Aim: Adhesive liners used in sandwich restorations between glass-ionomer cement (GIC) and composite should have sufficient strength and bonding properties. Resin-modified glass ionomers (RMGIs) exhibit good bonding to the tooth structure, GIC, and composite. They also exhibit good mechanical and bonding characteristics compared with other unfilled resins. Hence, the present study aimed to compare the shear and flexural bond strength of sandwich restorations when resin-modified glass-ionomer liners are used sandwiching conventional GIC and composite restorations compared with unfilled resins under artificial saliva in vitro.

Materials and methods: Eighty-eight specimens prepared following specific criteria for flexural (44 specimens) and shear strength (44 specimens) testing was divided into two groups consisting of RMGI and unfilled resin bonding agent sandwich restorations. Three-point bending test and the Instron universal load testing machine were used for flexural and shear testing, respectively. SPSS v.18 was used to analyze the raw data obtained and comparison between the groups. Selected samples were prepared for a scanning electron microscopy (SEM) investigation, to observe the interfaces between the GIC and composite, as well as to provide a detailed analysis of the modes of failure in the specimens.

Results: Sandwich restorations using resin-modified glass-ionomer cement (RMGIC) adhesive liner showed a statistically significant increase in shear bond forces and shear strength of the final restoration compared with an unfilled resin. There was no significant difference in the flexural strength of forces between the two groups. Scanning electron microscopy results revealed cohesive failure within the GIC as a major cause of failure of these restorations.

Conclusion: Resin-modified glass ionomer liners show promising results in terms of shear and flexural strength of the sandwich restoration compared with unfilled resins.

Keywords: Composite resin, Glass-ionomer sandwich, Laminate technique, Restorative strength, Restorative technique.

Introduction
Glass-ionomer cement (GIC) has been used with composite resin in sandwich technique1,2 to improve the adhesion to the tooth structure and also provide the best esthetics in restorative dentistry. However, due to undesirable failures in bonding, microleakage, and poor mechanical properties of the final sandwich restoration, studies in the past tested modified materials and techniques to improve the overall outcome of these restorations.3-7 Factors that affect the bond strength between the glass ionomer and composite include tensile strength of the cement itself, the adhesive system used, type of GIC, type of composite and its filler content, and surface treatment of the cement.3-9 Etching the initial layer of GIC has been used in the past, resulting in excessive cement degradation and alteration of mechanical properties of the set cement.10-12 This resulted in testing the use of adhesive resins as a sandwich between GIC and composite. Resin-modified glass-ionomer cement (RMGIC) bonding agents were introduced as a combination of GIC and composite resins, with improved mechanical properties and handling characteristics compared with the conventional glass-ionomer, while retaining their beneficial properties like fluoride release and chemical bonding to the tooth structure. It has also been shown to produce predictable long-term bonds with composite and conventional GIC.5-9 The sequential layering, using conventional GIC followed by application of RMGIC bonding agent and then layering of composite resin and co-curing them, may improve the bond strength between these two materials and eliminate several steps in a sandwich restoration.1,2 The purpose of this in vitro study was to evaluate and compare the shear bond strength and flexural strength between GIC and composite resin using either RMGIC adhesive liner or an unfilled resin adhesive at the interface between initially set conventional GIC and composite resin.

Materials and Methods
Study Site and Study Sample
The study was conducted as an in vitro study in the Department of Restorative Dentistry, UCL Eastman Dental Institute. A total of 88 specimens were prepared, 44 specimens for shear bond strength testing and 44 specimens for flexural strength testing. These were further then divided into test and control groups of 22 each for both shear and flexural strength testing. Initially, a pilot study was undertaken for both shear bond and flexural strength testing. This was necessary to determine the number of specimens required to achieve precision and to determine the power of the study.
Preparation of Flexural Strength Specimens (Test and Control Group)

