Push-out Bond Strength of Fiber Posts in Long-Term Hypobaric Pressure Changes

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BACKGROUND: The purpose of this study was to evaluate the bond strength of fiber posts with different mixing methods and insertion into root canal techniques in long-term hypobaric pressure changes.

METHODS: We chose and decoronated 42 teeth with straight and single root canals. After post-space preparation, the posts were cemented with hand-mixed and auto-mixed resin cements that were inserted into the canals with an endodontic file (lentilo), dual-barrel syringe, and root canal tip (14 for each group). After cementation, each group was divided into two subgroups ($N = 7$): the control (ambient pressure) group and the hypobaric pressure group. The samples were exposed to hypobaric pressure 90 times. They were cut into 2-mm-thick segments and the push-out bond strength test was performed using a Universal Testing Machine. One-way ANOVA tests, Bonferroni tests, and Student-*t*-tests were used for statistical analysis.

RESULTS: The environmental pressure changes and insertion techniques affected the bond strength values. The auto-mixed with root-canal tip group showed the highest push-out bond strength values in both hypobaric (dual-barrel syringe group: 10.01 MPa; root-canal tip group: 11.61 MPa) and control (dual-barrel syringe group: 12.29 MPa; root-canal tip group: 14.58 MPa) group. In all root segments, the bond strength values of hypobaric groups were lower than atmospheric pressure groups. The most frequent failure type was adhesive between dentin and cement in all groups.

DISCUSSION: Dentists should use auto-mixed self-adhesive resin with a root canal tip for post cementations in patients likely to be exposed to hypobaric pressure changes.

KEYWORDS: fiber post, resin cement, prosthodontics, aviation medicine, push-out test.

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Endodontically treated teeth may be damaged by decay, excessive wear, or previous restorations, resulting in a lack of coronal tooth structure. The restoration of endodontically treated teeth with a significant loss of coronal tooth structure may require the placement of a post to ensure adequate retention of a core foundation.[18] Fiber posts are commonly used in dental restorations as they have an elasticity modulus close to the tooth structure and decrease the risk of root fracture by dispersing the stress on the tooth.[4,20] However, poor adaptation of prefabricated fiber posts to root canals results in a lack of retention. Many factors influence postoperative clinical success. The most common cause of fiber post failures is post dislodgements caused by luting cement types and cement insertion procedures.[7,9]

Resin cements can be categorized as self-cured, light-cured, or dual-cured according to their polymerization type and adhesion strategy to the dentin substrate.[23] Dual-cure resins improve clinical handling by promoting polymerization in critical parts of the light incidence. It was stated that dual-cure resins have lower penetrability in the dentin matrix through dentin tubules, superior mechanical characteristics, increased bond strength, and adhesive capabilities to teeth.[13,22,31]

Dental barotrauma is a condition characterized by tooth fracture, restoration failure, and prosthesis displacement.[29]

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Defective dental restorations, leakage, and secondary caries are considered to be the most significant risk factors for dental barotrauma. The predisposing conditions for dental barotrauma are described in a variety of case reports.[26,27] This condition is considered a potential cause of incapacity that might jeopardize the safety of flying and scuba diving. The pressure changes in the oral cavity show their physiological effect mostly with barodontalgia.[22] This condition is described by Boyle's Law. When a person ascends above sea level, as pressure decreases, the volume of the gases in the body (such as those in the sinuses and inside the resins in restorations) will increase. This situation will change inversely during diving. It was reported that atmospheric pressure changes can affect the retention of crowns due to the cementation technique and mixing methods.[10,19] Geramipanah et al. stated that the bond strength values of a fiber post can be affected by atmospheric pressure changes.[10] The most important reason for failures in dental restorations due to environmental pressure changes are the air voids formed during material handling.[24] The possible voids within the resin symbolize weak areas, reducing the resin's mechanical qualities and the restorations' longevity.[8]

In studies examining the adhesion of cements in hyper- or hypobaric conditions, it was determined that auto-mixed cements contain fewer air voids, owing to their reduced air interaction, and are, therefore, less impacted by air pressure variations.[21] In addition to experimental studies, it has been found that clinical studies showed a significant incidence of barodontalgia. It has been reported that barodontalgia was noticed in nearly half of the aircrews in retrospective surveys conducted in various nations.[28]

According to the literature review, a few preliminary studies have indicated the effect of atmospheric pressure changes on the bonding properties of dental materials. Previous research studied the short-term effects of hyper- or hypobaric pressure changes. To the best of our knowledge, the impact of long-term atmospheric pressure changes on the push-out bond strengths of fiber posts with different mixing methods of resins and insertion techniques into root canals has not been studied. Therefore, the aim of this research was to evaluate the bond strength of hand- and auto-mixed adhesive resins with different insertion techniques in the root canal after exposure to long-term hypobaric pressure changes.

