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# The Effect of Mechanical and Energetic Methods for Surface Treatments of Titanium Implant Abutments on The Tensile Bond Strength With (5) Yttria Zirconia Crowns

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## Abstract

**Objective**: The purpose of this study was to evaluate the effect of mechanical and energetic surface treatments of a titanium-abutment (Dentium/ Korea) on the tensile bond strength of a (5) Y Zirconia coping. **Methods**: forty implant analogs and standard titanium abutments of (5.5mm) in height and (4.5 mm) in diameter were embedded vertically in auto-polymerizing acrylic resin blocks. Zirconia crowns with a special design were fabricated using a CAD/CAM system. Samples were divided according to their surface treatment of titanium abutment into four groups (n 10 for each group); Group (1) acted as control (without any surface treatment for abutment). Group (2) bur surface treatment for an abutment. Group (3) cold atmospheric plasma surface treatment for abutment. Group (4) combine surface treatment with bur and cold atmospheric plasma. Forty crowns of (5)Y Zirconia were fabricated by CAD/CAM system, cemented with treated abutment by Allcem resin cement . After the (5000) cycles of the thermocycling process, crown retention was measured by a universal testing machine. After that each deboned surface was examined stereo-microscopically at a 20x magnification. The experimental results were statistically evaluated with a one-way analysis of variance, Duncan tests the honest significant difference. **Results:** Significant differences were found between groups based on the type of surface treatment (p<0.01). **Conclusion:** implant abutment treatment by combining bur and cold atmospheric plasma was the highest group of tensile bond strength followed by bur-only surface treatment. The lowest tensile bond strength was in control group.

## Introduction:

In contemporary prosthodontics, dental implants are now the standard treatment for lost teeth (1). Since nearby teeth do not need to be prepped, dental implants have a significant benefit over traditional tooth-supported fixed partial dentures in terms of preservation of tooth tissue. Due to issues with adaptation and/or reduced oral comfort, patients typically dislike wearing detachable dentures (2). Parts called implant abutments are tight to implant fixtures by a screw to support and/or hold a prosthesis. Because titanium is the most widely used material for abutments, it is preferred for implant abutments due to its exceptional mechanical strength and biocompatibility (3).

The retrievability of the prosthesis influences the choice of retention method for implant-supported fixed prostheses, such as cement or screw retention, The benefit of screw retention is that it can be retrieved, but the screw access hole's visibility and the difficulty in creating perfect occlusal contacts—which arise from the hole taking up at least 50% of the occlusal table—are its drawbacks, though (4). Conversely, prostheses held in cement exhibit better occlusion, aesthetics, passivity, and loading characteristics, but retrieval might be challenging (5).

Titanium has found widespread application as a material for dental implants., because of its exceptional mechanical qualities, biocompatibility, and ability to withstand corrosion through the development of a stable oxide layer. During surface treatment, titanium dioxide ($TiO_2$), a continuous, nonporous, adhesive oxide film layer that is corrosion-resistant and protective, forms on the titanium surface (5).

The purpose of titanium surface treatments is to create an adhesive layer that facilitates bonding and to remove the weak layers of bare titanium that hurt bond strength (6), to improve surface adhesion behavior a variety of surface treatments methods are used:

1) The common mechanical surface modification methods include: machining, bur grinding, polishing and sandblasting. The objective of mechanical surface treatment is to obtain specific surface topographies and roughness, remove surface contamination and/or improve adhesion in subsequent bonding steps (7).
2) Energetic treatment that concentrate primarily on surface free energy (such as plasma, flame, and UV/ozone); the primary goals of energetic treatments are to eliminate organic impurities, initiate oxidation processes, and improve the polarity and wettability of material surfaces (8).

