ORIGINAL RESEARCH

Evaluation of Clear Aligner Attachments Bonded to Lithium Disilicate Ceramic Prepared with Different Surface Roughening Methods: An *In Vitro* Study

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Abstract

Aim: This study aims to assess the effects of surface conditioning and different composite types on the surface roughness (SR) and shear bond strength (SBS) between lithium disilicate and clear aligner composite attachments.

Materials and methods: Eighty ivoclar vivadent pressable (IPS) e.max press specimens were randomly allocated into four groups ($n = 20$) based on the surface treatment method employed. Group I: Used sandblasting with 50 μm Al_2O_3 slurry particles; group II: Used 9.5% hydrofluoric acid (HFA); group III: Used 37% phosphoric acid (PhA); and group IV: Used an Er,Cr:YSGG laser. Surface roughness was measured using a stylus profilometer. For SBS, each group was split into two subgroups based on the composite type ($n = 10$): Filtek™ Z350 supreme ultra flowable and Filtek™ Z350. The evaluation of SBS was conducted using Instron universal testing equipment.

Results: The results indicated that the sandblasting group gave the highest mean surface roughness, while the 37% PhA group showed the lowest recorded value. In addition, the HFA group had the highest mean SBS, while the 37% PhA group demonstrated the lowest SBS.

Conclusion: The interaction of HFA and Filtek™ Z350 demonstrated the highest SBS, followed by sandblasting and Filtek™ Z350.

Clinical significance: The current study may guide orthodontists to choose the appropriate composite material and conditioning technique to achieve a strong SBS between clear aligner composite attachments and lithium disilicate ceramic.

Keywords: Clear aligner, Composite attachment, Lithium disilicate, Shear bond.

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Introduction

Over the past few years, the demand for aligner therapy has increased because patients choose thermoformed splints over standard fixed orthodontic appliances. This is because thermoformed splints offer better aesthetics and more comfort.[1,2] Nevertheless, utilizing aligners alone, without any auxiliaries, is associated with some restrictions. Specifically, they are only capable of exerting force on teeth to move them into predetermined gaps, away from the center of resistance.[3]

Manufacturers have been investigating innovative approaches to enhance the therapeutic properties of their products in response to patient interest. This involves incorporating auxiliary features like precise cuts, composite attachments, power ridges, and bite ramps into aligners, enabling the treatment of a wider range of malocclusions.[4] The utilization of composite attachments enables better control and active guidance of tooth movement. This results in an increased contact area and the positioning of the point where force is applied closer to the center of resistance. Consequently, this allows for more precise and comprehensive tooth movement.[5] Composite attachments became a fundamental component of the aligner treatment. However, it remains a frequent difficulty to successfully accomplish the intended teeth movement in a clinical setting.[6]

Orthodontists often come across patients who have one or many ceramic restorations. Bonding of orthodontic attachments to ceramics with high crystalline content, such as lithium disilicate, is quite challenging.[7] The application of the composite to the ceramic surface without roughening resulted in a bond strength that was too weak to withstand the forces required for orthodontic tooth movement.[8]

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Various methods, both mechanical and chemical, have been suggested to enhance the bonding strength between clear aligner attachments and ceramic surfaces to produce a strong bond strength. Mechanical roughening can be achieved through sandblasting or by employing a diamond bur.[9] Regarding chemical treatment, numerous investigations have indicated that phosphoric acid (PhA) does not etch ceramic surfaces. However, when combined with silane coupling agents, PhA has been shown to possess adequate adhesive strength.[10,11]

According to reports, techniques like hydrofluoric acid (HFA), laser irradiation, or sandblasting have been found to offer the best adhesion when used as surface treatments for glass ceramics.[12–14] Laser irradiation is a suggested alternate method for treating the surfaces of restorations manufactured from composites, ceramics, or resin matrix ceramics (RMCs).[15] Many researchers prefer to employ

Table 1: The Chemical composition and manufacturer name of the materials used in this research