The null hypotheses were listed as follows: 1) there will be no statistically significant difference in push-out strength at different environmental pressure changes; 2) there will be no statistically significant difference in terms of application techniques and mixing methods on push-out bond strength; and 3) there will be no statistically significant difference in push-out bond strengths among different root sections.

METHODS

The study was approved in advance by the Eskisehir Technical University Ethical Committee. We selected 42 teeth with single-root canals, which were previously extracted for orthodontic or periodontal problems. Samples with diameters larger than the post's diameter (1.6 mm) were eliminated. Teeth were kept in 0.5% chloramine-T for one month before use.

Materials

Teeth were cut 2 mm below the buccal cemento-enamel junction with a diamond bur (TMAX, Fujian, China). The roots were modified to the same length of 14 mm to standardize the lengths of root canals. The same operator instrumented the root canals. When preparing the post space, irrigation with a 5% NaOCl solution was used. The post space was enlarged to 9 mm long with a low-speed universal drill (Endo Thread Quartz, Tree Dental, China). Distilled water was used for irrigation for 30 s. Before cementation, the remaining water was removed from the post space with absorbent paper points. According to the mixing and insertion methods, teeth were randomly divided into three groups ($N = 14$).

- Hand-mix/endodontic file group (HE): Equal amounts of the two resin pastes (MaxCem Elite Chroma, Kerr, USA) were manually mixed for 20 s. A manually controlled Lentilo spiral was used to put the resin into the canal, and the post was covered with cement. The post was placed and held for 1 min with finger pressure. After removing the excess cement, the buccal, lingual, and incisal sides were light-cured for 40 s.
- Auto-mix/dual-barrel syringe (AD): The resin was mixed in a dual-barrel syringe (regular) and inserted directly into the post canal, and the post was covered with cement. The post was then placed into the root canal space and resin was light-cured according to the manufacturer's instructions.
- Auto-mix/root canal tip (ARC): According to the manufacturer's instructions, the resin was mixed in a dual-barrel syringe and put directly into the post space with a root canal tip (endo tip, 0.98 mm diameter). The post was also covered with cement. The post was then placed into the root canal space, and resin was light-cured according to the manufacturer's instructions.

Procedure

The control group was kept in distilled water at a controlled temperature for the 30-d duration of the test phase. The samples for hypobaric pressure testing were also put in distilled water at a controlled temperature before, during, and after the hypobaric pressure testing. Hypobaric groups ($N = 7$ from each group) were subjected to the Hypobaric Chamber (ETC; Southampton, PA, USA). The chamber was decompressed to a height of 8200 m (1/3 atm-27.000 feet) in 5 min. After 30 min at 8200 m, it was recompressed. This method was performed three times a day for a total of 90 times. The control group was kept in distilled water for 30 d at ambient pressure.

Under water cooling, the samples were sliced horizontally with a slow-speed diamond blade (TMAX, Fujian, China) to generate three 2-mm thick post–dentin segments.

