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RESEARCH ARTICLE

HYPERBARIC PRESSURE EFFECT ON DENTAL LUTING CEMENTS

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ABSTRACT

Purpose: The aim of this study was to evaluate the flexural strength values of five luting cements that are commonly used in dental restorations after exposed to hyperbaric pressure.
Material and Methods: Five luting cements (polycarboxylate cement, glass ionomer luting cement, manual-mixed resin cement, and two auto-mixed resin cement) were prepared. (25 x 2 x 2 mm^3) (n=16 for each) The specimens were divided into two subgroups (n=8) and were exposed to hyperbaric pressure (3 atm) 20 times for 30 minutes. The control groups stored in ambient pressure. Universal testing machine was used for flexural strength measurement with a crosshead speed of 1 mm/min.
Results: One-way ANOVA test was used for statistical analysis, the differences in flexural strength values were additionally evaluated by Weibull Analysis. Glass ionomer and polycarboxylate cement were the most effected resins from hyperbaric pressure changes. Regardless of the pressure changes, the highest flexural strength values were seen for the self-adhesive resin cements and polycarboxylate cement showed the lowest strength value.
Conclusion: Resin cements can be used for cementation of the dental restorations in divers and individuals who are subjected to hyperbaric pressure.

Keywords: prosthetic dentistry, self-adhesive resin cement, luting cement, flexural strength, hyperbaric medicine

INTRODUCTION

Divers, personnel working in submarines and hyperbaric environments may encounter dental problems such as toothache, dislocation of restorations as a result of atmospheric pressure changes. Dental barotrauma refers to the effect of pressure changes on teeth, including restorative failure, tooth fracture, and toothache (1). Due to barotrauma, external otitis barotrauma, barotitis media, barosinusitis, and barodontalgia may occur (2,3). Barodontalgia is defined as toothache caused by barometric changes. The adverse effect of hyperbaric pressure is based on Boyle's Law. The pressure exerted by a gas (a given mass held at a constant temperature) is inversely proportional to its volume. Barodontalgia and barotrauma can mostly be seen at an altitude of 3000 m above sea level or over a depth of 10 m (3).

Atmospheric pressure changes can influence the adhesion and durability of luting cements (2,4-7). Kielbassa et al. (2018) assessed the impact of atmospheric changes on restorations (8). They suggested auto-mixed resin modified glass ionomer cements rather than zinc phosphate cements. Geramipanah et al. (2016) studied retention of fiber posts, and they reported that auto-mixed resin cements were the least affected resins from atmospheric pressure changes (9). Additionally, Gulve et al. (2012) suggested resin-modified glass ionomer cements for cementing the orthodontic bands (10), and Lyons et al. (1997) advised resin cements for full-cast crowns (3).

An appropriate cementation technique is necessary for the long-term success of restorations (11). Zinc polycarboxylate, an acid-based reaction cement, is commonly used as dental adhesive and cavity liner. Besides, glass ionomer cements have been shown to be rechargeable with fluoride ions (12). This property makes these cements popular because fluoride can promote remineralization of dental hard tissue (13). On the other hand, in comparison to traditional water-based cements, resin cements offer greater marginal sealing, physical characteristics, and bonding (14,15).

To the best of our knowledge, there is not any study evaluating the flexural strength of conventional glass ionomer luting cement (GILC), zinc polycarboxylate cement (ZPC) and adhesive resin cements (NXS, MXM and ZE)—commonly used in clinical settings—after variations in hyperbaric pressure. Therefore, this study aims to assess the mechanical properties of luting cements after hyperbaric pressure changes, using the 3-point flexural strength test. The null hypothesis was that variations in hyperbaric pressure would not affect luting cements' flexural strength.

MATERIAL AND METHODS

Preparation of Specimens

The specimens were prepared using a teflon mold (25 x 2 x 2 mm^3). The manufacturers' directions and manufacturers' names for the cements are listed in Table 1. Owing to the nature of the study (effect of hyperbaric pressure on a dental material), ethical committee approval was waived.

Glass ionomer luting cement (GILC) and zinc polycarboxylate cement (ZPC) were available in powder and liquid forms. The cements were prepared according to the manufacturer's recommendation and put into the mold. The cements were adapted to the mold with slight pressure. The glass slide was placed on the mold, excess cements were removed.

Auto-mixed self-adhesive resin cements (MXM, NXS) were mixed with a tip, manual-mixed self-adhesive resin (ZE) was mixed manually with one operator. After mixing the pastes, cements were inserted into the mold. The glass slide was placed on the mold. The resins were light-cured for 40 sec (Labolight LV III, GC, Japan). Sixteen specimens were prepared for each cement.

