Influence of atmospheric pressure changes on dentin bond strength of conventional, bulk-fill and single-shade resin composites

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Abstract
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Introduction: The purpose of this study was to investigate the dentin bond strength of composite resins in response to environmental pressure changes.
Methods: Ninety extracted human molar teeth were used. A mould (3 mm x 4 mm) was adapted on dentin, resin composites (conventional [*n* = 30] and single-shade composites [Ohmnicroma] [*n* = 30]) were filled in two increments of 2 mm. The bulk-fill composites (*n* = 30) were filled with one 4 mm increment. The specimens were stored for 30 days in artificial saliva. The specimens were exposed to hyperbaric pressure (283.6 kPa; 2.8 atmospheres absolute [atm abs]) or hypobaric pressure (34.4 kPa; 0.34 atm abs) once daily for 30 days and the control group was stored at atmospheric pressure for 30 days. The bond strength was tested with a universal testing machine and the failures were examined with a stereomicroscope and scanning electron microscope. Statistical analyses were performed using analysis of variance with post hoc tests, and the Weibull analysis.
Results: Regardless of environmental pressure changes, the bulk-fill composites showed the highest bond strength. There was no significant difference in bond strength between the hypobaric and atmospheric pressure (control) groups after 30 days in all resins. The hyperbaric group showed lower bond strength for bulk-fill composites than the control group.
Conclusions: Dentists experienced in diving and aviation medicine should definitely take part in the initial and periodic medical examinations of divers and aircrew to give appropriate treatment. Bulk-fill composite resins can be preferred in divers and aircrew due to high bond strength values.

Introduction

Composite resins have undergone many developments in terms of their mechanical and aesthetic properties since the 1950s. These improvements have made them the preferred material in many treatments such as for dental caries and the repair of crown fractures.[1]

Most of the composite resins used today can be placed on the tooth with a thickness of up to 2 mm for an ideal restoration. When composite resins are applied with a layering technique, the restoration times are prolonged, and there is a risk of the possibility of incorporating voids or contamination between composite layers.[2] These disadvantages may result in bond failures. Recently, bulk-fill composites have been introduced to reduce the application time and eliminate the problems associated with incremental placement techniques. Bulk-fill composite resins can be placed up to 4 mm thick by curing once.[3] Current reports indicate that the bulk-fill resin has improved mechanical properties,[4,5] less polymerization stress and less microleakage.[6,7]

Omnichroma, which was first introduced in 2019, is the first composite resin-based material that could match any tooth with any shade, on any patient. This one-shade property of Omnichroma is unique. Thus, dentists do not need to be concerned that they may create multiple shades. This offers a fast, simple system with desirable and functionally esthetic restorations.[8]

Although atmospheric pressure is relatively constant within weather variations in daily life, in some situations like high-altitude flights, mountain climbing, diving and working under hyperbaric pressure, signficant environmental pressure changes occur.[9,10] The most important pressure change effect in the oral cavity is barodontalgia. The term barodontalgia was first used in the 1940s to describe pain in the orofacial region associated with environmental barometric changes.[11] This mechanism is explained by Boyle's Law. The volume and pressure of an ideal gas at a constant temperature vary inversely. When a person descends under the sea, pressure increases and the volume of gas spaces in the body (e.g., sinuses) or within artificial substances like resins and restorations, will decrease. The reverse is true for ascents to altitude where ambient pressures are lower. These pressure changes may cause microleakages and dislodgement of dental restorations and crowns.[12,13] It was reported that environmental pressure changes can affect the retention of crowns depending on the cementation technique and the dental material.[13,14] Also, it was reported that one of the underlying causes of barodontalgia is leaking restorations (4–50%).[15]

Few studies have examined the effect of pressure changes on dental restorations. Most studies examining environmental pressure changes in dentistry pertain to cementation type, material and techniques. Within the development of new techniques, bulk-fill composites and Ohmnicroma are preferred due to their aesthetic and mechanical properties. As crown dislodgements or restoration fractures may cause painful and distressing problems in diving or flying, it is important to select the appropriate dental restoration. To the best of our knowledge, this is the first research that has assessed the effect of environmental pressure changes on the bonding strength of composite resins to dentin. There is also scant research on the mechanical properties of single-shade composites and bulk-fill composites. Therefore, the aim of this study was to investigate the bonding strength of different composite resins to dentin in artificial saliva after exposure to hypobaric and hyperbaric pressure changes. The null hypothesis was that the bond strengths of composite resins to dentin do not differ in specimens that are exposed to different environmental pressures.