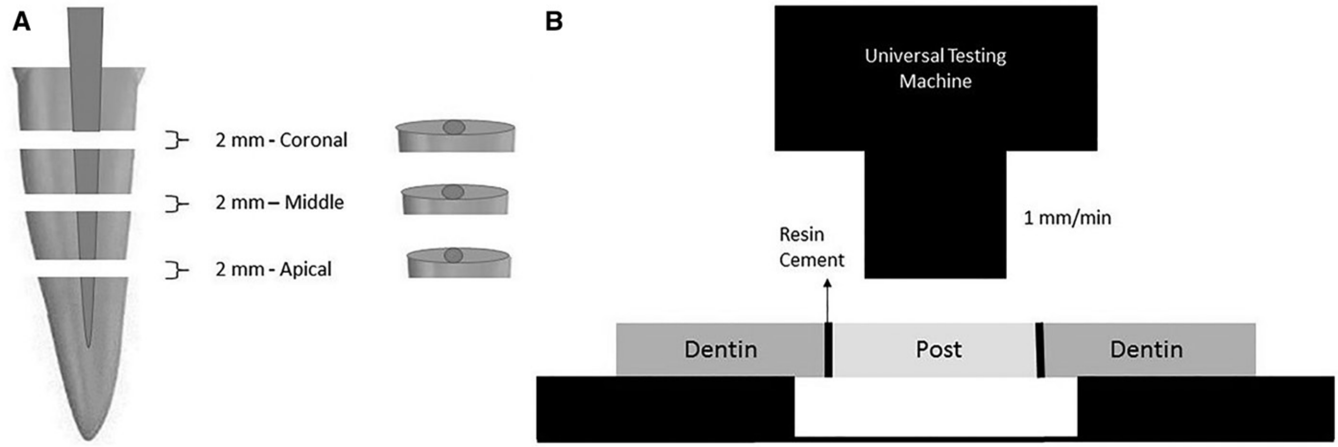

Fig. 1. Schematic view of specimen preparation for the push-out test: A) specimen sectioning into three 2-mm-thick post–dentin sections (coronal, medium, and apical) and B) push-out test device.

The cervical (Section 1), middle (Section 2), and apical (Section 3) areas of the post space preparation were represented by the first, second, and third slices, respectively (**Fig. 1A**). During sectioning, no slices were failed and all slices were used for the test. The length of each section was measured with a digital caliper (Mitutoya, Tokyo, Japan). The push-out jig was fixed to each section. The samples were positioned over the jig's hole. A cylindrical plunger (1 mm in diameter) was used to load the tooth sections, which were centered on each section to avoid contact with the surrounding dentin surface. The samples were put into a Universal Testing Machine (Lloyd-LRX, Lloyd Instruments, Fareham, UK) in an apical-to-cervical direction at a crosshead speed of 1 mm/min until the post was dislodged (**Fig. 1B**). The adhesive surface area (A) was calculated for both interfaces using the formula: $A = \pi(r_1 + r_2)\sqrt{(r_1 - r_2)^2 + h^2}$, where r_1 and r_2 are the diameters of the two surfaces, respectively, and h is the height.

Push-out strength values (b) were determined with the formula: b = Fmax/A. Fmax is the maximum load at fracture, and A is the adhesive surface area. Megapascals (MPa) were used to convert debond stress values. A light microscope (Olympus Corp., Tokyo, Japan) was used to examine the debonded surface of the samples at a magnification of 50×.

Statistical analysis

The Shapiro-Wilk and Levene's tests were used for normality of the data distribution and homogeneity of variances. Push-out bond strengths were investigated at three levels of the segments. The differences between the coronal, middle, and apical segments and also between the mixing methods were assessed with one-way ANOVA and Bonferroni's multiple comparison test. The differences according to pressure changes within segments and mixing methods were assessed with Student-*t*-test. A significance level of 0.05 was used.

RESULTS

The bond strength values were affected by the mixing-insertion technique and hypobaric pressure changes in this study (**Table I** and **Fig. 2**). Regardless of the pressure changes, the HE group showed the lowest and the ARC group showed the highest push-out bond strength values in this study. The bond strength values for each post decreased from cervical to apical in all groups. Table I shows the standard deviation and mean (MPa) of the post cementation systems' push-out bond strength values in root segments.

Table I. Bond Strength Values in MPa (Mean and Standard Deviation) by Insertion-Mixing Method and Root Segment for: A) Hypobaric Pressure Group and B) Control Group.