In addition to the three states of matter, solid, liquid, and gaseous, plasma is a metastable state of matter made up of a gaseous mixture of highly energetic protons, electrons, reactive oxygen species, and highly energetic ultraviolet photons at various densities and temperatures. In contrast to regular matter, plasmas may exist throughout a large temperature range without changing their physical characteristics. William Crookes, a British scientist, discovered plasma in 1879; Irving Langmuir gave it its name in 1929 (9).

The application of plasma in dentistry can be sub-divided into two approaches: A) Treatment of surfaces, materials or instruments to increase specific properties for subsequent special applications including disinfection, sterilization, and increased adhesion with other materials or cells, this approach can be made in the form of chairside applications. B) Direct Applications on lesions for therapeutic purposes (10).

In dentistry, all-ceramic crowns and bridges are becoming more popular due to growing patient aesthetic expectations and advancements in CAD/CAM technology (11)(12).

Zirconia restorations for prosthodontics have the finest mechanical qualities of any ceramic restoration (13). However, their application is troublesome due to their extreme hardness and challenges with proper conditioning for cementation (14)(15).

Various elements such as yttrium(Y), cerium(Ce), calcium(Ca), magnesium(Mg) and others are added and dissolved in zirconia to stabilize it at room temperature and reduce low temperature degradation (LTD) , The addition of Yttria to zirconia stabilizes the tetragonal phase of zirconia Following LTD, yttria is consumed through reaction of phase transformation (16).

To improve the translucency of zirconia, 5 mol.% yttria-partially stabilized zirconia (5Y-PSZ) or ultra-translucent zirconia (denoted as 5YZ in this study) has been recently prepared (17)(18)(19), so increasing the concentrations of yttria increases the amount of the optically isotropic cubic phase (20).

Resin cement is type of cements have been utilized extensively for luting ceramic restorations due to their appropriate mechanical qualities (21), low solubility (22), biocompatibility (23)(24), and strong adherence to the tooth structure (25). Resin cements can often be cured using one of three methods: chemical, light, or a mix of both (26). To achieve excellent mechanical qualities and a high degree of conversion in either the presence or absence of light, dual-cured cements were produced (27).

Clinical situations reduced inter-arch space leads to a lack of retention problem in cemented prostheses. Because implant-supported cement-retained restorations can improve esthetics, optimize occlusal inter digitation, and offer a passive fit, their use has grown. In these kinds of clinical scenarios, using a cement-retained prosthesis instead of a screw-retained one becomes required. The use of airborne particle abrasion, bur modifications and plasma surface treatment is recommended to improve retention (28).

The purpose of this study to evaluate the effect of different surface treatment for titanium implant abutment on tensile bond strength with (5)Y Zirconia crown, so the null hypothesis was no effect of mechanical and energetic methods of surface treatment of titanium implant abutments on tensile bond strength with (5) Y Zirconia crown.

# Materials and Methods

***Samples Preparation:***

A total of forty prefabricated titanium abutments (hex type abutments) from Dentium System, Korea, measuring (5.5mm) in height, (4.5mm) in diameter, (1.5 mm) in gingival height, and (8º) tapering per side were utilized in the study. Each titanium abutment was fixed to its fixture or laboratory analog using a screw. forty laboratory analogs, measuring (12 mm) in height and (4.5 mm) in diameter, were then prepared for use in this investigation.

Using a torque-controlled ratchet (29), each titanium abutment was screwed into its corresponding laboratory analog and torqued to (35 N/cm) before being inserted into an acrylic mold as shown in Fig. (2). Diagram of study in Fig. (1).

***Zirconia crowns fabrication:***

In this study we used (5) Yttria tetragonal zirconia polycrystalline high transparent (5Y-TZP/VITA YZ® HT, shade white, VITA Zahnfabrik, Germany) was the type of zirconia utilized in this investigation. Forty crowns were needed, and they were made using a CAD/CAM system in the manner described in (30)

**Surface treatment of sample:**

forty specimens (which include the Dentium titanium abutments adapted to the analogs in the acrylic mold) were randomly divided into four main groups according to the type of surface treatment:

***Group 1**: (Consists of ten samples) acts as the control group which is no surface treatment of titanium implant abutment

***Group 2:** (Consists of ten samples), which is the titanium abutments treated with an Abrasive tapered bur (Technology 780.8C) by use modified dental surveyor as shown in Fig. (3).

