The effect of pressure changes during simulated diving on the shear bond strength of orthodontic brackets

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Abstract
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Introduction: This study investigated the effect of pressure variations to which divers are subjected on shear bond strength of orthodontic brackets bonded to teeth with resin modified glass ionomer cement (RMGIC) or composite resin.
Methods: Eighty extracted premolars were randomly divided into two groups. Group 1: orthodontic brackets were bonded with RMGIC. Group 2: orthodontic brackets were bonded with composite resin. Each group was further divided into two subgroups. Subgroup A: The samples were kept at sea level pressure (101 kPa). Subgroup B: The samples were pressurised once from 101 kPa to 405 kPa for five minutes, then depressurised to 101 kPa. Shear bond strength was then measured.
Results: Shear bond strength of brackets bonded with RMGIC in the simulated diving group was significantly less than that of the sea level pressure group ($P = 0.019$), while no significant difference was found between the simulated diving group and sea level pressure group for brackets bonded with resin cement ($P = 0.935$). At sea level pressure, there was no significant difference between shear bond strength of brackets bonded with RMGIC and composite resin ($P = 0.83$). In simulated diving conditions, there was a statistically significant difference between shear bond strength of brackets bonded with the RMGIC and composite ($P = 0.009$).
Conclusions: Pressure changes during scuba diving may have an adverse effect on the retention of brackets bonded with RMGIC. Using composite resin for bonding brackets appears to be good strategy for patients such as divers who will be exposed to pressurised environments.

Introduction

In light of overwhelming popularity of scuba diving, general dental practitioners should be prepared to address complications arising as a result of diving and to provide patients with accurate information.[1] The relevant conditions for dentists who treat divers include diving-associated headache, sinus and middle ear barotrauma, trigeminal or facial nerve baroparesis (pressure-induced palsy), mouth piece associated herpes infection, pharyngeal gag reflex, temporomandibular joint disorder, barodontalgia (barometric-related dental pain) and barotrauma (barometric-related tooth injury).[2]

The changes in volume inside the body's gas-containing cavities associated with the changing ambient pressure, can cause several adverse effects, which are referred to as barotrauma.[1] Dental barotrauma refers to mechanical dental injuries related to barometric pressure changes. It can manifest as tooth fracture (also called barodontocrexis), restoration fracture, and dislodgement of crowns etc.[3] Other than a need for dental treatment, potential consequences include aspiration or swallowing of the dislodged restoration or dental fragment, and pain which may lead to incapacitation while diving and premature discontinuation of the planned dive.[4,5] Previous studies have reported that pressure changes can affect retention of restorations,[4,6] crowns,[7,8] orthodontic bands[9] and endodontic posts.[10–13]

With the increasing number of divers, it is inevitable that the dentist will have orthodontic patients who participate in diving.[14] Orthodontic treatment involves using fixed or removable appliances on teeth to correct their position. The success of a fixed dental appliance depends on the metal attachments (brackets and bands) being securely attached to the teeth so that they do not become loose during treatment. Brackets are usually attached to the incisors, canines and premolars, whereas bands are more commonly used on the molars. The most common adhesives used for attaching bands to teeth are conventional glass ionomer luting cement and resin modified glass ionomer luting cement.[15] To attach brackets to teeth, composite resin and resin modified glass ionomer cement are commonly used.[16]

It is important to be aware of the effect of pressure changes on orthodontic components in terms of retentive strength, as the potential danger resulting from dislodgement of such components during a dive is obvious. One study assessed the effect of environmental pressure on the retentive strength of cements for orthodontic bands,[9] showing that strength of bands cemented with conventional glass ionomer luting cement is reduced after pressure cycling. Whether the pressure variations that divers are exposed to affect the retention of orthodontic brackets is still unknown.

The aim of the present study was to investigate the effect of pressure variations to which divers are subjected on shear bond strength of orthodontic brackets bonded with resin modified glass ionomer cement (RMGIC) or composite resin. The null hypothesis was that, regardless of the type of cement used, the shear bond strength of orthodontic brackets would not change after simulated dives.

Methods

Ethical approval was obtained prior to the study from our Institutional Ethics Committee (protocol ref no. 579/2021-22).

TEETH

Eighty extracted human premolars were used in the study. Tooth inclusion criteria included absence of endodontic treatment, carious lesions, restorations and enamel defects such as enamel hypoplasia, enamel hypomineralisation or visible cracks. The selected teeth were disinfected with 70% alcohol for 30 minutes. Soft tissue and calculus was removed by ultrasonic scaling. Teeth were stored in distilled water at room temperature and used within six months of extraction.

The teeth were embedded using autopolymerising acrylic blocks, with the buccal surface parallel to the load direction under shear bond strength testing. The facial surfaces of teeth were cleaned with a mixture of water and pumice. The teeth were rinsed thoroughly with water and dried with compressed air.

ORTHODONTIC BRACKETS

Eighty premolar brackets (0.022 MBT Preadjusted Gemini stainless steel, 3M Unitek, USA) were used. The average surface of the bracket base was 9.6 mm^2.

BONDING PROCEDURE

Teeth were randomly divided into two groups of 40 premolars.