Methods

The Eskisehir Osmangazi University Ethical Committee approved the study protocol (Approval No: 182155).

SPECIMEN PREPARATION

Ninety sound caries-free human molars, newly extracted due to periodontal diseases or orthodontic treatment, were selected. Adherent tissue was removed, and the teeth were cleaned and placed in 0.5% Chloramine-T solution and stored at 4°C until used. The roots were separated from the crowns at the cementoenamel junction. The teeth were bisected mesiodistally at the middle to buccal and palatal parts using a low speed saw, (Isomet Buehler, USA), and embedded in methacrylate resin (Birlesik Group Dental, Turkey) in plastic moulds (inner diameter 25 mm, height 20 mm) with their buccal and palatal surfaces facing up. The enamel surfaces were removed with 250 grit silicon carbide grinding paper and then roughened with 600 grit silicon carbide grinding paper. The teeth were then stored in distilled water and divided into 3 groups of 30 teeth per group. The specifications of materials are listed in Table 1.

Gluma, self-etch priming agent (Kulzer GmbH, Germany) was applied to the dentin surface and light-cured for 20 s in according to the manufacturer's instructions (Labolight LV III, GC, Japan). A cylindrical silicone mould was prepared in a diameter of 3 mm and 4 mm in height.

Group 1: The mould was adapted on dentin and filled with composite resin (Estelite Posterior Packable Composite, Tokuyama Dental, Japan) in two consecutive increments of 2 mm, followed by polymerizing each increment for 20 s.

Table 1

Experimental materials used in this study; 4-META – 4-methacryloxyethyl trimellitate anhydride; BisGMA – bisphenol A-glycidyl methacrylate; MDP – methacryloxydecyl dihydrogen phosphate; SiO_2 – silica; TEGDMA – triethylene glycol dimethacrylate; UDMA – urethane dimethacrylate; ZrO_2 – zirconia

Material (Manufacturer)	Composition	Lot	City Country
Reveal HD Bulk Fill (Bisco)	UDMA, Bis-GMA, Ytterbium fluoride	1800005251	Schaumburg, USA
Estelite Posterior Packable Composite (Tokuyama Dental)	UDMA, Bis-GMA, TEGDMA, ZrO_2-SiO_2	W110	Tokyo, Japan
Ohmnicroma (Tokuyama Dental)	UDMA / TEGDMA (Filler loading 79 wt% [68 vol%]), Uniform sized supra-nano spherical filler 260 nm SiO_2-ZrO_2, round shaped composite filler including 260 nm spherical SiO_2-ZrO_2	0062	Tokyo, Japan
Gluma Bond Universal (Heraeus Kulzer GmbH)	MDP phosphate monomer, 4-META, dimethacrylate resins, acetone, fillers, initiators, silane	K010923	Hanau, Germany

Group 2: The mould was adapted on dentin and filled with one 4 mm increment with bulk-fill composite resin (REVEAL HD Bulk, Bisco, USA), and light-cured for 20 s.

Group 3: The mould was adapted on dentin and filled with single-shade resin composite (Ohmnichroma, Tokuyama, Japan) in two consecutive increments of 2 mm, followed by polymerizing each increment for 20 s.

The samples were then stored for 24 h at room temperature in artificial saliva. The artificial saliva contained 16.5 mol·m^3 NaCl, 4.1 mol·m^3 KH_2PO_4, 24.8 mol·m^3 $KHCO_3$, 4.0 mol·m^3 Na_2HPO_4, and 0.25 mol·m^3 $CaCl_2$. The pH was adjusted to 7.[16,17]

PRESSURE CHAMBER TESTS

To test the effect of pressure cycling, each group was divided into three subgroups of 10 (Figure 1).

