Introduction

Glass ionomer cements (GICs) were developed in the early 1970s by McLean and Wilson [Wilson and Mclean, 1998]. The material was based on the hardening reaction among aluminosilicate glass powders and aqueous solutions of polymers and copolymers of acrylic acid [Wilson and Kent, 1972]. GICs have been usually preferred as restorative materials in paediatric dentistry due to their low sensitivity to moisture, good adhesion ability [Kilpatrick, 1996], and high fluoride content [Croll, 1990]. However, insufficient mechanical properties limit the use of the material and numerous researches have been carried out in attempts to improve the longevity and the success of the restorations [Woolford, 1994; Towler et al., 2001; Kleverlaan et al., 2004; Algera et al., 2005; Skrinjaric et al., 2008; Yan et al., 2007].

Besides the new additives, Woolford [1994] investigated the effect of heat activation on the GICs and found that rising the temperature of the surface of the cements to a maximum of 60 °C significantly improved the early surface hardness of the cement after 24 h compared to cements which had not been heat treated. Towler et al. [2001] showed that the application of ultrasound to GICs improved the short-term surface mechanical properties. The initial setting obtained by the application of ultrasound provides improved surface hardness, particularly within the first 24 hours after setting. Kleverlaan et al. [2004] investigated the influence of externally applied command setting applications on the mechanical properties of conventional GICs. Significant temperature rise in the GICs was observed with ultrasonic excitation, so it was hypothesized that its effect on the setting of GICs may partially be explained by the increase in temperature. Algera et al. [2005] investigated the influence of heat and ultrasound application on the setting reaction of GICs and determined that the heat curing (70±2) and ultrasound accelerated the setting reaction. Furthermore, in that study it was shown that mechanical properties could be improved with ultrasound and heat. Ultrasound especially affected glass ionomer cements properties by producing heat. Skrinjaric et al. [2008] showed that the heating procedure during setting of GICs sealants can not be recommended as routine treatments in clinical practice. Yan et al. [2007] investigated the dimensional changes caused by thermal stimuli of GICs with different glass matrix ratios and showed that water loss from conventional GICs with different power/liquid (P/L) ratios compensated for thermal expansion and resulted...
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It was shown that under wet conditions glass ionomer cements maintained their original dimensions upon heating. Rafeek [2008] showed that heat treatment of conventional GICs seemed to have no significant effect on the compressive strength, fluoride release and modulus on stress relaxation characteristics. O’Brien et al. [2010] investigated the effects of various energy sources on the upper and lower surface hardness of a setting GIC and showed that preheating GIC capsules prior to mixing resulted in superior hardness values.

Thermal response of glass ionomer cements when heated is a very important clinical implication for the longevity of the restored tooth [Yan et al., 2007]. The objective of this study was to assess the effect of heat application on the mechanical properties and microstructure of conventional GICs. It was also the subject of this study to analyse the heat transfer degree through the specimens.

Materials and methods

Fuji IX (GC, Japan), a condensable glass ionomer cement, and Amalgomer CR (AHL, England), a ceramic-reinforced glass ionomer cement, were used as test materials. The information about some characteristics of the test materials are summarized in Tables 1 and 2.

The materials were mixed according to the manufacturers’ instructions and Fuji varnish was applied after the initial setting time (Table 1) for both glass ionomer cements. The study was carried out at room temperature (23±1°C) and relative humidity of 50%±10 as stated in the ISO Standard 9917-1:2003 (E) for glass polyalkeonate cements. The stainless steel molds were preheated to 37°C and the cement surface was covered with a single cellulose acetate sheet in order to obtain a smooth surface. The other molds were placed on top of the cellulose sheet to give the specimen a flat surface and GICs samples were kept in the incubator during initial setting time of the cement. Heat was applied with a soldering iron (Lotstation MLS-48, McVoice, Verzeuge, Germany). The active tip of the soldering iron was 5 mm in diameter. The soldering iron was set to 80±2°C and applied on one surface of the specimens in the study group for 2 minutes. The samples were kept in distilled water at 37°C and all tests were carried out 24 hours after the setting of glass ionomer cements. Eighty specimens were prepared and then divided into 4 groups. The effect of heat on the mechanical properties of conventional GICs was evaluated by measuring compressive strength, flexural strength, microhardness and temperature rising in the test materials was also measured and noted.

Compressive strength

Cylindrical specimens were prepared in stainless steel molds [ISO] of 4 mm in diameter and 6 mm in height. Heat was applied only on the circular surface of the cylinder, and a universal testing machine (Shimadzu AG-IS 100kN Autograph, Japan) was used on the heated surface for compressive strength test at a loading rate of 0.5 mm/min.

Flexural strength

For testing flexural strength, the prepared specimens dimensions were 25x2x2 mm. Heat was applied on the square surface of 2x2 mm. The flexural strength of these materials was determined using a three-point bending machine with Autograph (the distance between supports was set to 20 mm) (Shimadzu AG-IS 100kN Autograph, Japan).

