Effect of a hyperbaric environment (diving conditions) on adhesive restorations: an *in vitro* study

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In brief

- A more interventionist approach is needed to treat dental diseases for patients who are divers.
- Etch-and-rinse adhesive systems or self-etch systems with a preliminary enamel etching may be preferred to limit enamel penetration.
- A perfect marginal adaptation must be achieved between the restorative material and dental tissues.
- Indirect restorations for wide and deep cavities for patients who are divers are recommended.

Objectives No recent study has addressed the effect of diving conditions (pressure increase) on adhesive restorations. We evaluated the impact of a simulated hyperbaric environment on microleakage of the dentine-composite resin interface. The ultimate aim was to propose recommendations for restorative dentistry for patients who are divers to limit barodontalgia (dental pain caused by pressure variations of the environment) and may lead to dangerous sequelae. **Methods** We bonded 20 dentine disks by using an adhesive system (Scothbond Universal) to ten intact composite cylinders and ten composite cylinders with porosity (Ceram X mono). For each group, the samples were divided into two subgroups, one submitted to a simulated hyperbaric environment and the other to an ambient environment. All samples were immersed in a silver nitrate solution to evaluate microleakage at the interface after analysis with a camera. **Results** Dye percolation for groups in the hyperbaric environment was greater than groups in ambient environment. For each subgroup, dye percolation was greater for samples with than without porosity. **Conclusions** High percolation percentages demonstrate that our simulated hyperbaric condition led to loss of sealing at the dentine-composite resin interface, especially with porous composites. **Clinical significance** Respect of the protocol and the quality of condensation for adhesive restorations are important in all clinical situations, especially for patients who are divers. A more interventionist approach must be adopted with these patients.

Introduction

The number of Professional Association of Diving Instructors (PADI) certifications increased from 17 million in 2008 to 23 million in 2015.[1] Consequently, dentists are increasingly seeing patients with dental pain after an underwater dive (barodontalgia) but also patients wondering about restorative treatment before diving.

Barodontalgia is defined as dental pain caused by pressure variations of the environment. This pain was previously called aerodontalgia because it concerned essentially pilots in a hypobaric environment ('aero' meaning air in Greek). After the Second World War, many studies investigated this phenomenon.[2] In 1965, Shiller studied dental pain under hyperbaric conditions:[3] the phenomena involved in dental pain in hypobaric and hyperbaric conditions were similar. Therefore, the term barodontalgia resulted from this study, 'baro' referring to the variations of pressure.[4,5]

Barodontalgia may be associated with dental fractures or restoration fractures but also to lack of retention of fillings, called dental barotrauma. The variations in volume involved in barotrauma are explained by the law of Boyle-Mariotte: at constant temperature, the volume of a gas is inversely proportional to its pressure (pressure × volume = constant).[6] Dental pain can also occur without a diving barotrauma. It is an acute expression of a pre-existing clinical pathology (reversible pulpitis, irreversible pulpitis, necrosis or periapical disease). For divers, the ultimate consequence of extreme barodontalgia can be an oversight of safety rules, in particular respecting decompression stops, which can lead to death.

Most studies of barodontalgia were published before 1990, so articles and case reports do not correspond to the current treatment protocol for restorative dentistry.[7-10] The aim of our study was to evaluate whether restorative dentistry protocols should be refined for patients who are divers. Indeed, Ranna *et al.* reported in a study of 100 recreational divers, that among the divers who experienced dental symptoms, 54% had a tooth cavity or a previous filling.[11] We also performed an experimental *in vitro* study to measure the impact of a pressure increase on microleakage at a dentine–composite resin interface and we examined restorations with a perfect marginal adaptation to dental structures and composite restorations with porosity.

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Materials and methods

Samples

We collected 20 third molars extracted for orthodontic reasons from young adult patients. All teeth were obtained with the patients' informed consent and with approval of our local ethics committee for human studies (Art R1211 CSP). Immediately after collection, teeth were gently cleaned with tap water and kept in a 1% chloramine solution at 4°C for up to one month.

Materials

The materials used were for the adhesive protocol Scotchbond Universal Etchant and Scotchbond Universal Adhesive (3M ESPE Dental Products, St. Paul, Minnesota, USA, batch 70201,139,014) and Ceram X mono (Dentsply, Milford, Delaware, USA, batch 141,000,804) for the composite resin. The polymerisation involved use of light Astralis 7 (Ivoclar Vivadent, Schaan, Liechtenstein) for all samples. The irradiance tested with a curing radiometer was 750 mW/cm^2, which was consistent during all procedures.