Group A was exposed to hyperbaric pressure. The hyperbaric chamber was a custom-made device (Hipertech Electronic and Machine Industry Company, Istanbul, Turkey) that enabled electronic control of pressure changes. The pressure cycle regimen consisted of 30 pressure cycles from 101.3 to 283.6 kPa (1.0 to 2.8 atmospheres absolute [atm abs]), a pressure exposure equivalent to 18 metres of seawater (msw) at a rate of 50.5 kPa·min^{-1}, reaching the maximum pressure in approximately 5 min. After 30 minutes at 283.6 kPa, the decompression phase began, again at a rate of 50.5 kPa·min^{-1} taking approximately 5 min. This process was repeated for 30 days, one cycle each day.

Group B was exposed to hypobaric pressure. The hypobaric chamber was a custom-made device (ETC; Southampton PA, USA) that enabled electronic control of pressure changes. The hypobaric chamber was decompressed to 34.4 kPa (0.34 atm abs, equivalent to 27,000 feet or 8,200 m altitude) over 5 min. After 30 min at 34.4 kPa, the chamber was recompressed to the normal atmospheric pressure over a period of 5 min. This process was repeated for 30 days, one cycle each day.

Group C was stored at atmospheric pressure in artificial saliva for 30 days.

SHEAR BOND STRENGTH MEASUREMENT

The shear bond strength was measured with the Universal Testing Machine (Lloyd-LRX, Lloyd Instruments, Fareham, UK) at a crosshead speed of 1 mm·min^{-1}. Specimens were put in the jig of the testing machine with the dentin surface parallel to the loading direction with a 500 N load cell in the testing machine (Figure 2). The bond strength values