Group 1: Brackets bonded with RMGIC (GC Fuji Ortho LC; GC International Corp., Tokyo, Japan). The enamel surface was etched with 37% phosphoric acid gel for 30 seconds, then rinsed with water spray for 20 seconds and left moist. Cement mixing was done according to manufacturer's instructions. On a mixing pad, one level large scoop of powder to two drops of liquid was dispensed. The powder was divided into two equal parts. The first portion was mixed with liquid for about 10 seconds. After this the remaining powder was incorporated and mixed thoroughly for 10 seconds. The mixture was placed on the bracket base. A bracket positioning gauge was used to place the bracket on the mid-buccal surfaces of the teeth at least 4 mm away from the buccal cusp ridges, while the bracket slot was perpendicular to the tooth coronal long axis. Using a force gauge, a 300 g compressive force was applied to each bracket to reduce and standardise the adhesive thickness. Excess cement was removed with a dental probe.

Group 2: Brackets bonded with composite resin (Transbond XT; 3M Unitek, St Paul, Minnesota, USA). The enamel surface was etched with 37% phosphoric acid gel for 30 seconds, then rinsed with water spray for 20 seconds and dried with oil-free compressed air for 20 seconds. According to manufacturer instruction, the primer (Transbond XT Primer; 3M Unitek, St Paul, Minnesota, USA) was applied to the etched surface. The single-component composite resin was then applied to the bracket base and placed on the tooth in a similar manner to group 1.

All the brackets of both groups were cured using an Ortholux LED Curing Light (3M Unitek, Monrovia, CA, USA) for 10 seconds each from the occlusal, mesial, distal and gingival aspects. After light curing, specimens were stored in distilled water at 37°C for 24 hours to allow complete polymerisation of the bonding material.

Each group was randomly divided into two subgroups A, B of 20 samples each.

- Subgroup A (sea level pressure). The samples were kept at normal atmospheric/sea level pressure (~101 kPa) and treated as a control.
- Subgroup B (simulated dive). The samples were exposed to pressure to simulate a dive. The simulator was a customised pressure chamber (Ashirwad Manufacturing, India) with a pressure controller programmed to change internal pressure between 101 to 405 kPa. The samples were placed in the pressure chamber in an open glass container soaked in distilled water. Compressed air was introduced to increase the pressure from 101 to 405 kPa at a rate of 101 $kPa{\cdot}min^{-1}$ to simulate a descent. Once the maximum pressure of 405 kPa was reached it was maintained for five minutes and then decreased back to 101 kPa at 101 $kPa{\cdot}min^{-1}$ to simulate ascent. This procedure was designed to simulate conditions that a recreational scuba diver might experience on a single dive to 30 metres depth.

SHEAR BOND STRENGTH TESTING

Each specimen was loaded into a universal testing machine (Five Star Manufacturing, India), with the long axis of the specimen kept perpendicular to the direction of the applied force. A knife-edge chisel was positioned in the occluso-gingival direction and in contact with the bonded specimen

Figure 1
Shear bond strength testing configuration

(Figure 1). Bond strength was determined in the shear mode at a crosshead speed of 0.5 mm·min^{-1} until fracture occurred. The values of failure loads in newtons (N) were recorded and converted into megapascals (MPa) by dividing the failure load (N) by the surface area of the bracket base.

STATISTICAL ANALYSIS

Descriptive statistics, including the mean, standard deviation, standard error, and minimum and maximum values, were calculated for each of the groups tested. The Kolmogorov-Smirnov test determined the data were normally distributed and parametric tests were therefore used. One-way analysis of variance (ANOVA) and Tukey multiple comparison tests were used to compare shear bond strength among the groups. Significance for all statistical tests was predetermined at $P < 0.05$.

Results

Descriptive statistics for the shear bond strength of all groups are presented in Table 1. Shear bond strength of brackets bonded with RMGIC was significantly less in the simulated diving group than the sea level pressure group ($P = 0.019$), while no significant difference was found between the simulated diving group and sea level pressure group for brackets bonded with resin cement ($P = 0.935$). In the sea level pressure group there was no significant difference between shear bond strength of brackets bonded with RMGIC and composite resin ($P = 0.83$). In the simulated diving group, there was a statistically significant difference between shear bond strength of brackets bonded with the RMGIC and composite ($P = 0.009$).

Discussion

With a growing number of divers, dentists will increasingly encounter oral complications of pressure changes and these would require careful attention.[17] These conditions potentially may cause distraction or incapacitation that could jeopardise diving safety.

Fixed orthodontics is a type of orthodontic appliance where brackets are bonded to teeth. The bond strength between the enamel surface and bracket must withstand the mechanical and thermal effects of the oral environment.[18] To best of our knowledge, this is the first investigation that has assessed the effect of pressure change on the bond strength of orthodontic brackets. In the present *in vitro* study, orthodontic brackets bonded with two different types of cement were subjected to a single simulated dive in a pressure chamber and the shear bond strength was investigated. RMGIC and composite resins were selected because they are the most frequently used bonding material in orthodontics.