		ATMOSPHERIC PRESSURE			HYPOBARIC PRESSURE		
GROUP		MIN (MPa)	MAX (MPa)	MEAN ± SD (MPa)	MIN (MPa)	MAX (MPa)	MEAN ± SD (MPa)
Coronal	HE*	7.92	13.34	10.51 ± 2.32	6.28	11.73	8.31 ± 1.82
	AD**	9.24	14.58	12.29 ± 1.89	7.90	12.42	10.01 ± 1.62
	ARC†	11.98	17.21	14.58 ± 1.93	9.85	13.72	11.61 ± 1.40
Middle	HE	7.29	11.82	8.96 ± 1.63	4.12	7.12	5.70 ± 1.06
	AD	7.12	11.69	8.63 ± 1.64	5.33	8.32	7.26 ± 1.41
	ARC	7.23	14.92	10.39 ± 2.77	7.34	12.32	9.76 ± 1.74
Apical	HE	2.69	6.21	4.54 ± 1.15	1.15	5.41	2.78 ± 1.37
	AD	4.89	7.48	6.08 ± 1.02	3.66	6.11	4.63 ± 0.98
	ARC	5.19	8.27	7.15 ± 1.03	4.78	8.53	6.53 ± 1.32

*HE: Hand-mix/endodontic file group; **AD: Auto-mix/dual-barrel syringe; †ARC: Auto-mix/root canal tip group.

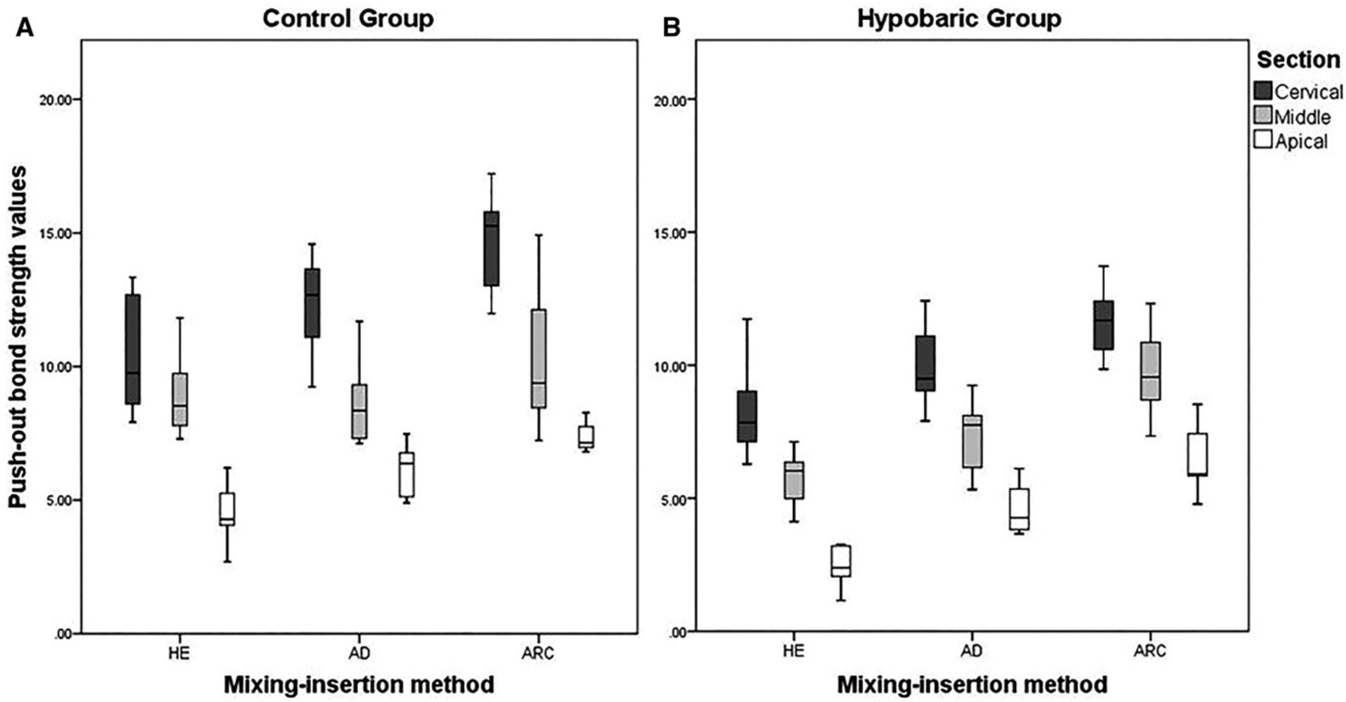

Fig. 2. Boxplot graph presenting the push-out bond strength values in different root sections and cement insertion techniques: A) control group and B) hypobaric group.