Figure 1
Experimental design of the study

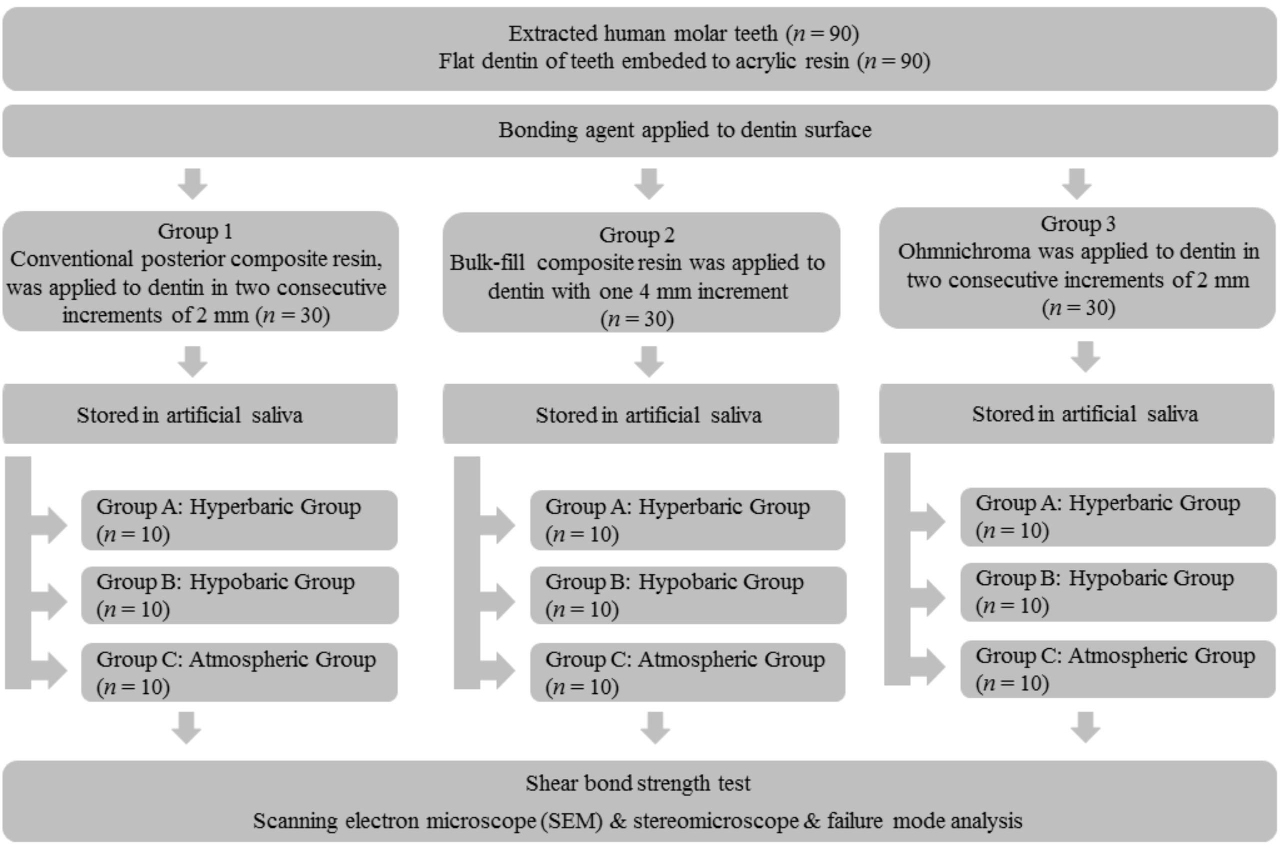


Figure 2
Composite resin bonded to dentin was mounted in the jig of the testing machine with the dentin surface parallel to the loading direction

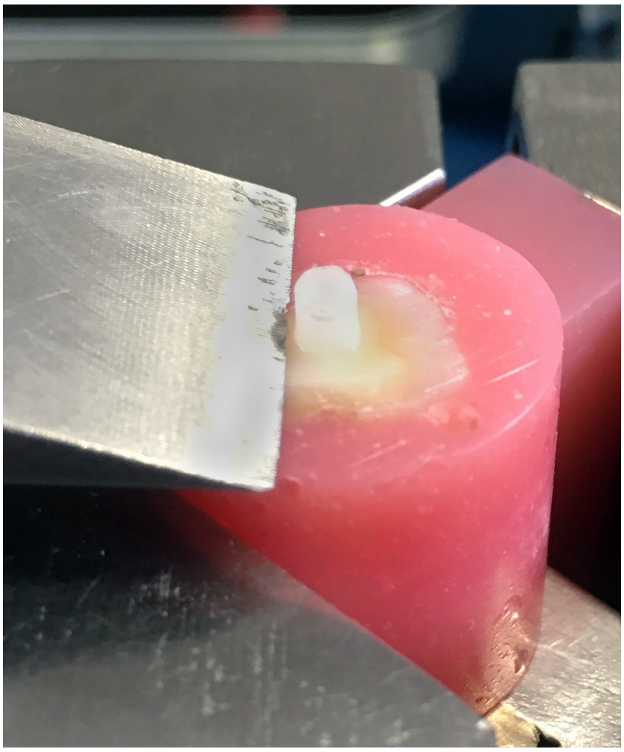
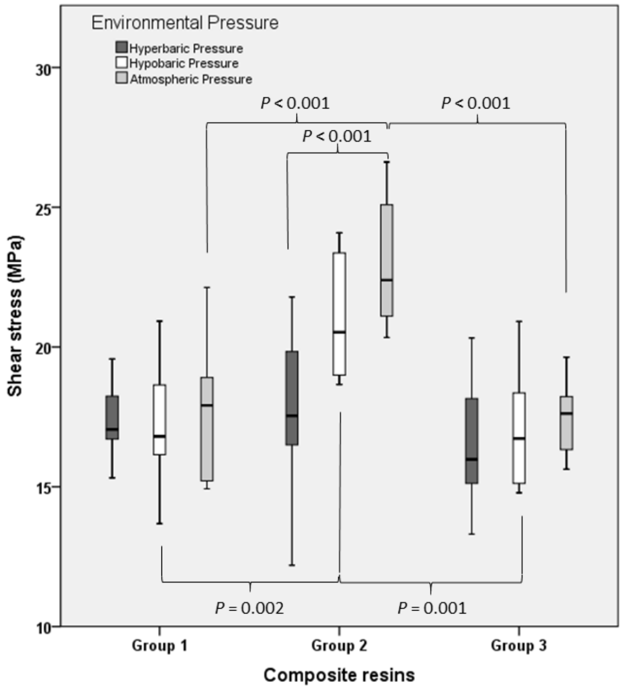


Figure 3
Boxplot graph of shear bond stress values. The box plots represent the median and the interquartile range; the whiskers represent the minimum and maximum values. Group 1 – Conventional; Group 2 – Bulk-fill; Group 3 – Ohmnicroma



were calculated by dividing the force at which bond failure occurred by the bonding area.

