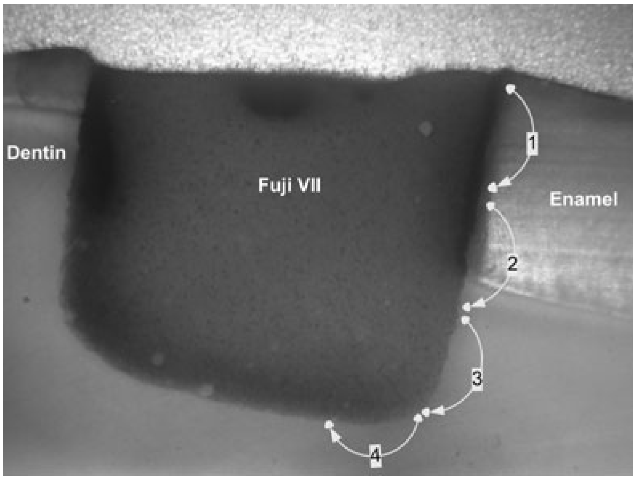

Fig. 1 Scoring method used for microleakage determination according to Oberholtzer criteria: 0 – no dye penetrations; 1 – to less than one-third from the margin; 2 – up to two-thirds from the margin; 3 – up to the floor; 4 – along the floor of the cavity.

margins of each restoration. After finishing the restorations, the teeth were stored in distilled water at 37 °C for 24 hours.

Microleakage test

Teeth were thermocycled for 1800 cycles between 5 °C to 55 °C with a dwelling time of 10 seconds. After thermocycling, the teeth were subjected to a 50% silver nitrate solution in accordance with Wuu *et al.*[15] Teeth were then rinsed with water and placed in freshly mixed developer solution (Kodak developer) under a strong light for 12 hours. After rinsing with water, the teeth were embedded in acrylic resin (Citofix Kit, Struers A/S, Ballerup, Denmark) and sectioned buccolingually using a diamond cutting saw (Minitom, Struers A/S, Ballerup, Denmark) operating at a speed of 125 rpm with an applied load of 100 g in 2–3 sections. Sectioned restorations were examined under a stereomicroscope (Opton, Oberkochen, Germany) at 25× magnification and photographed (Camedia, Olympus).

Marginal leakage was measured on enamel, dentine and cementum in contact with the applied materials using an Olympus DP soft, Version 3.2. Oberholtzer criteria[16] were used for the evaluation of 5122 margins (Fig. 1). The degree of microleakage was scored as follows: score 0 = no evidence of dye penetration; score 1 = penetration of dye to less than one-third from the margin; score 2 = penetration of dye up to two-thirds from the margin; score 3 = penetration of dye up to the cavity floor; score 4 = dye along the cavity floor.

The worst scores of leakage on enamel, dentine and cementum were used for statistical analyses (N = 711) (Fig. 1). Data were compared using two-way and three-way ANOVA.

RESULTS

The results for marginal leakage are presented in Fig. 2. The heat-cured GIC showed statistically significant lower microleakage values than the other tested groups (SC, UC) ($p < 0.001$). Class V cavities with and without a conditioner agent application were restored with GICs. It was found that cavities with applied conditioner (10% polyacrylic acid) presented lower marginal microleakage ($p < 0.001$). There was a marked difference in mean microleakage scores between Fuji VII and Megacem when conditioner is not used. GICs in groups with HC and conditioned cavities had lower microleakage scores. The highly viscous material Fuji IX GP Fast in the HC and conditioned cavities groups demonstrated the best marginal adaptation. The other three GIC products reacted similarly to heating treatment (Fig. 3). Leakage at the enamel margins was significantly lower than at the cementum/dentine margins ($p < 0.001$). There was a statistical significant difference between investigated material and techniques.