Hyperbaric Pressure Chamber Testing

Each group was divided into two subgroups of eight for hyperbaric pressure testing. The samples were placed in the multi-person custom made hyperbaric chamber (Hipertech; Hipertech, Istanbul, Turkey). The device enabled pressure changes electronically. The pressure cycle was adjusted to a maximum value of 3 atm at a rate of 0.5 atm/min. So it took approximately 6 min. to reach 3 atm. After 30 min. at 3 atm the ascending phase began at a rate of 0.5 atm/min and took approximately 6 min. to reach the surface atmospheric pressure. This process was repeated once a day for 20 days.

The control group was kept in ambient pressure for 20 days (n= 8 from each group).

Flexural Strength Test

Universal Testing Machine was used for flexural strength test (Lloyd-LRX, Lloyd Instruments, Fareham, UK). A load was applied to the center of the samples at a crosshead speed of 1 mm/min until a fracture occurred. The maximum force (N) and flexural strength (mm) values of each sample were automatically recorded in the processing unit of the machine.

Statistical Analysis

The statistical analysis was performed using IBM SPSS 24.0 for Windows. (SPSS Inc., Chicago, IL, USA; SPSS Version 24.0) With the Shapiro Wilk test, the normality of the data distribution was assessed, and a normal distribution was found. One–way ANOVA and the Post Hoc Tukey test were used to assess differences between groups. For statistical significance, P values of less than 0.05 were accepted. For the reliability of the findings, Weibull analysis was used. Line graphs were obtained using the median regression method.

RESULTS

Flexural strength

Table 2 shows the mean flexural strength and min-max values for each group. The flexural strength values of all samples exposed to hyperbaric pressure decreased compared to the control groups. However, this decrease was not statistically significant. The MXM-C group had the highest mean flexural strength (61.54 MPa), while the ZPC-H group had the lowest mean flexural strength (13.26 MPa). The most affected resin by hyperbaric pressure changes was

GILC (28.7%). Figure 1 depicts the boxplot graph for each group.

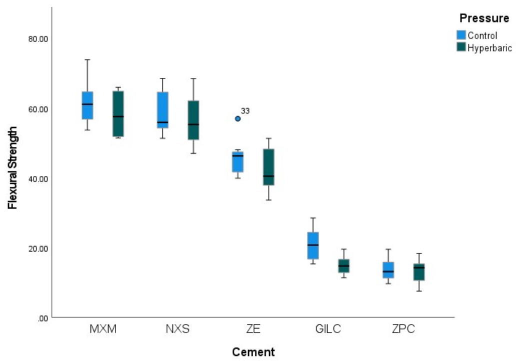

Figure 1. Boxplot graph of flexural stress values of each group.

Weibull Modulus

The flexural strength values of cements tested with different environmental pressures were further analyzed using the Weibull analysis to understand the statistical behavior of the strength of cements. The Weibull analysis for cements under different environmental pressures are shown in Table 2. MXM-C group's Weibull modulus was the highest and ZPC-H group was the lowest. Weibull characteristic strength for control groups was significantly high in all resins (Table 2 and Figure 2).

Representative images of fracture areas of cements are shown in Figure 3.

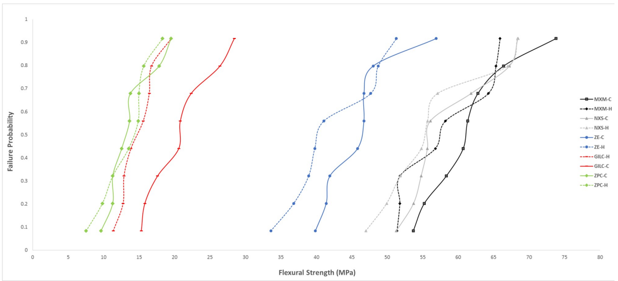

Figure 2. Weibull plot of failure probability against stress to failure (MPa) for each group.

DISCUSSION

The null hypothesis was rejected, as the conventional luting cements were significantly affected by hyperbaric changes in this study. MXM showed the highest flexural strength values, both in control and hyperbaric pressure group. The NXS and the ZE group followed. GILC and ZPC group was the most affected resin from hyperbaric pressure changes.

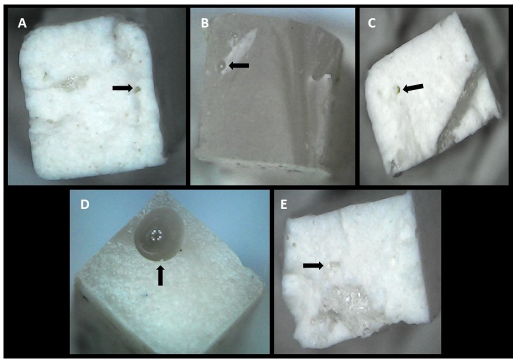

Figure 3. Representative light microscopy (30x) images of the fractured surfaces. **A**: ZPC-H; **B**: GILC-H; **C**: NXS-H; **D**: MXM-H and **E**: ZE-H. Black arrows represent pores at the cement's surface.