Material	*Chemical composition*	*Manufacturer*
Lithium disilicate glass ceramic (IPS e.max Press)	Lithium disilicate crystals with approximately 70% crystals by volume. Additional contents: Li_2O, K_2O, MgO, Al_2O_3, P_2O_2	Ivoclar Vivadent, Lichtenstein, Germany
Phosphoric acid	37% PhA, chlorhexidine digluconate, thickener, stain and water	Ivoclar Vivadent, Lichtenstein, Germany
Hydrofluoric acid	9.5% HFA, 5.3% ethyl alcohol, thickening agent, dye, and water	Bisco, Schaumberg, IL, USA
Aluminum oxide particles (Al_2O_3)	Al_2O_3 99.80%, SiO_2 0.023%, Fe_2O_3 0.035%, TiO_2 0.006%, CaO 0.01%, Na_2O 0.15%	Jeep, Guangdong, China
Single-bond universal adhesive	MDP phosphate monomer, Dimethacrylate resins, HEMA, Vitrebond copolymer, filler, ethanol, water, initiators, silane.	3M ESPE, Neuss, Germany
Porcelain primer	3-(Trimethoxysilyl)propyl-2-methyl-2-propenoic acid, acetone	Bisco, Schaumberg, IL, USA
3M Filtek^{TM} Z350 XT composite	Matrix: Bis-GMA, UDMA, Bis-EMA Filler: Silica, zirconia nanoparticles (20 µm) (72.5 wt%/55.9 vol%)	3M ESPE, Neuss, Germany
3M Filtek^{TM} Z350 XT flowable composite	Matrix: Bis-GMA, TEGDMA, procrylat resin Filler: ytterbium trifluoride, silica, zirconium oxide (46 vol%/65 wt%)	3M ESPE, Neuss, Germany

ESPE, Espe Spezial-Fabrik Für Zahnmedizinische Präparate GmbH; HEMA, hydroxyethyl methacrylate; IPS, ivoclar vivadent pressable; MDP, methacryloyloxydecyl dihydrogen phosphate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate

lasers to increase the surface roughness of restorative materials in order to achieve micromechanical retention.[16]

Materials and Methods

This *in vitro* study was approved by the ethical committee of Mansoura University (code no: A0403024OR). This study was done in 2024 for 6 months.

Calculation of Sample Size

The sample size (PASS) software (version 2017). NCSS, LLC. Kaysville, Utah, USA and power analysis were used to calculate the sample size based on experience gained from previous study.[17] For surface roughness (SR), sample sizes of 20 specimens are obtained from each of the 4 groups whose means are to be compared. The total sample of 80 specimens achieves 85% power to detect differences among the means vs the alternative of equal means using an F test with a 0.0500 significance level.

For shear bond strength (SBS), a factorial design with two factors at 4 and 2 levels has 8 cells (treatment combinations). A total of 80 specimens are required to provide 10 specimens per cell. This design achieves 84% power when an F test is used to test factor A at a 5% significance level and the effect size is 0.400.

Materials

Table 1 provides a comprehensive list of the materials, their compositions, and the manufacturers utilized in this research.

Preparation of Lithium Disilicate Specimens

Eighty lithium disilicate specimens with the dimensions of ($10 \times 5 \times 3$ mm^3) were fabricated using the lost wax technique. The computer-aided design and manufacturing system were used to create the wax specimens. Subsequently, all the wax patterns were affixed to the silicon ring's base using sprues measuring 3 mm in diameter and 3 mm in length. They were then immersed in a phosphate-bonded investment (BEGO, Bremen, Germany). Next, the wax was inserted into a preheated furnace (Program thermal, Luoyang, China) at a temperature of 850°C. Once the wax was eliminated, the ceramic ingot was placed on top of the sprues of the investment ring set and inserted into the pressing furnace (Programat EP 3010, Ivoclar Vivadent, Liechtenstein, Austria). The temperature was raised automatically at a rate of 60°C per minute from an initial temperature of 700°C to a final temperature of 920°C, and it was kept for 20 minutes. At the final stage of this process, the ingot had already undergone plasticization, and the ceramic material was then pressed into the investment mold. The set was promptly collected from the pressing furnace following the pressing process, enabling it to gradually reach the ambient temperature. The samples were collected and subjected to sandblasting using a sandblaster (Renfert GmbH, Hilzingen, Germany) with 110 µm aluminum oxide particles and then glazed by applying a coat of glaze material (Kulzer, GmbH, Hanau, Germany) in glazing equipment (P300, Ivoclar Vivadent, Liechtenstein, Austria). After that, ceramic specimens were mounted using self-cured acrylic resin blocks into rings of standard size (25 mm diameter and 14 mm length).