DISCUSSION

The restorations placed without any conditioning showed significantly greater microleakage at the enamel interface. GICs do not have enough inherent acidity to penetrate and remove the smear layer from the enamel surface. There was a marked difference in mean microleakage scores between Fuji VII and Megacem. This may depend on a number of factors such as molecular weight and composition of the polyacid matrix, concentration of acid solution and glass powder/liquid ratio. Megacem used in this study was hand mixed and Fuji VII was capsulated. Only standard cured Megacem restorations were discoloured by the dye. This could be due to microporosities in the Megacem. Lower porosities were shown in heated and ultrasonic cured Megacem restorations. The other tested glass ionomers did not show dye discolouration and microscopically appeared more homogenous.

The role of the conditioner is to effectively remove the smear layer and provide good wetting of the surface by glass ionomer, an essential requirement for good bonding.[17] These results are in agreement with Yilmaz *et al.*,[18] who reported greater microleakage when the cavity was not conditioned prior to GIC restoration. The role of chemical bonding of the GIC with enamel may be insufficient to obtain an adequate seal between the GIC and enamel. The smear layer formed during cavity preparation procedures should be removed with the manufacturer's recommended conditioner agents. Glasspoole *et al.*[19] stated that acidic conditioning is beneficial in achieving better bonding to enamel for the conventional glass ionomer. There is evidence suggesting that micromechanical bonding may play a role in

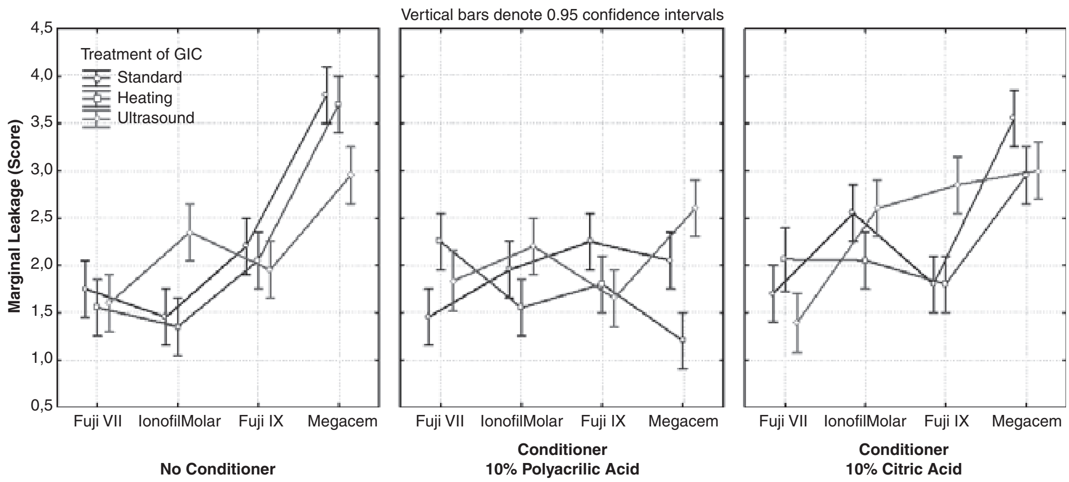

Fig. 2 Mean value of marginal leakage (score) of glass ionomer materials (Fuji VII, Ionofil Molar, Fuji IX GP Fast and Megacem) cured in three different ways (standard, heat, ultrasonic excitation) and applied in cavities which were conditioned with polyacrylic acid, citric acid and without conditioning ($p < 0.001$).

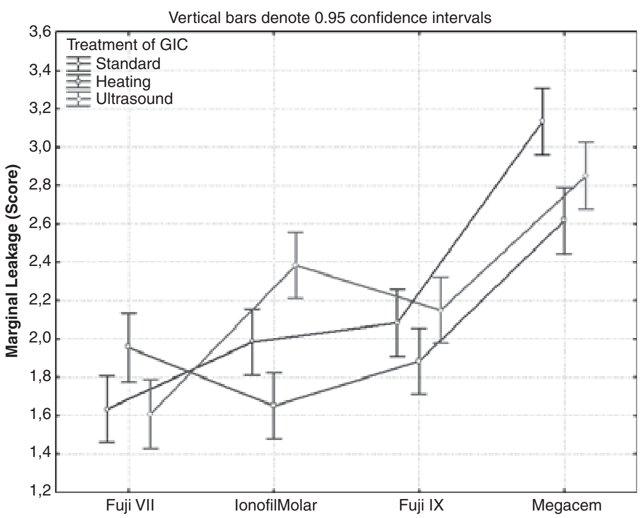

Fig. 3 Mean value of marginal leakage (score) of GICs cured in three different ways: standard, heat, ultrasonic excitation ($p < 0.001$).