In this study, flexural strength values of GILC more decreased after exposed to hyperbaric pressure when compared to resin cements. It has been reported that more volumetric contraction is observed in brittle cements such as GILC and ZPC when compared to resin cements (3,16,17). Volumetric contraction during polymerization can cause microcracks inside the material. When materials are exposed to atmospheric pressure changes, existing microcracks and voids inside the material can generate internal stresses that exceed the material's cohesive and adhesive strength, resulting in a significant reduction in the mechanical strength of the material (3). For these reasons, brittle cements can be expected to be more affected by environmental pressure cycling than resin cements.

In this study GILC was the most affected resin from hyperbaric changes. Although GILC' flexural strength values and weibull modulus values are higher than ZPC, the reason why it is more affected by hyperbaric pressure changes can be explained by the differences in the amount or size of the air voids formed in the cement during mixing or application. Specifically, for GILC, it has been reported that fluoride release affects the amount of porosity (18). However, the pores occurred in fluoride diffusion are on the submicron scale (18,19). The expansion or contraction of micro-voids during the pressure cycle, due to pores and voids that may form during mixing, may cause deterioration and weakening of the cement layer (20). More studies are needed to evaluate the quantities and dimension of the air-voids and microcracks inside the cements.

Self-adhesive cements are widely used in dentistry due to their ease of use. Using a single-step adhesive cement reduces the hassle of moisture control and

Table 1. Shows the composition, and manufacturer of materials used in this study.

Materials-Abbreviation	Manufacturer	Components	Application Method
Glass Ionomer Luting Cement (GILC)	Riva Self Cure, SDI, Victoria, Australia	Polyacrylic acid 20%-30%, tartaric acid 10%-15%, remainder water, fluoroaluminosilicate glass 90%-95%, polyacrylic acid 5%- 10%	One level scoop of powder was mixed with three drops of liquid, the mixing of the cement was completed in 90 sec.
Zinc Polycarboxylate Cement (ZPC)	Adhesor Carbofine, Pentron, Czech Republic	Water, Acrylic/Itaconic acid copolymer< 50%, tartaric Acid< 10%, Zinc oxide<90%, Magnesium oxide<5%, Aluminum hydroxide<5% and Pigments<1%	Two level scoops of powder were mixed with five drops of liquid; the powder was incorporated into the liquid within 30 sec.
Auto-mixed Self-adhesive resin (NXS)	Nexus dual-cure, Kerr, Scafati, Italy	Uncured methacrylate ester monomers, HEMA, PTU, HPO, free tertiary amines and benzoyl peroxide, inert mineral fillers, titanium dioxide, radiopaque agent, and pigments	One turn of pastes from the cement dispenser was mixed for 30 sec. to a uniform consistency, inserted to mold with tip and light cured.
Auto-mixed Self-adhesive resin (MXM)	Maxcem Elite Chroma, Kerr, Scafati, Italy	Bis-GMA, UDMA, GPDM, glyceroldimethacrylate, mono-, di-, and multi-methacrylate co-monomers, CQ,barium alumino borosilicate glass, fluoro alumino silicate glass, stabilizer, others	One turn of pastes from the cement dispenser was mixed for 30 seconds to a uniform consistency and inserted to molds with tip and light cured.
Manual-mixed Self-adhesive resin (ZE)	Zenitcem, President Dental, Germany	Barium glass, Bis-GMA, pigments, additives, catalysts	Pastes were mixed and inserted to molds manually and light cured.

Abbreviations: Bis-GMA: 2,2-bis[4-(2-hydroxy-3-methacryloyloxypropoxy) phenyl]propane; CQ: DL-camphorquinone; GPDM: glyceroldimethacrylate dihydrogen phosphate; HEMA: 2-hydroxyethyl methacrylate; UDMA: urethanedimethacrylate.

control of primer and/or adhesive application during cementation (21). In adhesive cements, activator and initiator are mixed to initiate polymerization. Campherquinone is used for light activation and benzoyl peroxide for auto polymerization (22). The polymerization process is delayed by inhibitors to gain sufficient time New generation self-adhesive cements provides two activation systems to guarantee complete polymerization (23). In this study, three of self-adhesive cements showed higher flexural strength values both in control and hyperbaric group. This can be explained by the fact that resin cements complete the polymerization, and their mechanical properties are superior than conventional cements.