Surface Roughness Test

Eighty samples were randomly allocated into four groups ($n = 20$) based on the surface conditioning approach. Group I: Sandblasting using 50 µm Al_2O_3 particles for 5 seconds. The sandblasting was done at a pressure of 2 bar, in a perpendicular direction, and at a distance of 10 mm using an intraoral sandblaster (Jeep, Guangdong, China). Group II: Underwent etching using a 9.5% HFA solution for a duration of 1 minute. Group III: underwent etching using a 37% PhA solution for a duration of 2 minutes. Group IV utilized an Er,Cr:YSGG laser (Waterlase; Biolase Technology, Irvine, CA, USA) with a power output of 3.5 W. The laser tip was positioned at a distance of almost 1 mm from the lithium disilicate surface. The laser was directed perpendicular to the surface with 65% air and 55% water spray. The laser had a pulse duration of 140 µs and a wavelength of 2.780 nm. The average exposure period was 10 seconds and the laser operated at a repetition rate of 20 Hz.

All samples were tested for surface roughness using a stylus profilometer (Surftest SJ-210, Mitutoyo, Japan), as shown in Figure 1.

Shear Bond Strength Test

Eighty specimens were categorized into four groups ($n = 20$) based on the surface treatment procedure. Afterward, each group was categorized based on composite type ($n = 10$), as depicted in Figure 2.

Following the surface treatments, the porcelain conditioner was administered for 2 minutes and subsequently dried for 30 seconds. Then a single-layer SBU adhesive was applied to the lithium disilicate surfaces using a microbrush in a scrubbing motion for 20 seconds. After that, it was air dried for 5 seconds and lastly, light cured for 10 seconds, following the manufacturer's recommendation.

A rectangular acrylic mold was fabricated with the dimensions ($5 \times 2 \times 1.5$ mm^3) to match the rectangular attachment's dimensions.[17] The mold was placed onto a glass slap, loaded with composite material, pressed on the lithium disilicate surface, and exposed to light cure for 20 seconds. Subsequently, the lithium disilicate specimens with bonded composite attachments underwent 1,000 cycles of thermocycling, alternating between temperatures of 5 and 55°C with a dwell time of 15 seconds and a 10-second transfer time between temperatures[8] utilizing the (SD-Mechatronik, Westerham, Germany) Thermocycler. Subsequently, all samples underwent an SBS test utilizing an Instron universal testing machine (Model 3345, England, UK) as seen in Figure 3. The test involved applying a force of 50 kg and the speed of a crosshead of 0.5 mm/min until the composite attachment detached from the lithium disilicate surface.

Statistical Analysis

Quantitative data were mentioned as mean ± standard deviation (SD), and standard error whenever appropriate. For SR, one-way ANOVA and *post hoc* Turkey testing were utilized. Two-way ANOVA and *post hoc* Turkey tests were utilized for the SBS. A significance level of 0.05 has been set for all analyses.

Results

Surface Roughness

The sandblasting group had the highest average surface roughness of 1.253 ± 0.12 μm, whereas the PhA group showed the lowest surface roughness of 0.399 ± 0.08 μm. Between all groups, there was a statistically significant difference that was evaluated ($p < 0.05$), as indicated in Figure 4.

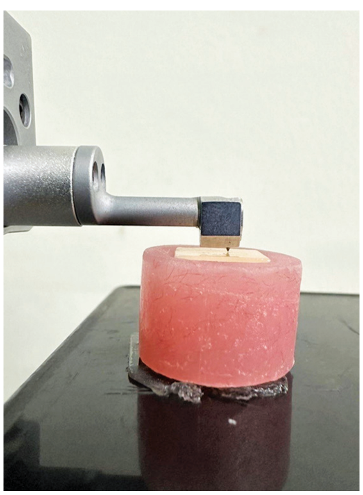

Fig. 1: Surface roughness testing using stylus profilometer

Shear Bond Strength

Table 2 displays the SBS outcomes for various conditioning techniques and composite materials. Among the conditioning methods, HFA exhibited the highest SBS with a mean value of 17.518 MPa, followed by sandblasting (14.263 MPa) and then laser (13.115 MPa). In contrast, PhA demonstrated the lowest SBS value (4.421 MPa), and pairwise comparisons revealed a statistically significant difference between all groups ($p < 0.001$), except between groups sandblasting and laser ($p = 0.379$).