Forty-four uniform clear plastic molds of 20 mm length were filled sequentially using capsulated GIC (GC Fuji IX* GP EXTRA, Capsulated, GC Europe N.V. Leuven, Belgium) shade B2, an adhesive liner, and composite resin shade A3. Glass-ionomer cement was mixed in the amalgamator for 10 seconds according to the manufacturer’s instructions and injected into the pre-cut clear plastic molds which were positioned on top of a glass slide and compacted using a condenser. The GIC was allowed to set for 3 minutes. Excess GIC was removed using a small excavator. Twenty-two specimens in the test group received RMGIC adhesive liner (light-cured reinforced glass-ionomer dentine/enamel bonding agent, GC Fuji BOND LC®) which was used with a micro-brush for 15 seconds. The adhesive was air-dried with oil-free compressed air to a thin film and was light-cured for 20 seconds. Twenty-two specimens in the control group were lined with unfilled resin adhesive (Adper Scotchbond® Multipurpose Adhesive, 3M ESPE®) for 15 seconds. The composite resin (Gradia Direct* Posterior light-cured Composite Resin, GC Corporation Tokyo, Japan) was then incrementally packed (2 mm thickness) packed with a condenser and cured for 40 seconds for each increment. The clear plastic molds were cut to release the cylinder beam form specimens (Fig. 1), which were then immersed in artificial saliva (Macknight-Hane and Whitford formula)31 and incubated at 37°C for 48 hours.

Preparation of Shear Strength Specimens (Test and Control Group)

Forty-four uniform epoxy resin [Bisphenol-A (epichlorohydrin) Epoxy resin*, Struers Ltd., Solihull, UK] embedded metal rings were prepared (Fig. 2). Clear plastic pipettes of 4 mm diameter were sectioned to create uniform 44 clear plastic molds of 4 mm length. Fuji IX* capsulated GIC was mixed in the amalgamator according to the manufacturer’s instructions and injected into the resin embedded metal rings, compacted using the uniform weight of two glass slabs and left to set for 3 minutes. The test and the control group of 22 each received resin-modified glass ionomers (RMGI) adhesive liner (light-cured reinforced glass-ionomer dentine/enamel bonding agent, GC Fuji BOND LC®) and unfilled resin adhesive (Adper Scotchbond Multipurpose Adhesive, 3M ESPE®), respectively, similar to flexural testing specimens. Composite resin was then incrementally packed into the pre-cut clear plastic molds on top of the GIC and cured for 40 seconds each time. After that, the clear plastic molds were cut and removed to release the composite resin cylinders (Fig. 3). The specimen was then immersed in artificial saliva and incubated at 37°C for 48 hours.

Flexural and Shear Testing

Flexural testing is used to determine the flexure or bending properties of a material. Flexural strength was measured using a three-point bending test. The axial load was applied on top of the prepared specimens and at the composite resin–GIC junction at a rate of 0.5 mm/minute until the specimen fractured. Maximum stress and strain are calculated on the incremental load applied.

Shear bond strength is defined as the measurement of how well one material bonds with another. The Instron Universal Load Testing Machine (4505, Instron Corporation, Buckinghamshire, UK) was used for shear bond strength testing. The machine was connected to a computer and was programmed to apply a load to the specimens through a crosshead shearing blade at a speed of 1 mm/minute. The specimens were positioned into the alignment jig perpendicular to the direction of the load, ensuring that the crosshead blade was positioned at the composite–GIC junction. The recorded measurements were a distance of displacement of the shearing blade in millimeters (mm) and load failure measured in kilo Newtons (kN).

After collecting and converting the raw data into a Microsoft Excel Worksheet, IBM SPSS v.18 was used to analyze the data and compare the groups for both shear bond strength and flexural strength. The failure loads were measured in Newtons and converted to megapascals and expressed as shear bonds and flexural strengths. The point of failure was the largest force at which the specimen showed a definite separation. The results obtained were shear and flexural forces in kilo Newtons (kN) and displacement (mm). Descriptive statistics were used to assess the distribution of the results and the significance level was 0.05.