In both the atmospheric and the hypobaric groups, the ARC group was statistically much higher than the HE group. Regardless of the atmospheric pressure changes, when all the sections were compared to each other, there were statistically significant differences between them. Moreover, when comparing sections exposed to pressure with those not exposed to pressure, all sections in the hypobaric group were found to be statistically significantly lower.

After evaluation with a light microscope, the adhesive failures were mostly observed at the cement–dentin interfaces. Cohesive failure within the resin was noted only in the apical segment for the ARC group (**Fig. 3**).

DISCUSSION

The results of this study showed that hypobaric pressure changes and different insertion and mixing techniques of self-adhesive resins could affect the bond strength values of posts. The hypotheses were rejected because a statistically significant decrease was observed in the manual-mixed lentilo group exposed to hypobaric pressure compared to the control group at all root sections. Regardless of hypobaric pressure alterations, all groups showed lower bond strength values in apical root segments.

Barodontalgia during flight can be simulated in hypobaric chambers more simply and affordably.[2] This study was carried out in an altitude chamber to simulate the change in altitude during actual flight. It is important for a dentist to be aware of the effects of pressure changes on the retentive strength of dental restorations, since the risk of component dislodgement during diving or flying could be dangerous. When using dental cement or filling material on patients who are exposed to variations in air pressure, it is crucial that dentists use the appropriate materials and application techniques that produce fewer air voids. As a consequence of this investigation, it might be suggested to use auto-mixed resins during the bonding of canal posts and special tips during canal application.

One of the reasons of fiber post dislodgement is the decrease in bond strength due to air voids that remain in the canal after bonding.[21,24] After atmospheric pressure changes, the contraction and expansion of voids inside the resin may have weakened the adhesion of restorations.[19] According to Boyle's law, if a void occurs, it will expand with hypobaric pressure. When porosity or air inclusion in a dental restoration is minimal, atmospheric pressure impacts are predicted to be lower. Geramipanah et al. investigated the atmospheric pressure changes using two different mixing procedures and application methods between fiber post and resin cements.[10] They concluded that atmospheric pressure changes could change bond strengths between the post and dentin, and that resin cement type, mixing methods, and application procedures all have a role. In the current study, all groups showed lower bond strength values after hypobaric pressure changes. Continuous volumetric shrinkage or expansion of the voids inside the cements due to pressure changes may have affected our results.

The mixing methods of luting cements, and their mechanical and chemical properties (such as viscosity, microshrinkage values, water sorbtion, and hygroscopic expansion), all have an effect on porosity and voids that occur inside the cements.[15]

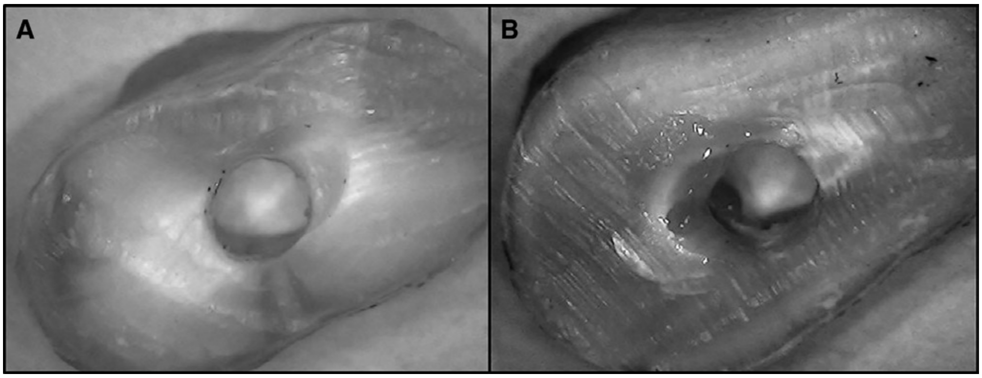

Fig. 3. Representative images of adhesive and cohesive types of failure with light microscope after debonding (50× magnification). Categories of failure modes: A) adhesive failure between root dentin and adhesive resin; and B) cohesive failure with resin partially covering the root dentin.