The results for composite types indicated a statistically significant distinction between the groups ($p < 0.001$). The SBS value of Filtek Z350 was higher than that of Filtek Z350 Supreme Ultra flowable, measuring 13.352 and 11.306 MPa, respectively.

The correlation between various conditioning techniques and composite materials is depicted in Figure 5. The greatest SBS was achieved with the combination of HFA and Filtek Z350, followed by the combination of HFA and Filtek Z350 supreme ultra-flowable, and then the combination of sandblasting and Filtek Z350 (18.6004 ± 2.05558, 16.4348 ± 2.09360, 15.0031 ± 2.55980 MPa, respectively). On the other hand, the combination of PhA and Filtek Z350 supreme ultra-flowable exhibited the lowest SBS (2.9559 ± 1.16110 MPa).

Discussion

The increasing aesthetic expectations of dental patients have led to a growing demand for lithium disilicate crowns as a very effective option. Ivoclar vivadent pressable (IPS) e.max is classified as a type of glass ceramic that possesses superior mechanical qualities compared to traditional feldspathic or leucite-strengthened glass ceramics. Ceramic restorations might solve certain aesthetic issues, while others may require additional orthodontic intervention.[19]

Regarding ceramic bonding, orthodontists face a dual challenge: Maintaining the integrity of ceramic restorations after debonding while simultaneously achieving high bond strength during treatment to avoid bonding failures.[20]

The present study used various techniques to roughen the surface, including mechanical sandblasting, chemical treatment with 9.6% HFA or 37% PhA, and thermal treatment using an Er,Cr:YSGG laser. The selection of these approaches for treating the ceramic surface is based on their high potential and effectiveness in clinical practice. Nevertheless, each approach possesses constraints and inherent hazards.[21] This study aims to assess the effectiveness of