Microleakage method

Dentine disk preparation (n = 20)

Each tooth was embedded in a cold curing epoxy resin, ClaroCit Kit (Stuers, Westlake, Cleveland, USA). Then samples were cut horizontally twice with use of a diamond circular blade under constant irrigation to obtain a disk located at the one-third median of the dentine. Then the sectioned surfaces were polished with abrasive paper disks (Struers) of decreasing grit size of P500 (30.2 µm) to P1200 (15.3 µm) at 3,000 rpm under water irrigation to obtain standardised surfaces.[12] The 'P' referring to the classification system used by the Federation of European Producers of Abrasives.[13] The last granulometry (P1200) corresponds to the yellow ring of a diamond bur (Extra-fine – 15 µm[14]). Between each polishing sequence, the disks were left ten minutes in an ultrasonic bath. Dentine disks were 10 mm in diameter and 3 mm high.

Composite resin disk preparation

Composite Ceram X mono cylinders were created by means of nylon slices 8 mm in internal diameter and 2 mm high to produced two types of cylinders: ten uniform cylinders (Fig. 1) and ten cylinders in which a polyester ball (2 mm in diameter) was placed before polymerisation to simulate porosity (Fig. 1). Each sample was polymerised for 20 seconds.

Fig. 1 Composite resin samples without (left) and with (right) porosity

Table 1 Distribution of samples

SAMPLES	HYPERBARIC CONDITION	AMBIENT PRESSURE
With porosity	Group A.1 (n = 5)	Group A.2 (n = 5)
Without porosity	Group B.1 (n = 5)	Group B.2 (n = 5)

Fig. 2 Hyperbaric simulation apparatus

Bonding of dentine disks and composite resin disks

To create an adhesive interface, dentine disks were bonded to composite cylinders (n = 10 with porosity: group A; n = 10 without porosity: group B) by using an adhesive system (Scotchbond Universal) according to the manufacturer's instructions as a total etch protocol. A phosphoric acid etching gel (about 35%), Scotchbond Universal Etchant, was applied to dentine for 15 seconds, then rinsed thoroughly with water and dried with water-free and oil-free air without overdrying. Scotchbond Universal Adhesive was applied with the disposable applicator to the entire tooth structure and rubbed for 20 seconds. If necessary, the disposable applicator was re-wet during treatment. Then a gentle stream of air was directed over the liquid for about five seconds until it no longer moved and the solvent had evaporated completely. The composite disk was placed on the dentine disk, and the adhesive was polymerised with a commonly used curing light for ten seconds. The periphery of the cylinder obtained was polished with use of a Diamond flame bur red ring until the alignment of both dentin disks and composite resin disks (diameter 8 mm).

Group distribution function of experimental environment

Groups A and B were divided into two groups of five samples treated under hyperbaric conditions (groups A1 and B1) or ambient pressure (groups A2 and B2) (Table 1).

The hyperbaric condition involved placing samples in a cylinder that simulated a dive (Fig. 2). The cylinder was connected to a

12-litre dive bottle by means of a pipe and a manual valve for controlling the pressure inside the cylinder. The samples were subjected to six cycles of 30 minutes each to a pressure between 5.5 and 6 bars, equivalent to a depth of 45 to 50 metres underwater.

Dye protocol

The external surfaces of each sample were completely coated with two layers of nail varnish, with a 1 mm wide margin around the interface restoration left free of varnish. Specimens were immersed in a 50 weight (wt) % silver nitrate aqueous solution for two hours in total darkness, then placed in distilled water and exposed to fluorescent light for 12 hours. They were immersed in photodeveloping solution for two hours (Kodak SA), then rinsed thoroughly in running water and immersed in acetone to dissolve the nail varnish. Each was embedded in a cold curing epoxy resin (ClaroCit Kit).

By using a diamond blade circular disk (Accutom, Struers) at a disc speed of 550 rpm and with a cutting lubricant (Struers), each sample tooth was sectioned vertically into three sections, thereby obtaining six interfaces. The dye penetration was measured at the dentine–composite resin interface by using a binocular loop connected to a camera and analysed by using Leica software (Leica Microsystems Imaging, Cambridge, UK). The percentage microleakage was defined as the measured length of the dye penetration divided by the measured length of the interface. The mean percentage microleakage was the mean of five specimens (5 × 3*6 = 90 interfaces) for each group investigated.

Statistical analysis

Data were analysed by one-way ANOVA with the Turkey test. Groups were compared by Mann-Whitney U test. P <0.05 was considered statistically significant.

Results

The results are presented on the Table 2 and represented in a graph in Figure 3.