FAILURE MODE ANALYSIS

The debonded surface of the samples was observed under scanning electron microscopy (Hitachi Regulus 8230 FE-SEM, Japan) at x30, x350 and x1,000 magnification, and under a stereomicroscope (Nikon SMZ-745T, Nikon, Tokyo, Japan) at x30 magnification to assess the mode of failure. Type of failure was classified as:

- Type 1, Adhesive (less than 20% resin observed at dentin surface).
- Type 2, Cohesive (more than 80% resin observed at the dentin surface).
- Type 3, Mixed (20% to 80% resin observed at the dentin surface).

STATISTICAL ANALYSIS

IBM SPSS 24.0 for Windows (Armonk, New York, USA) was used for statistical analysis. The Shapiro-Wilk test was performed to establish that data were normally distributed. Differences between groups were tested using ANOVA followed by the *post hoc* Tukey test. Data were expressed as mean (SD). A P-value < 0.05 was considered statistically significant. Strength variations within each group were examined by calculating the Weibull modulus. A spreadsheet was used to rank the shear strength data in ascending order and appoint a rank over the range 1 to 10; a line graph was then fitted through the points using the median rank regression method. The Weibull modulus was calculated by slope analysis.

Results

SHEAR BOND STRENGTH

Shear bond strength outcomes are given in Table 2, and the boxplot graph is showed with statistical differences in Figure 3. The highest mean shear bond strength values were observed for Bulk-fill composite resins in atmospheric pressure, compared to Ohmnicroma and conventional posterior composite resins ($P < 0.001$). Also, a significant difference was observed between the bulk-fill composite resin groups exposed to hyperbaric and atmospheric pressures ($P < 0.001$). However, there were no significant differences between hypobaric and atmospheric pressure groups regardless of the type of resin.

WEIBULL MODULUS

The shear bond strength data of composite resins bonded to dentin and exposed to different environmental pressures were further analysed using the Weibull distribution function

Table 2
Shear bond strength values, results of Weibull analysis and number of failure types; Ad – Adhesive; Co – Cohesive; WCS – Weibull characteristic strength

Group	Composite resins	Environmental condition	Bond Strength (MPa)		Weibull modulus	WCS (MPa)	Failure analysis (*n*)		
			Mean (SD)	Range			Ad	Co	Mixed
1A	Posterior	Hyperbaric	17.3 (1.3)	15.3–19.6	14.7	17.9	9	–	1
1B	Posterior	Hypobaric	17.1 (2.1)	13.7–20.9	8.8	18.0	9	–	1
1C	Posterior	Atmospheric	17.9 (2.4)	14.9–22.1	7.9	19.0	8	–	2
2A	Bulk-fill	Hyperbaric	17.9 (2.8)	12.2–21.8	6.5	19.2	10	–	–
2B	Bulk-fill	Hypobaric	21.0 (2.1)	18.7–24.1	10.3	22.0	10	–	–
2C	Bulk-fill	Atmospheric	23.0 (2.3)	20.3–26.6	10.4	24.1	9	–	1
3A	Ohmnicroma	Hyperbaric	16.5 (2.1)	13.3–20.3	8.6	17.4	10	–	–
3B	Ohmnicroma	Hypobaric	17.0 (2.0)	14.8–20.9	9.1	17.9	9	–	1
3C	Ohmnicroma	Atmospheric	17.4 (1.3)	15.6–19.6	14.8	18.0	9	–	1

to predict the failure probability of bonding. The Weibull analysis for composite resin bonded to dentin under different environmental pressures is shown in Table 2. The Weibull modulus was the highest for Group 3C and the lowest for group 2A. Weibull characteristic strength for control (atmospheric pressure) groups was significantly higher in all resins (Group 1C, 18.98 MPa; Group 2C, 24.97 MPa; Group 3C, 18.00 MPa). The probability of failure versus shear stress for different environmental pressure changes is shown in Figure 4.