Zeeler et al. and Mocuat et al. reported that a high viscosity feature may limit the filler loading capacity and result in the presence of air voids.[12,30] It was also reported that the polymerization stress may cause the formation of gaps and voids.[25]

Cementation using auto-mixed resin and insertion with a root canal tip were less affected by pressure variations. Besides, in the middle and apical segments, the hand-mixed-lentilo group demonstrated the lowest bond strength values in this study. Silva et al. studied the effects of cement-mixing and insertion into the root canal techniques.[21] They reported that auto-mixing and using an endo tip resulted in fewer voids and stronger bond strength. According to Boschian Pest et al. and Milutinovi-Nikoli et al., hand-mixing the cements included more and larger voids than auto-mixing, while injected resin cements had fewer voids.[3,11] Void formation in cement could be influenced by resin insertion techniques.[6] Pedreira et al. observed more voids when the conventional technique was used, and more homogeneous cement was seen when a syringe was used.[16] The injection of resin cement into the root canal, especially in the deeper root canal areas, minimized air retention, reduced resin porosity, and resulted in fewer voids.[5,17] Using syringe devices and transferring the cement directly to the root canal after mixing may avoid existing voids inside the cement and post interface. The mixing procedure may help to reduce voids when utilizing dual-syringe-mixed resin cements since neither the catalyst nor the base pastes make contact with air. In comparison to manual mixing, this characteristic makes the injection method more favorable. Although the quantity of voids inside the resin was not assessed in this study, the most probable reason of hypobaric pressure change effects in root sections were the microvoids incorporated accidentally during the insertion of cement into the root canal. Alterations in atmospheric pressure may result in a continuously repeated expansion and contraction of voids, thus damaging the resin composition, leading to deterioration and microleakage, resulting in dislocation of dental restorations.

In this study, the auto-mixed root-canal-tip-inserted group showed the highest push-out bond strength values in hypobaric pressure changes and all root sections. As the cement may include voids and pores both during mixing and inserting into the canal, this may affect our findings. In evaluating the effects of environmental pressure changes on the adhesion of dental materials, the location and size of the voids inside the dental materials are of great importance. For this reason, there is a need for more studies in which the void quantity in materials and resins is examined by various methods and compared with the void quantity after pressure changes. This is the limitation of this study.

In this study, one type of resin cement and fiber post were used for standardization. In contrast to the clinical setting and in order to eliminate a potential confounding factor, the root canals were not filled with paste and gutta-percha. The post spaces were rinsed with NaOCl. Rinsing with 5% NaOCl was reported to improve the bonding strength of the resins to dentin.[1]

The failure modes were evaluated using a light microscope. In this study, the samples mostly showed adhesive failures occurring at the cement–dentin interface, with only smallish remnants of cement retained on the dentin surface. Air voids or insufficient polymerization during application or mixing of the resins may have reduced the dentin–resin adhesion. In addition, although the post-resin adhesion appeared to be stronger than the dentin–resin adhesion in this study, mechanical or chemical roughening methods can be applied on the surface of fiber posts to increase the micromechanical interlocking. However, since these methods will increase the roughness of the surface, due to the pits and pores, there may occur more voids between the cement and the post, resulting in lower bond strength values in environmental pressure changes.[14]

Tooth fractures or restoration displacements can cause toothache that can compromise flight safety. Although void parameters inside the cement, as well as on dentin surfaces of the canal and post interfaces, could not be measured in this study, the possible voids in dental materials are the main reason for decreasing bond strength values and restoration fractures due to environmental pressure changes. Therefore, more research is needed in which the voids generated during polymerization and bonding of dental materials are assessed by devices like micro-CT and then pressure variations are compared.

Due to there being so many different luting agents and posts, the current study provides only some insight into the influence of aviation dentistry on the retention of posts. More interventional approaches are needed, as dental treatments and materials may differ in individuals exposed to different atmospheric pressure changes.

In conclusion, auto-mixed adhesive resins can be considered in patients who are exposed to hypobaric pressure changes. During the insertion of the resin into the canal, root canal tips can be recommended to eliminate air voids in root canal treatments. Due to the amount of air voids in materials and resins and given that the localization of the air void is one of the most important factors influencing the strength and adhesion of the material (especially in atmospheric pressure changes), additional studies, such as micro-CT evaluation, are required to examine the amount of air voids in dental materials.

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