Scanning Electron Microscope Analysis

Selected samples were prepared for a scanning electron microscopy (SEM) investigation, to observe the interfaces between the GIC and composite resin, as well as to provide a detailed analysis of the modes of failure in the specimens.

Results

Results of the shear bond forces show the mean value for the test group was 135.6161 and for the control group was 70.488 (Table 1). This indicates that there was a significant difference between the two groups favoring the test group. In flexural forces, the mean value for the test group was 40.316 and for the control group was 40.398 (Table 2). This indicates that there was no significant difference between the two groups. The results also showed a statistically significant increase in the shear bond strength (p value < 0.001) for the specimens lined with RMGI adhesive liner at the interface between GIC and composite resin, compared with the control group which was coated with unfilled resin adhesive at the interfaces (Table 1). There were no significant differences among the flexural strengths for both the control and test group (p value 0.901) (Table 2).

Twelve GIC–composite resin specimens, three from each group among flexural and shear bond testing specimens, were prepared and analyzed under the scanning electron microscope. Results...
from SEM indicate that cohesive failure within GIC was the main fracture mode for the specimens in both shear and flexural strength tests (Fig. 4). It was evident that the majority of specimens failed cohesively through the bulk of GIC while some failed adhesively at the interface. None of the failures were cohesive in the composite resin. Scanning electron microscopy examination of the test samples of GIC bonded to composite resin using RMGIC adhesive liner showed the closest adaptation of the bond at the interface between GIC and composite resin (Fig. 5). Higher magnification under the SEM examination revealed cracks in the GIC specimens was due to dehydration of the GIC during the preparation of specimens.

**Table 1:** Mean value and p value of shear force and stress

<table>
<thead>
<tr>
<th>Shear force</th>
<th>Sample (N)</th>
<th>Mean (SD)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMGI group</td>
<td>22</td>
<td>135.61 (47.05)</td>
<td><em>p = 0.000</em></td>
</tr>
<tr>
<td>Unfilled resin group</td>
<td>22</td>
<td>70.4 (47.3)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2:** Mean value and p value of flexural force and stress

<table>
<thead>
<tr>
<th>Flexural force</th>
<th>Sample (N)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMGI group</td>
<td>22</td>
<td>40.93 (13.09)</td>
<td><em>p = 0.000</em></td>
</tr>
<tr>
<td>Unfilled resin group</td>
<td>22</td>
<td>40.39 (13.00)</td>
<td></td>
</tr>
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</table>

**Discussion**

This *in vitro* laboratory study was aimed to identify the shear and flexural strength differences of sandwich restorations using GIC and composite resin sandwiched by RMGIC adhesive liner compared with unfilled adhesive resin. Results from the study indicate that sandwich restorations using RMGIC adhesive liner showed a statistically significant increase in shear bond forces and shear strength of the final restoration compared with an unfilled resin liner sandwich. There was no significant difference in the flexural strength between the two groups tested. Scanning electron microscopy results revealed cohesive failure within the GIC as a major cause of failure of these restorations. Adhesive failure was also noted. Scanning electron microscopy examination of the test samples also showed the closest adaptation of the bond at the interface between GIC and composite resin. Higher magnification under the SEM examination revealed cracks in the GIC specimens was due to dehydration of the GIC during the preparation of specimens.

The sandwich restorations, also known as the laminate technique, is of specific importance in moderate to deep restorations, in particular, at the gingival margins of class II cavities with extension onto the root surface. Subgingival restorations are always prone to issues related to bonding because of the inability to maintain adequate moisture control. This is of prime importance for the success of any bonded restorations. The laminate technique provides composite resin-dentin bonding with the use of GIC acting as an intermediary layer. This minimizes microleakage by a considerable reduction in the composite bulk, postoperative sensitivity, and secondary caries due to the adhesive and fluoride-releasing properties of GIC and also achieves desirable esthetics with composite.