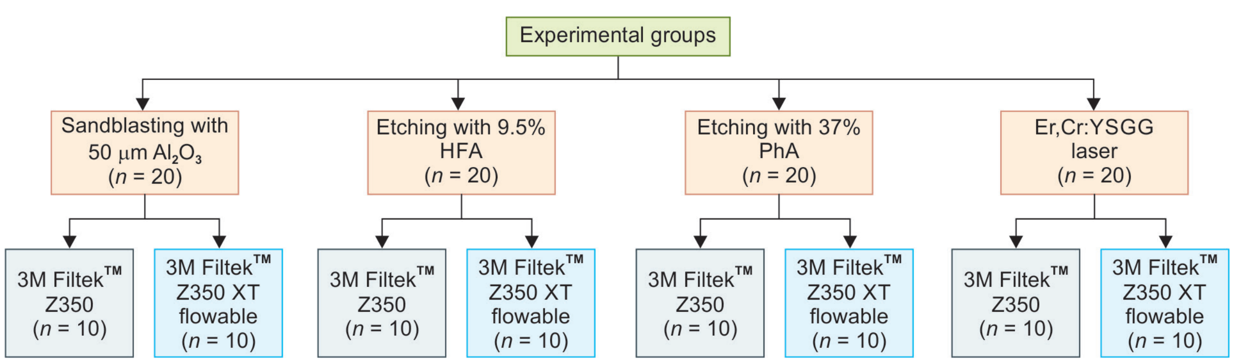

Fig. 2: Represented study design

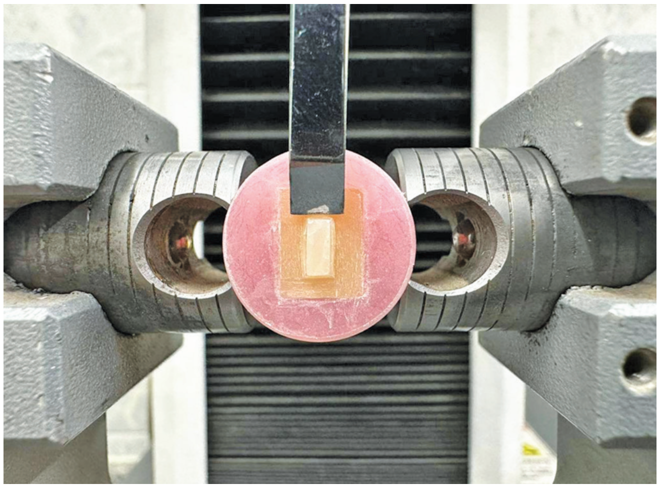

Fig. 3: Shear bond strength testing using an Instron testing machine

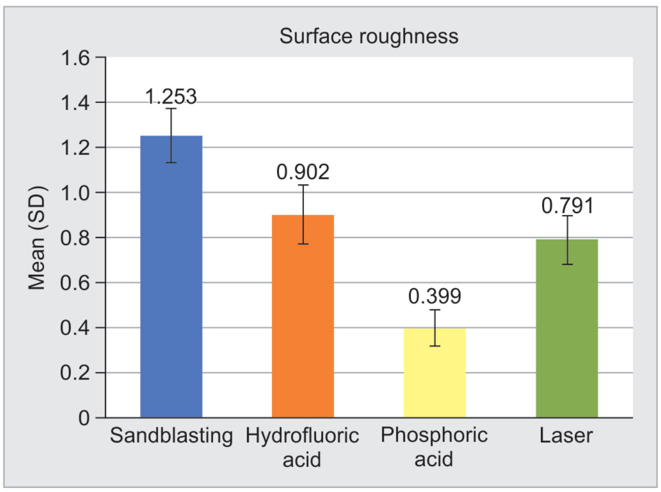

Fig. 4: Bar chart showing surface roughness among studied groups

Table 2: Comparison of SBS between the groups was conducted based on two different factors: Conditioning methods and composite types

Factor conditioning methods	*Mean*	*SE*	*F* *F (3, 72)*	*Sig.*	*Partial η²*
Sandblasting	14.263	0.430	168.862	<0.001	0.876
Hydrofluoric acid	17.518	0.430			
Phosphoric acid	4.421	0.430			
Laser	13.115	0.430			
Composite			*F (1, 72)*		
Filtek Z350	13.352	0.304	22.611	<0.001	0.239
Filtek Z350 supreme ultra flowable	11.306	0.304			

Notes: SE = standard error. Sig. = *p*-value. Partial eta squared (η^2) is a measure of the effect size

attaching clear aligner composite attachments to lithium disilicate after applying the surface treatment techniques indicated above.

In the present study, sandblasting (1.253 ± 0.12) showed the highest surface roughness, followed by HFA (0.902 ± 0.13), and then laser (0.79 ± 0.108) while PhA (0.399 ± 0.08) showed the least surface roughness. This result was in harmony with two studies,

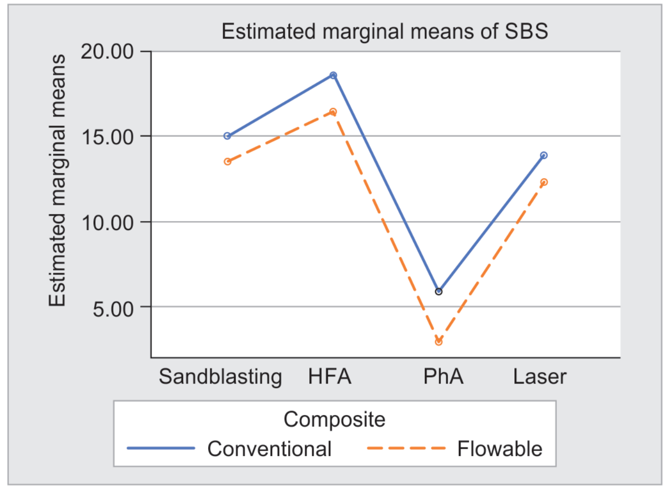

Fig. 5: Profile plot represents the correlation between various conditioning techniques and composite materials

Alsaud et al.[17] and Bayoumi et al.[22] with the exception that the two studies didn't use laser and due to the limited study on the Er,Cr:YSGG laser's effects on lithium disilicate, there was no result to compare with.