bonding of conventional glass ionomer to enamel. It was also reported that polyacrylic acid has a minor effect on dentine, removing the smear layer and surface contaminants without opening the dentine tubules too widely.[20]

The microleakage scores in this study were significantly reduced in the heated group and also in the ultrasonic excited group. These results demonstrated that heat and ultrasound improved marginal integrity and seal. Temperature is a crucial factor in the setting and reaction time of GICs. Given that no studies, to our knowledge, have evaluated the microleakage of GICs after heating or ultrasound as a 'command set' method, it is difficult to compare the results obtained in this investigation. Regardless, there are similar studies about mechanical properties of GICs after heat application or ultrasonic excitation. Kleverlaan *et al.*[11] showed a significant increase in mechanical properties of the GICs after ultrasonic excitation and heat treatment compared to the standard method. The mechanism by which ultrasound enhances the setting time of cements is unclear. Towler *et al.*[12] proposed that ultrasound may increase powder surface area by breaking up aggregates or breaking down glass particles and this may account for increased reactivity. Several studies have shown the effect of ultrasonic excitation on the initial setting reaction[8,21] and on the properties of the set cement.[10,11] The ultrasonic excitation of GICs enhances the bonding to tooth surfaces[10] and the release of fluoride.[22]

Currently there is a paucity of data in relation to the effect of external energy sources through depth of a GIC[1] and only a few studies that use heat in the same way, as a 'command set' method for GICs. Therefore, it is difficult to comment and compare the results obtained in this investigation. Kleverlaan *et al.*[11] put GIC in a mould between two metal elements preheated to 70 °C. In this study, heat was added with a polymerization unit at 1200 mW/cm^2 for 40 seconds. It seems that changes in molecular kinetic energy due to an elevated temperature can lead to a rearrangement of the molecules in the material during setting.[23,24] In spite of a relatively modest increase in temperature on the surface of the filling (up to 2–3 °C), this molecular rearrangement may facilitate a better adhesion of the material or achieving a more stable zone of ionic exchange. The mechanical movement of the tip during ultrasonic excitation improves the mixing of particles and polyalkenoic acid chains, resulting in homogenous reaction kinetics. As a consequence, the total reactive surface increases, which can enhance the setting time.[11] A recent study on GICs showed that an effect produced by ultrasound (enhanced F release) was not produced by heat (F release was reduced).[25] The use of an external energy source such as a high irradiance light-curing unit or ultrasonic scaler has been found to significantly improve outer surface hardness at the initial stages of the glass ionomer setting reaction.[1] The clear clinical benefit of this outcome is a reduction in the negative sequelae of early moisture contamination of the GIC surface and adhesive interface with tooth structure. It would be most beneficial to acquire a homogenous set through the material bulk in order to improve resistance to mastication forces at early stages of the setting reaction. The moisture contamination during setting of GICs may occur at the interface between the restorative and dentine in deeper cavities, but it should be in a lesser degree compared with exposed surfaces to oral contaminants.

CONCLUSIONS

The objective of this work was to determine the microleakage of several commercially available GICs, depending on externally applied 'command set' methods: heat and ultrasonic excitation. Heating the GIC during setting decreased microleakage and improved marginal adaptation. Heat can also be utilized as a 'command set' modality. The microleakage scores were also significantly reduced in the ultrasonic excited group. Further *in vitro* investigations in the application of ultrasonic excitation and heating as a 'command set' modality for glass ionomer cements are recommended so that more comprehensive comparisons of results can be made as a possible lead up to clinical trials.

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