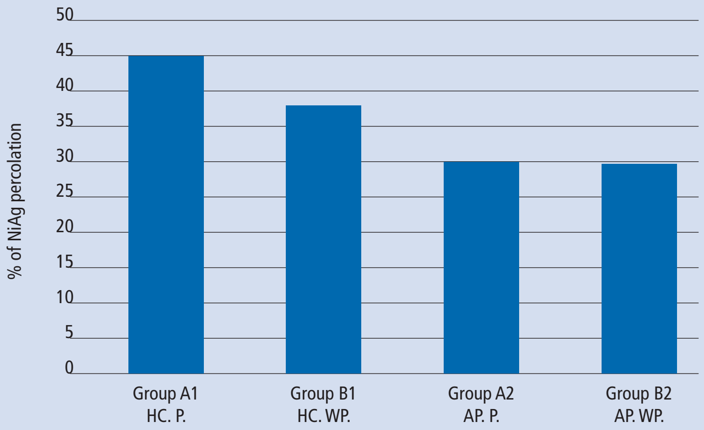
The percentage penetration was greater for samples with than without porosity subjected to a hyperbaric condition (45%, Fig. 4 vs 37.9%) and to ambient pressure (29.8%, Fig. 5 vs 29.4%). Significant differences were found between Group A1 (submitted to hyperbaric conditions and presenting a porosity) and the two groups left at ambient pressure.

Table 2 Percentage of dye penetration

Groups	Group A1	Group B1	Group A2	Group B2
	HC. P.	HC. WP.	AP. P.	AP. WP.
% of percolation	45 (4.5) ^{a,b}	37.9 (5.3)	29.8 (8.83)^{a}	29.4 (4.96)^{b}

(HC: Hyperbaric condition, AP: Ambient pressure, P: porosity, WP: without porosity).
Statistical analysis: same letters represented examples with statistical differences p <0.05

Fig. 3 Percentage of dye penetration (mean data)



Note: HC : Hyperbaric condition, AP: Ambient pressure, P: porosity, WP: without porosity)

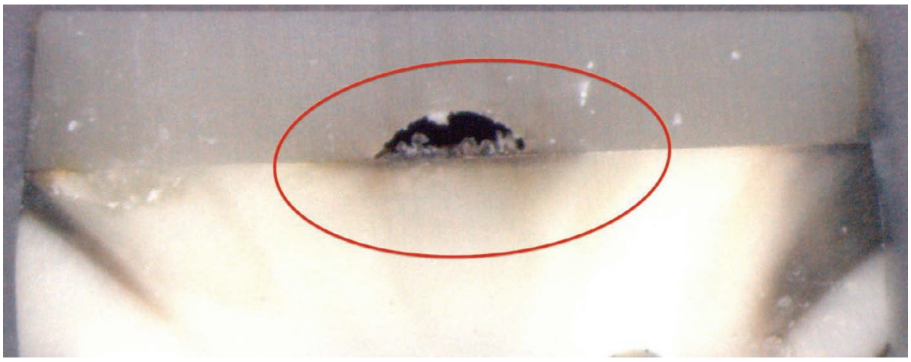


Fig. 4 Example of dentine – composite resin interface of sample restored with composite presenting a porosity subjected to a hyperbaric environment (Group A1)

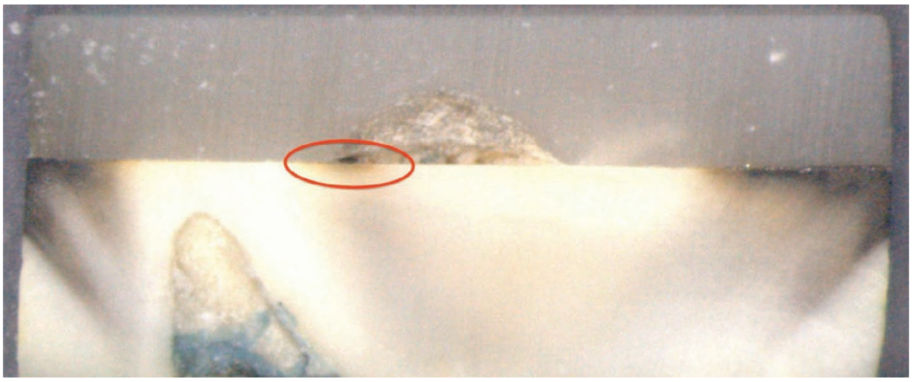


Fig. 5 Example of dentine – composite resin interface of sample restored with composite presenting a porosity subjected to an ambient-pressure environment (Group A2)

Discussion

In this paper we have addressed the effect of diving conditions (pressure increase) on adhesive restorations. At the pressure used in this experiment, equivalent to a depth of 45 to 50 metres underwater, only experimental divers (with certification PADI TEChnical 45 and 50) or professional divers (military or speleologist) can dive but not recreational divers.