FAILURE ANALYSIS

The failure analysis for each group is listed in Table 2. All specimens exhibited mostly adhesive failure, regardless of environmental pressure changes. Fisher's exact test found no significant differences in the type of failure mode for both composite resin types and environmental pressure changes. Representative images of adhesive and mixed failures of samples are shown in Figure 5.

Discussion

The null hypothesis that the shear bond strengths of composite resins to dentin exposed to different environmental pressures do not differ in specimens was rejected as the bond strength of bulk-fill composite resins exposed to hyperbaric pressure were significantly lower than that of the bulk-fill composite resins at atmospheric pressure. Regardless of the environmental pressure changes, the bulk-fill composite resin showed the highest shear bond strength value and Weibull modulus and Ohmnicroma showed the lowest bond strength and Weibull modulus.

As dentin depth, tubule configuration and permeability have been shown to affect the bond strength, dentin was grounded to nearly the same depth in the present study.[18,19] Light curing conditions were standardised because inadequate polymerization might induce discoloration, microleakage, and reduce the bonding strength of restorations.[20] One type of self-etch adhesive system was used for standardisation and to eliminate the complications of multistep adhesive systems.

The bonding strength of composite resin depends on many factors such as the mechanical properties, composition, viscosity, the amount of shrinkage, translucency, and the method of application. In this study regardless of environmental pressure changes, the bulk-fill composite resin showed the highest bond strength. One study[21] evaluated the influence of curing light intensities on the translucency and surface gloss of bulk-fill composite resins. Reveal bulk-fill resin showed the highest translucency value with a high curing intensity. Higher translucency to curing light can provide full polymerization of the resin. The increased depth of cure, low polymerization stress from shrinkage, mechanical properties of bulk-fill composites may affect the results. However, in our study, the bond strength of the Ohmnicroma composite with the incremental technique was found to be low despite its high translucency. It was previously reported that use of the incremental technique showed lower polymerization shrinkage stress and microleakage compared to the bull-fill technique.[22] The differences in results may be due to the composition of composite resins with respect to components such as photoinitiators, polymerization inhibitors, and organic monomers. For instance, the bulk-fill composite used in this study does not contain the TEGDMA monomer, conversely the Ohmnichroma contains TEGDMA. It has been reported that the use of TEGDMA may reduce the mechanical properties and increase the water absorption of resin composites.[23] Higher tendency to water absorption, which leads to swelling of the matrix and breaking of polymer chains, may weaken the mechanical properties of resins.[24,25] As the samples were stored in artificial saliva for 30 days, this may have affected the results of our study. As material types and methodology differ in this study, also

Figure 4

Weibull plot of failure probability against stress to failure (MPa) for each group; A – Group 1 (Conventional); B – Group 2 (Bulk-fill); C – Group 3 (Ohmnicroma)