Automatic mixing method is recommended for cements to minimize the formation of pores and bubbles as a result of air inclusion or operator-induced during mixing. In this study, ZE group showed lower strength values than MXM and NXS both in control and hyperbaric group. The MXM and NXS were mixed with a tip and dispensed into the

Table 2. The mean flexural strength values, SDs, min- max values, Weibull modulus, Weibull Characteristics of each group.

Groups	Mean ± SD	Min	Max	Weibull Modulus	Weibull Characteristics
MXM-C	61.54±2.27	53.67	73.79	10.18	64.43
NXS-C	58.63±2.27	51.29	68.43	9.35	61.63
ZE-C	45.92±1.89	39.87	56.91	8.91	48.38
GILC-C	20.92±1.67	15.32	28.44	4.67	22.84
ZPC-C	13.70±1.20	9.65	19.52	4.35	15.03
MXM-H	58.19±2.23	51.39	65.91	9.29	61.18
NXS-H	56.47±2.71	46.98	68.39	7.77	59.86
ZE-H	42.23±2.22	33.59	51.28	7.11	44.95
GILC-H	14.91±0.95	11.37	19.54	5.95	16.03
ZPC-H	13.26±1.24	7.54	18.32	3.73	14.70

MXM-C: Maxcem Auto-mixed self-adhesive resin- Control Group; NXS-C: Nexus Auto-mixed Self-adhesive resin-Control Group; ZE-C: Zenitcem Manual-mixed self-adhesive resin- Control Group; GILC-C: Glass Ionomer Luting Cement-Control Group; ZPC-C: Zinc Polycarboxylate Cement- Control Group; MXM-H: Maxcem Auto-mixed self-adhesive resin- Hyperbaric Group; NXS-H: Nexus Auto-mixed Self-adhesive resin-Hyperbaric Group; ZE-H: Zenitcem Manual-mixed self-adhesive resin- Hyperbaric Group; GILC-H: Glass Ionomer Luting Cement-Hyperbaric Group; ZPC-H: Zinc Polycarboxylate Cement- Hyperbaric Group.

mold using this applicator. ZE was mixed and inserted into the molds manually. Mixing methods may have affected our results, as ZE showed minimum flexural strength values among the resin cements. On the other hand, it was reported in a previous study that manual mixing did not affect the porosity or mechanical properties of glass ionomer cements (24). In addition, it was emphasized that the porosity of manual mixing was lower than auto mixing methods (25). Only hand-mixed conventional glass ionomer cement was used in this study; the hyperbaric effect of auto-mixed glass ionomer cement can be evaluated in future studies. This may be a limitation of our study.

In this study, GILC showed an average value for flexural strength of 20.92 MPa for the control group and 14.91 MPa for the hyperbaric group. The flexural strength of GILC was determined by Mitra and Kedrowski (1994) and Xie et al. (2000) and found between 14.2 and 31.4 MPa values in both studies (26,27). The variation in flexural strength values between cements were attributed to differences in mixing method, surface structure, and void or particle dimensions. Additionally, a study evaluating the flexural strength of MXM showed a mean value of 68.4 MPa, which is similar to our results (61.54 MPa) achieved for control and hyperbaric group in this study (28). Besides this, Cassina et al. (2016) assessed the flexural strength of seven different resin cements, and they found the mean flexural strength values of the resins between 78.1-119.0 MPa (23). They concluded that the type of activator, initiator, and the low degree of polymerization used in a cement influences the degree of conversion (28,29).

Diving conditions were simulated with hyperbaric chamber in this study. During diving the pressure increases approximately 1 atm every 10 meters (30). Many of the divers make recreational diving. And most of these divers have basic level scuba diving certificates, such as scuba diver and open water diver. The depth limitation of these certificates are 40 feet and 60 feet. Therefore, in this study, the hyperbaric pressure was adjusted to 3 atm, once a day, a total of 20 times.

Dental restorations are subjected to complicated mastication pressures, which result in significant flexural stresses (31). The bending stress values of cements are related to the cement content and mechanical properties. To estimate the ability of resin cements to resist masticatory stresses and prevent prosthesis dislodgement and restorative failure, flexural strength measurement is required (32). Flexural strength test was used for evaluating the mechanical properties of cements in this study.

CONCLUSION

Within the limitation of the present study, auto-mixed resin cements showed higher flexural strength values than manual mixed resin cement. Brittle cements (GILC, ZPC) were the most affected cements from hyperbaric pressure changes. For a dental material to be least affected by hyperbaric pressure changes, the air voids and microcracks inside the resin should be minimum. To reduce the formation of air voids inside the resin, automatically mixing methods can be preferred rather than manually mixing during preparing the cements.

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Conflict of interests: None.
Ethical approval: This is a in-vitro mechanical study with dental materials. There is no need any ethical committee approval.
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