We evaluated the impact of a simulated hyperbaric environment on microleakage of the dentine–composite resin interface. We aimed to evaluate whether restorative dentistry protocols should be refined for patients who are divers.

Highest percolations in groups A.1 and B.1 respectively, compared to groups A.2 and B.2, show that a simulated hyperbaric condition leads to a loss of sealing at the interface. This highlights the importance of the adhesive selection and the respect of the adhesive protocol. For divers with adhesive restorations or planning to undergo such restorations, etch-and-rinse adhesive systems or self-etch systems with a preliminary enamel etching may be preferred to limit enamel penetration.[15,16]

The greater dye penetration into the group A.1 with porosity compared to the group B.1 without porosity shows that a defect in the restoration will promote the microleakage between the inside and the outside of the interface. To limit this situation, a perfect marginal adaptation must be achieved between the restorative material and dental tissues. The use of flow composite,[17] instruments generating vibrations on composite[18] or preheating composite[19] could help limit the presence of air bubbles. Respecting the protocol and the quality of condensation are important in all situations, but especially for patients who are divers. This explanation is supported in a study by Ranna *et al.* In this study, more than half of the teeth affected by pain were molars.[11] Molars are the teeth most susceptible to decay and most frequently restored.[20]

Calcium silicate-based materials (Biodentine, Pro Root MTA etc) for indirect pulp capping may ensure good restoration (given that direct pulp capping is not recommended for patients who are divers) but such materials are porous during the initial crystallisation phase, and perhaps patients should wait to dive until after the end of the reaction so that the material completely matures.[21–23]

Also, current techniques for treating deep carious lesions may not be appropriate for patients who are divers. Such techniques consist of a selective removal of carious tissue, localised in the restoration margins, which leaves the cavity bottom in the affected or infected dentine. These tissues have a porous demineralised and deproteinised supporting structure with low mechanical properties. Moreover, the adhesion properties of this tissue are lacking as compared with sound dentine, and bond durability and strength are lower.[24,25]

Recommendations in restorative dentistry

During an appointment, any doubt concerning the leakage of a restoration must involve reintervention. For patients who are divers, many older publications (before 1990) recommended establishing a bottom for the cavity with zinc-oxide eugenol under the amalgam filling.[26] The available materials require consideration of their mechanical properties, porous character and thixotropy (marginal adaptation) before their implementation in patients who are divers.

Glass-ionomer cement has thermal and electrical insulation, spontaneously adheres to dental tissue by reaction of chelation, compensates the composite contraction and ensures good adhesion with calcified tissues. These properties may help prevent barodontalgia.[27] However, glass-ionomer cement is sensible to desiccation.[28] In diving, the oral environment is exposed to dry air from the regulator. To prevent this desiccation of glass-ionomer cement, a surface treatment can be applied. Simmons *et al.* have showed that a surface treatment with 5% NaF improved antimicrobial and strength properties of desiccated glass-ionomer cement.[29] Consequently, in order to limit this problem and as this material has weak mechanical properties, we recommend using it as dentine substitute.

The use of a calcium hydroxide cavity liner must be limited. Indeed, due to the poor adherence and low sealing ability of a calcium hydroxide, glass-ionomer cement, tricalcium silicate cement or composite resin are more appropriate for indirect pulp capping or liner.[30–32] For direct restorations, adhesive restorations seems to be preferred as amalgam does not adhere to dentine or enamel. But we cannot advocate amalgam restorations or composites for patients who are divers, because any studies compare microleakage in hyperbaric condition on interface dentine/amalgam *versus* dentine/composite. In ambient pressure, the results of studies are contradictory.[33,34] For diver patients, using an adhesively bonding amalgam seems interesting to increase the sealing. However, it has not been highlighted an additional benefit of adhesively bonding amalgam in compare with non-bonded amalgam.[35] Indirect restorations for wide and deep cavities for patients who are divers are recommended. Indeed, the risk of defects increases with the volume of the cavity.[36] For prevent microleakage at the outer margins it seems recommended to apply glycerine gel to the surface of bonding composite resin during polymerisation for increase marginal adaptation.[37]

Conclusions

During the examination for dental restoration, dentists should investigate their patients' activities, to estimate whether the activities might affect the orofacial structures. Similarly, patients who are divers should inform their dentists about their activities/hobbies so as to prevent barodontalgia. The consequences of restorations during diving that can cause the pain and the loss of a tooth fragment or restoration are very dangerous, especially when patients are isolated during an activity. Therefore, a more interventionist approach is needed to treat dental diseases in patients who are divers.

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