Microhardness

Vickers Hardness Testing Machine (HMV-2 Shimadzu Kyoto, Japan) was used to test microhardness of these materials. Disc-shaped specimens of 5 mm diameter and 2 mm height were prepared in a plastic mold. A load of 300 g was applied to the heated surface of the specimens. The load was applied for 10 s and the application was repeated 5 times.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>MANUFACTURER</th>
<th>LOT</th>
<th>COMPONENT</th>
<th>INITIAL SETTING TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amalgomer CR</td>
<td>AHL, ENGLAND</td>
<td>Powder 020615-1</td>
<td>Powder: Glass, Polyacrylic acid, tartaric acid, zirconium oxide Liquid: polyacrylic acid, water</td>
<td>3 min, 30 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid 040522-7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuji IX</td>
<td>GC, JAPAN</td>
<td>Powder 0411051</td>
<td>Powder: Glass, polyacrylic acid, tartaric acid Liquid: polyacrylic acid</td>
<td>2 min, 20 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid 0411051</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1 Materials tested.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>Al</th>
<th>Si</th>
<th>Ca</th>
<th>Na</th>
<th>P</th>
<th>F</th>
<th>Sr</th>
<th>La</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amalgomer CR</td>
<td>15.8</td>
<td>18.7</td>
<td>7.1</td>
<td>5.5</td>
<td>1.6</td>
<td>12.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuji IX</td>
<td>17.9</td>
<td>13.7</td>
<td>0</td>
<td>1.0</td>
<td>2.2</td>
<td>10.2</td>
<td>19.9</td>
<td>0</td>
</tr>
</tbody>
</table>

TABLE 2 Weight percentage composition of GICs.
Heat Application on GICs

In this case were used 20 disc-shaped specimens of 5 mm diameter and thickness of 2, 4 and 6 mm. Temperature increase due to heat application from the top surface of the specimens to bottom was measured by thermocouple (Thermometer HD 8605, Delta OHM, Italy).

Statistical analysis

Statistical analysis was done using two-way ANOVA where appropriate and independent samples t-test was used when there was interaction.

Results

The results of the compressive strengths and the statistical analysis between groups are shown in Figure 1. No significant (ANOVA) differences in compressive strength were reported between Fuji IX and Amalgomer CR. Moreover, no significant differences in compressive strength were found between control group and heated group, as well.

The flexural strengths of the materials with and without heat application are shown in Figure 2. No significant differences in flexural strength among Fuji IX and Amalgomer CR were found in the study. When heat was applied to the Fuji IX, no significant differences (independent samples t-test) in flexural strengths were found between control and heated groups. When the heat source was applied to the Amalgomer, the mean flexural strengths were higher than that of the corresponding control group and significant differences were found (p<0.05).

The mean surface hardness of Fuji IX was 66.5 (±11.4) VHN. When heat was applied to the surface of the Fuji IX, the mean surface hardness was found to be 84.8(±7.5) VHN. The mean surface hardness of Amalgomer was 60.1(±16.4) VHN. When heat source...
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was applied to the surface of the Amalgomer, the mean surface hardness was measured as 65.4(±8.5) VHN. Significant differences in micro-hardness were found between control and heated groups (p<0.05) (Fig 3).

Temperatures measured at the bottom of the specimens after heat application on the top surface are shown in Table 3 and it can be seen that temperature rising in both materials was inconsiderable.

Discussion

The effect of heat on the setting reaction is likely to make the polyalkenoic acid more active [Woolford, 1994]. When the acid gets in contact with the surface of the glass, it is able to break down the surface of the glass more readily. It increases the rate at which the ions are leached and released from the glass. The total effect of all these accelerated reactions produces a more rapid formation of the calcium polyalkenoate matrix. Gu and Fu [2004] showed that particle size of GICs increases after heat application. This is due to particle agglomeration, coalescence and growth at high temperatures. Particle size distribution influenced the mechanical properties of glass ionomer cements significantly [Gu et al., 2004].

The thermal behaviour of GICs is different because of interaction with water from the environment [Carrick and McCabe, 2007]. Thermal behaviour may be affected by the original P/L ratio and the structure of the set cement [Yan et al., 2007]. The matrix of GICs contains loosely bound water as well as tightly bound water [Wilson and McLean, 1998]. Depending on the environment, loosely bound water is easily lost or gained, depending on the level of moisture/humidity in the wet or dry environment. Wilson et al. [1998] showed that the water content and especially the loosely bound water in GICs depends on the P/L ratio and the storage method. A great amount of mass loss was observed in GICs after heating in a dry environment [Yan et al., 2007]. The mass loss of GICs in wet conditions is significantly lower.

Yan et al. [2007] showed that all the GICs tested in their study lost weight during the heating process and the greatest P/L ratios produced the lowest final weight loss. The lowest P/L ratio produced the greatest contraction after heating. The water content and its relative mobility in the GICs matrix have been considered as major factors in determining the thermal response behaviour of GICs. The ratio of reinforcing glass-core and matrix affects the diffusion of water in the glass ionomer matrix [Davies et al., 1993]. When GICs are mixed at a high initial P/L ratio, the ratio of reinforcing glass core in the matured cement matrix is increased. Decreasing the P/L ratio reduces the amount of the reinforcing fillers in the matrix [Fleming et al., 2003]. The ratio of reinforcing glass core in the matured cement matrix was increased in the SEM evaluation [Kuter et al., 2010] this was particularly evident at SEM on the heated specimens.