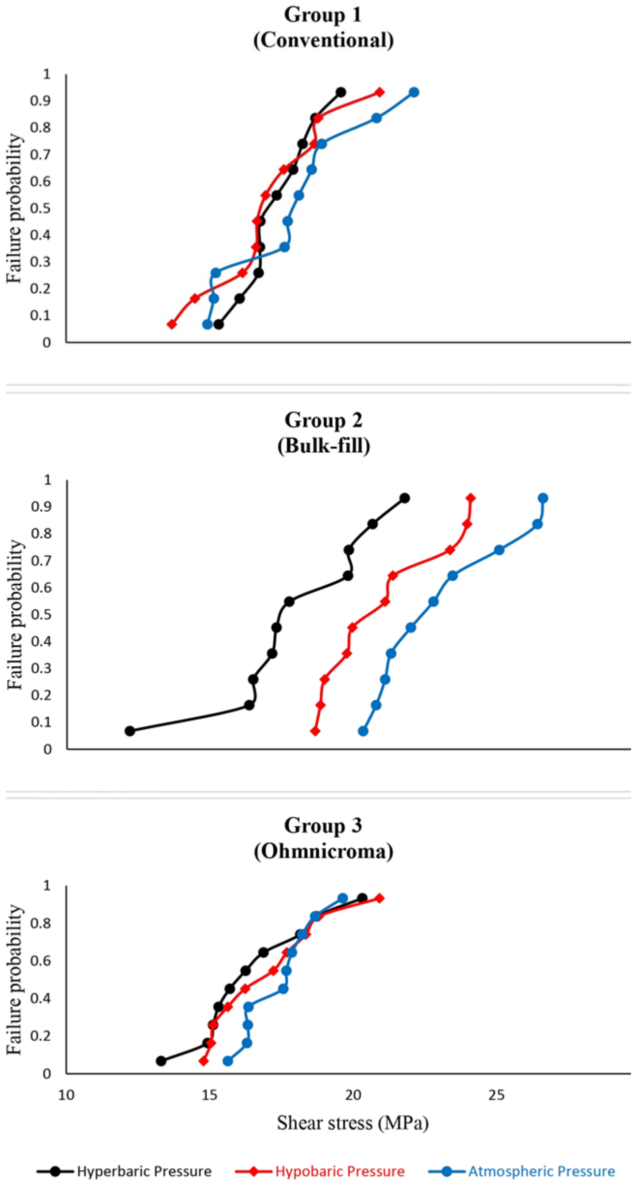
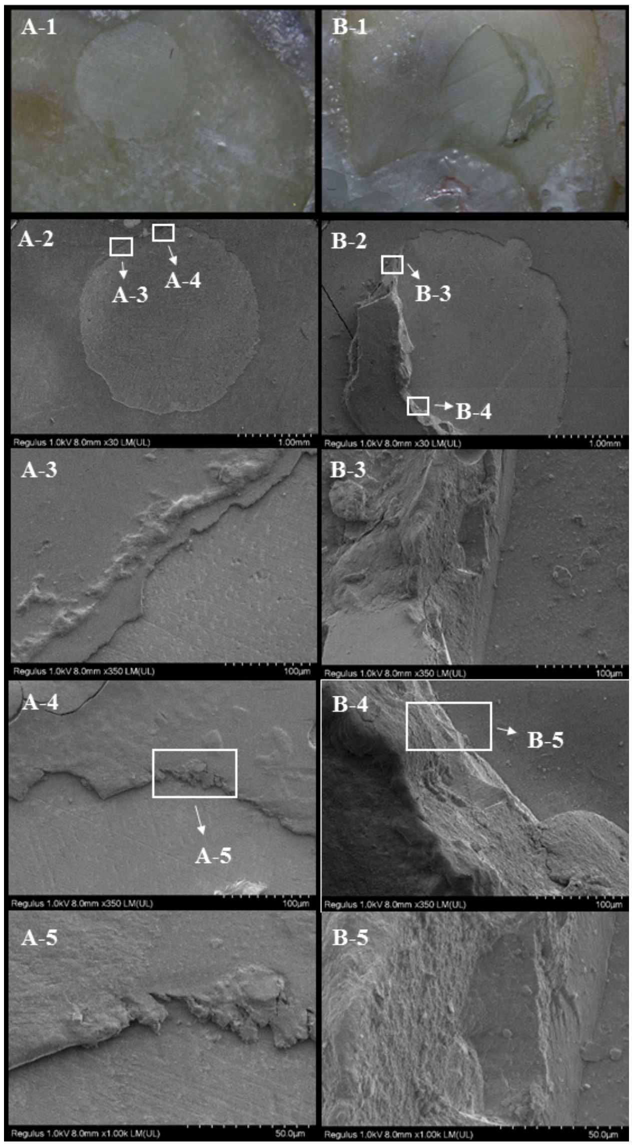


Figure 5

Representative stereomicroscope and scanning electron microscope (SEM) images of adhesive (A1–A5) and mixed (B1–B5) types of failure after debonding; A1 and B1 are stereomicroscopy images (magnification x30). All other images are SEM; A2, B2 x30; A3, B3, A4, B4 x350; A5, B5 x1,000



the structural defects of composite resins, dentinal tubule orientation, or misalignment during testing may affect the results of our findings.