The imperfections caused by sandblasting led to a rise in surface free energy and elimination of the glassy matrix, resulting in a subsequent increase in bond strength.[23,24] Furthermore, an increase in surface roughness offers supplementary areas for adhesive cement to securely interlock, hence enhancing the SBS.[25] The changes in the HFA's characteristics can be assigned to the acid's capacity to attack the glassy structure of a ceramic, resulting in the revelation of lithium disilicate crystals. Consequently, the irregularities and SR are increased, thereby enhancing the micromechanical interlocking capabilities with resin cement.[26,27] The surfaces treated with Er,Cr:YSGG lasers displayed a certain level of SR; however, this level was significantly lower compared to the surfaces treated with sandblasting and HF etching. Phosphoric acid caused a decrease in surface roughness, possibly because it was unable to dissolve the glassy matrix, resulting in less surface areas for retention.

The optimum attachment material possesses numerous key properties, such as user-friendliness, durability against wear, and a high level of resistance to detachment. At present, clinical research on clear aligner technology keeps going in advance, while studies on the choice of attachment materials remain limited.[28] This investigation utilized two composite resins that are frequently employed for attachment bonding, based on their viscosity. A high-viscosity universal restorative material called Filtek™ Z350 composite and a low-viscosity flowable resin called Filtek™ Z350 supreme ultra flowable composite are the used materials. The results from all groups in this investigation demonstrated that Filtek™ Z350 had a greater SBS value (13.352 MPa) compared to Filtek™ Z350 Supreme Ultra flowable (11.306 MPa).

The results of our study align with the findings reported by the two studies, Alsaud et al.[17] evaluated the impact of the same type of composite material used in our study on the SBS of clear aligner attachments bonded to ceramic. It was found that the flowable composite had a bond strength of 10.18 ± 5.38 MPa, which was lower than the bond strength of the traditional Filtek™ Z350 (13.79 ± 7.47 MPa). Also, Chen et al.[28] assessed the SBS of extracted premolars utilizing the same composite materials, and they observed that the bond strength of the flowable composite was 15.3 ± 2.33 MPa, which was less than that of the traditional Filtek Z350, which had a bond strength of 20.53 ± 2.59 MPa.

The results were mostly influenced by the quantity of inorganic fillers. Filtek™ Z350 has a composition of 78.5% inorganic fillers, whilst 65% of the fillers in Filtek™ Supreme Ultra flowable are inorganic. Increasing the amount of inorganic filler content helps reduce polymerization shrinkage and stresses, leading to a stronger bond. Therefore, a higher SBS guarantees a more secure treatment as it reduces the chances of attachments detaching.[28]

Regarding the comparison of SBS among different conditioning procedures, the findings indicated that HFA yielded the highest SBS value (17.518 MPa) followed by sandblasting (14.263 MPa), and then Er,Cr:YSGG laser (13.115 MPa) while PhA revealed the lowest SBS (4.421 MPa), which was in harmony with the results mentioned by Alsaud et al.[17] who documented the effect of surface roughness on SBS of HFA, AA, and PhA (15.82 ± 4.72, 14.91 ± 5.38, 5.22 ± 4.03 MPa, respectively), with an exception for the laser group, which was not mentioned by the previous study.

Limitations of this Study

It is essential to acknowledge that this study has certain limitations. The experiment was performed *in vitro*, hence it may not exactly reflect clinical conditions. Consequently, it is essential to validate the findings of the *in vitro* experiment with thorough clinical studies in the future. Additional research is required to assess the shear bond strength between composite attachments bonded to different types of ceramic materials.

Conclusion

With the limitation and results of this study, we conclude that sandblasting caused the highest significant change in the lithium disilicate's surface roughness followed by HFA then laser and the least was PhA. The group conditioned with HFA exhibited the highest SBS value followed by sandblasting and the difference between them was significant. Nevertheless, the PhA group exhibited the lowest SBS value, which was statistically distinct from the other groups ($p < 0.05$). Using of Filtek supreme Ultra flowable composite in attachment bonding provides lower SBS than Filtek Z350 composite.

Clinical Significance

The current study may guide orthodontists to choose the appropriate composite material and conditioning technique to achieve a strong SBS between clear aligner composite attachments and lithium disilicate ceramic.

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