Algera et al. [2005] showed that heat may contribute to acceleration of the reaction by de-clustering glass particles and enhancing the diffusion of the reaction components. SEM evaluation did not show de-clustering of the glass particles or a reduction of porosity in that study [Algera et al., 2005]. Kuter et al. [2010] showed that the portion of GICs specimens closer to the heat were affected to a greater extent. In that study the top part where heat was applied had a better and more meaningful differentiation. The bottom part had a lesser differentiation after the heat treatment. Voids decreased, texture became denser and there were particles with larger sizes with the heat applied. These results showed that application of heat affected the top portion where heat was applied more than the lower portion and for this reason, mechanical strength of heated GICs specimens highly increased only microhardness.

Kleverlaan et al. [2004] showed that an increase in compressive strength of the Fuji IX was found with the heat and ultrasonic application. No significant differences in compressive strengths of the Fuji IX heat and control groups were found 24 hours later, in this study. However, Kleverlaan et al. [2004] stored the samples in lubricants, in order to prevent dehydration, and the glass ionomer cement was placed between two heated metal elements for 5 minutes. Algera et al. [2005] showed that materials cured in oil reached a significantly higher compressive strength compared to storage in water. Jones et al. [2007] showed that the temperature rise on the samples lubricated with oil were greater than samples lubricated with water. For this reason, the results of our study did not show a similarity with that study, since all of the samples in our study were stored in water according to ISO [ISO] and heat was applied for 2 minutes from one surface of the glass ionomer cement.

When Rafeek [2008] carried out his study with samples stored in water, like in our study, he showed that compressive strength values between the control and the heat-treated conventional GICs specimens were not statistically different.

There were no statistically significant differences in flexural strengths of Fuji IX in both groups. On the contrary, when the heat was applied to the Amalgomer, its mean flexural strength reached a value that was higher than that of Amalgomer control, and this time significant differences were noted. When temperature is high, the P/L ratio can increase due to evaporation of the liquid, which results in high strength of materials [Kleverlaan et al., 2004]. Increasing the P/L ratio can improve the mechanical properties of the glass ionomer cements. Fuji IX is a condensable glass ionomer cement, but Amalgomer CR is a ceramic-reinforced glass ionomer...
cement and Fuji IX has higher P/L ratio. Thus, Fuji IX that further increasing P/L ratio, due to the heat application, did not lead to higher flexural strength values.

When a temperature of 700°C was applied on the glass ionomer cement (Fuji IX Fast) with soldering iron, the temperature in the pulp chamber showed a maximum rise of 2.50°C after 60 seconds [Algera et al., 2005]. Kleverlaan et al. [2004] showed that when a temperature of 700°C was applied on the glass ionomer cement (Fuji IX) for 5 minutes on both surfaces, the temperature of the glass ionomer rose from 34.60°C to 45.30°C. When the temperature of 80±20°C was applied on one surface on the GICs 2, 4, or 6 mm thick (Fuji IX and Amalgomer CR) for 2 minutes at room temperature (23±1°C), temperature rising of both glass ionomer cements was inconsiderable through the glass ionomer cement.

On the other hand, significant differences in microhardness were reported between the control and the heated groups of Fuji IX and Amalgomer CR. Wang and Darwell showed the Amalgomer CR was sensitive to moisture and the same caused a deterioration by surface degradation [Wang and Darwell, 2009]. However, it has been shown in this study that application of heat improved the strength of the GICs, at least the surface strengths of the cement. As heat transfer in this study can not be conducted all the way through the specimens, the significant improvements in microhardness were obtained in the areas that were adjacent to the surfaces where heat was applied, whereas no increase in compressive strength of GICs was observed. Kuter et al. [2010] also showed that the top parts where heat was applied had a better and more significant differentiation and the bottom parts had less differentiation in the SEM evaluation. Increasing microhardness with heat yields higher abrasion resistance values and less retention areas on the GICs surfaces. It could be strongly thought that heat application could be an alternative in the prevention of harmful effects of oral liquids on the outer surface of GICs which are sensitive to moisture for a period of 24 hours. Since it is very difficult to prevent saliva contamination on application area, especially in children, heat application on the glass ionomer cements may be useful in paediatric dentistry.

Conclusion

We can conclude that the application of heat may improve the characteristics of GICs, especially on the surface. Therefore, it may be easily expected that the application of heat increases greatly the microhardness of GICs, whereas the application of heat increases the flexural strength to a relatively lower extent. Heat should be applied on the surface of the glass ionomer cements to avoid contact with oral liquid, particularly after initial setting time and to provide higher abrasion resistance and less retention areas on the glass ionomer cements. However, further research is necessary to establish the potential effect of heat and long-term results of the restorations.

References