Based on Boyle's law predictions, any air void in a material expands or contracts in response to pressure change. In dental restorations this may weaken the structure.[26] In diving or flying, stress may occur in air voids such as the pores in the resin layers, in bonding areas or inside the dentinal or root canals. When decompressing to sea level after diving or to an increased altitude during flight, any enclosed gas spaces experience compression or expansion forces. The cumulative stress of compression-expansion can produce fractures within the resin layer and/or along the interface surface. In this study, the bond strength decreased in both hypobaric and hyperbaric groups compared to atmospheric pressure groups. However, this reduction was only statistically significant in hyperbaric groups.

Another study[27] has compared the effect of different environmental pressures on the bond strength of fiber posts to root canals. They found a statistically significant decrease in the diver group, and concluded that rapid pressure changes in diving adversely affect the bond strength of dental restorations. Divers appear more likely to suffer barodontalgia than aircrew (9.8 versus 5.8%) due to dental therapy, deep dental caries, pulpitis and leaking restorations (4–50%).[15] Those results are in line with those reported here.

Additionally, the bulk-fill resin was the most affected by environmental pressure changes among the other composites and was significantly compromised by hyperbaric exposures. Viscosity properties and possible air voids occurring on the dentin-composite resin bonded interface may have caused microfractures during pressure changes. It was reported that flowable composite resin, vibration methods when applying composite or preheating composite could help limit the presence of air voids.[28] More studies are needed to select the appropriate resin in individuals exposed to environmental pressure changes.

In this study, diving and flight conditions were simulated in hypobaric and hyperbaric chambers for 30 days, 30 min a day. A 10-year study of the dental health of German naval personnel examined the long-term effects of barometric pressure changes. Over this 10-year period, it was observed that personnel working in hyperbaric environments suffered worse dental problems when compared to personnel working at ground level.[29] It is possible that prolonged exposure to environmental pressure changes can cause a negative prognosis in oral dental health. As greater effects may be expected during longer periods of cyclic pressure changes, the limited number of pressure cycles in the present study may be a limitation. More cycles over longer periods may produce greater changes.

Weibull distribution has shown to be an alternative method for evaluation of the fracture probability of materials.[25] In the present study, the Weibull modulus value was lower in all pressure-change groups compared to the control groups. This suggests that environmental pressure change decreases the reliability of the materials. These results are consistent with the shear bond stress results.

Analysis of the failure mode can help to explain bond strength results. In this research, bond-strength values were usually associated with adhesive failures. The specimens from all subgroups revealed bond failures occurring at the dentin surface. There were almost no remnants of composite resin observed on the dentin surface, suggesting that composite resin strength might be stronger than the resin-dentin bond strength.

So far only limited independent data on environmental pressure effects on dental restorations are available. The present study is the first that considers environmental pressure changes in the testing procedure. But physical and chemical changes in oral environmental conditions were not examined. Thus, confidently extrapolating the results to a clinical situation is not possible. More studies are needed with different environmental pressure cycles, longer durations, different dental materials and mechanical tests to fully understand the effect of ambient pressure changes on teeth and dental materials.

Conclusions

Within the limitations of this study, the following conclusions can be drawn.

First, the highest mean shear bond strengths were recorded for bulk-fill composite resins across all environmental pressure changes. Inversely, the bulk-fill resin was the resin most affected by the environmental pressure changes among the other composites. The hyperbaric group showed significantly lower bond strength values than the control group ($P < 0.001$). Second, Ohmnicroma composite resin showed the lowest bond strength. Third, barometric changes can affect the bond strength of composite resins to dentin. Dentists should be careful choosing the appropriate dental material in aircrew and divers, where fractures and cracks in dental restorations may cause painful and distressing problems. Finally, divers and aircrew should pay attention to their dental health as well as their general health. Dentists experienced in diving and aviation medicine should take part in the initial and periodic medical examinations of these people. In these examinations, dental caries should be evaluated, and a comprehensive examination including vitality tests of all teeth should be performed. For restorations that require treatment, planning should be done with appropriate treatment methods. Bulk-fill composite resins can be preferred in divers and aircrew due to high bond strength values.

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