In the constant sea level pressure condition, mean shear bond strength of RMGIC after acid etching of the enamel surface was similar to those of composite resin. This was consistent with previous studies.[19,20] However, after a simulated dive the brackets bonded with RMGIC showed significantly lower shear bond strength than the sea level pressure group. In contrast, in brackets bonded with composite resin, the shear bond strength was not affected by the simulated dive. The null hypothesis was therefore rejected.

During descent to depth gas-containing anatomic spaces will be compressed, and during ascent, any compressed gas introduced to these spaces will expand.[21] Problems arise when gas containing spaces cannot expand or contract to equalise internal and ambient pressures. Thus, bubbles and porosities in the cement or interfacial surfaces could be affected during pressure change. In diving, stress is induced when air contained in porosities in the cement layer attempts to compress. Conversely when returning to the surface, the enclosed gas expands inducing further stress. The accumulated stress of these compression- expansion cycles can cause cracks and/or propagation of existing cracks and flaws inside the cement layer and/or along the internal surface.[8] Each porous material might have blind pores, through pores (open porosity) and closed pores.

Table 1

Shear bond strength (MPa) comparisons between control (constant sea level pressure) and dive (simulated dive) sub-groups of orthodontic brackets bonded to teeth using composite resin or resin modified glass ionomer cement (RMGIC)

Cement	Constant sea level pressure (*n* = 20)		Simulated dive (*n* = 20)		*P*-value
	Mean (SD)	Range	Mean (SD)	Range	
RMGIC	11.35 (1.27)	8.8–13.2	10.03 (1.87)	5.5–12.4	0.019
Composite resin	11.72 (1.07)	9.1–13.7	11.46 (1.25)	8.6–13.6	0.935
P-value	0.83		0.009		

The blind pore terminates inside the material. The through pores pass through and through the material. Porosities that include closed pores are potentially most influential on the mechanical properties of the material.[12] The effects of pressure are expected to be less when porosity or air inclusion is lower.[11]

The formation of glass ionomer cement requires a chemical reaction between an acid and base reagent. The fluoraluminosilicate glass powder (base) and the polycarboxylic/water (acid) must be mechanically mixed prior to use.[22] It is recognised that such mixing methods may result in the incorporation of air porosity in the cement.[23–25] This may explain our findings that the hand-mixed RMGIC is affected by pressure exposure.

Light activated composite resin adhesives are single-component materials stored in opaque packages. Single-component resins are convenient because no mixing is required, thus there is less chances of incorporation of air porosities.[26] This could be the reason that composite resin was not affected by pressure exposure.

According to one study, the brittle cements are affected more by environmental pressure cycling.[8] Generally, resins are less brittle and more fracture-resistance than RMGIC.[26] This may be another reason that the shear bond strength of brackets bonded with composite resin was not significantly affected by pressure exposure.

There is no universally accepted minimum clinical bond strength for orthodontic attachments. However the strength should withstand normal orthodontic and masticatory forces (8–9 MPa).[27] On the other hand, adhesive forces should not be too strong in order to avoid enamel loss after debonding (40–50 MPa).[28] In the present study, the mean shear bond strength of brackets bonded with RMGIC in the simulated diving group was 10.03 MPa, ranging from 5.5 to 12.4 MPa. This indicates that some samples failed below optimal bond strength. Although the clinical condition and the forces applied to the teeth in the oral cavity are different from the design of this study, these numbers do have clinical significance.

A direct comparison between the results of the present study and those of others is somewhat difficult because of variety of dental components and material used. However, despite these variations, the present results may, at least in part, be compared with those of previous studies in which similar test methods and material were used. One study found that the retention of full cast crowns cemented with resin was not affected after pressure cycling.[7] Another investigated the effect of cyclic environment pressure changes on the retention of crowns on extracted teeth.[8] That study found that crowns cemented with either zinc phosphate cement or conventional glass ionomer cement had significantly reduced retention, whereas retention of crowns cemented with resin cement was unaffected by pressure cycling.

In the present study all the variables that could have an effect on shear bond strength such as pre-treatment of teeth, placement of light source, curing protocols and storage protocols of the prepared specimens were kept constant. Thus, the only variable affecting the shear bond strength in this study was the effect of pressure exposure on the bonding cement.

The studies which assessed the effect of pressure changes on the dental components, simulated a diving environment by using either hyperbaric chamber[11–13] or a customised pressure chamber.[6,29,30] In this study, a customised pressure chamber was used to simulate diving environment.

The clinical significance of this study should be tempered by its limitations. The oral cavity is a complex environment, with variations in temperature, stresses, humidity, acidity, and plaque. It is impossible to design a laboratory condition that fully reproduces the oral environment. Therefore, further clinical studies are needed to confirm these findings. This study aimed to recreate the conditions of a single simulated dive to 30 metres depth. Commercial and military divers dive more frequently and to greater depths than this. More research is needed to determine how these adhesives perform under higher pressures and for a greater number of pressure cycles.

Conclusions

Within the limitations of this study, it can be concluded that, pressure changes during diving may have an adverse effect on the retention of brackets bonded with RMGIC. Using composite resin for bonding brackets appears to be good strategy for patients such as divers, who are likely to be exposed to pressurised environments.

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