Different materials and techniques have been advocated to bring about the overall clinical success of the final restoration by improving...
the bond between GIC and the composites. These include surface treatment protocols and using different intermediary materials. Chemically cured or autocured GIC has been the material of choice since the past, however, necessitating the need to etch the surface of the GIC or using an intermediary bonding agent, or both, to obtain a desirable composite and GIC bonding. Studies in the past using the combination of acid etching and adhesive bonding showed that acid etching did not improve the sealing ability of sandwich restorations. The use of bonding agents alone showed significant improvement in the bond strength. Hence, the bond strength of a sandwich restoration with an intermediary adhesive liner is dependent upon the tensile strength of the GIC itself, which is dependent upon the manipulation and the powder to liquid ratio, the viscosity of the bonding agent which determines its wettability and flow, the volumetric change caused due to polymerization of the composite resin and the technique to pack the GIC and composite without the incorporation of voids. This concludes that the bond strength was more material-dependent and hence intermediary bonding agents were tested in this study. Among the various bonding agents tested self-etch adhesives showed increased shear bond strength compared with total-etch systems.

Resin-modified glass ionomers were used as liners and restorative material for deeper restorations very close to the pulp. Resin-modified glass ionomer bonding agents are dimensionally stable, exhibit good bonding to the tooth structure and restorative materials like GIC and composite, release fluoride, reduce stress on the tooth due to polymerization shrinkage of composite, and prevent microleakage, thereby reducing marginal discoloration and postoperative sensitivity. The shear bond strength of RMGI adhesive did not show a significant difference even in presence of saliva. Hence, RMGI adhesive was used in the present study and compared with unfilled resin adhesive.

Results from the current study indicate a statistically significant increase in the shear bond strength when RMGI adhesive liner was used sandwiching conventional composite and GIC compared with the unfilled resin adhesive. The results obtained are similar to previous laboratory studies. Additional results from previous studies also indicate that the bond strength was more with unset or partially set GIC and salivary contamination did not affect the shear strength. However, these were not tested in the present study, although the study was done under artificial saliva.

In the present study, RMGI adhesive bonding agent was applied on unset or partially set GIC and co-cured after the application of adhesive. This is based on the results from previous studies indicating the improved bond strength of self-etch systems on unset GIC. Also, the lower the viscosity of the adhesive used, the better will be the bond strength.

Scanning electron microscopy analysis from the present study indicates that the majority of failures occurred cohesively within the GIC. This is similar to the results obtained from previous studies. Possible reasons for this could be attributed to the physical properties of the material, the mechanism used in testing the specimens, stress distribution during strength testing, setting reaction, differences in setting mechanism between the two materials, and contraction during curing of the resin composite and RMGI bonding agent. There were limited failures reported adhesively; however, no cohesive failure was reported within the composite. Despite the type of adhesive liner or the etching technique used the adhesive strength of the composite was reported to deteriorate over some time when stored in water, from previous studies. Water sorption was reported to reduce the mechanical properties of the polymer matrix by swelling and reducing the frictional forces between the polymer chains, due to plasticization. Also, the residual products, such as, uncured resin monomers and other breakdown products were also reported to cause deterioration in adhesive bond strength and weakening the bond leading to adhesive failure.

The study is not without limitations. This study was undertaken in the most realistic way possible in an attempt to
to mimic the real clinical model with limitations like the technical difficulties involved in specimen preparation and material testing which might have a direct influence on the results obtained. The clinical parameters, such as, saliva, accessibility in the oral cavity, structure of enamel, and dentin for bonding, were not considered in this study. This could have a possible influence on the outcome when this technique is used in the oral cavity. However, the results obtained from the current study can be used for future long-term clinical trials to look for predictable evidence on this technique.

**Conclusion**

To conclude the use of RMGI adhesive liner sandwiching conventional GIC and composite showed increased shear bond strength compared with the use of an unfilled adhesive. Considering the results from this study long-term randomized controlled trials in a clinical setting are warranted to justify the clinical outcome of these restorations.

**References**