***Group 3**: (Consists of ten samples) which is the titanium abutments treated by plasma with CORE plasma activator as Fig. (4).

***Group 4**: (Consists of ten samples), which is the titanium abutments treated by combining Bur and Plasma surface treatment

**Cementation and thermocycling:**

Specimens Cementing using Allcem Cimento Dual, FGM Shade A2 Dual-Cure Resin Cement. An examiner loaded each crown with the luting agent, which was then spread over the whole inside surface of the crown by the explorer. The crown was then manually installed over the chosen abutment. A unique device known as the AS-Standardized Cementation Load was created to achieve a uniform seating pressure across the crown throughout the cementation process and to get rid of any errors that might arise from applying varied seating pressures over the crown.

The bonding material was then cured for approximately one minute using a light curing machine (Eighteeth, China) with an intensity of (1180 mW/cm$^2$) and a wavelength of 450 nm. The German-made Mevhatronic thermocycler, model number-100 SD, was utilized for this experiment. The samples were subjected to (5000) cycles of thermocycling in deionized water with transfer times of 10 seconds and dwell times of (30 seconds), within the temperature range of (5 to 55) degrees Celsius.

***Tensile bond strength measurement*:**

A crosshead speed of (0.5 cm/min) was applied to each crown (29) . The record was moved to the computer and preserved by the Universal Testing Machine as shown in Fig. (5) when the force at which the bond failure between the crown and the abutment appeared on the meter, which was already attached to the tensile machine.

***Mode of failure*:** The mode of failure was identified by stereo-microscopically examining each deboned surface at a 20x magnification after the tensile bond strength was tested. The failure mode was categorized as follows:

1. Adhesive failure at: A) the adhesive-abutment interaction and B) the Zirconia crown and adhesive interface.
2. Cohesive failure: An adhesive (resin cement) breakdown.
3. A mixture of cohesive and adhesive failures is known as mixed failure.

## Results

***Evaluation of the Tensile Bond Strength between the Crown and Implant Abutments*:**

Upon completion of the experimental technique. The forces needed to separate the titanium abutments from the crown copings were measured in Newton in each group and a descriptive analysis was performed on these data, The results are shown in Table. 2, one-way ANOVA test in Table. 3 and Duncan test in Table. 4, the analysis showed a statistically significant difference in retention among the four groups. Additionally, when comparing Group (4) with Group (2) compared to the other groups, more force was needed to remove the zirconia crown from implant abutments after cementation. (Table. 1) Describe statistical analysis of four groups, bur and plasma treatment of abutment had the highest mean (629) followed by bur treatment of abutment (438) and plasma treatment of abutment (150).(Table. 2) Describe one-way ANOVA test results which indicated that there is a significant difference between the groups at ($p$-value $\leq$ 0.01). This mean that one or all of groups are different from each other. (Table. 3) Describe the Duncan test which indicates all the groups different from each other.

***Evaluation Mode of failure***

It was observed that the cement failed adhesively (no cement residue on implant-abutment surface) in group (1) and group (4), but cement failed cohesively (cement residue on implant-abutment surface) in group (2) and group (4) as shown in table 4.

## Discussion

In the clinical situation, when dentists are enforced to use short or narrow implant abutment due to short interarch space, presence of malocclusion, presence of opposing hypererupted teeth or due to esthetic condition, it is clear that they need to increase the retention of the final prosthesis by either surface modification of the titanium abutments or the internal surface of the casting (prosthesis).

The current study's findings record group 4 (which is combine plasma and bur surface treatment for titanium abutment ) had the highest value of tensile strength with zirconia crown because combination of mechanical and energetic methods used for surface treatment of abutment, followed by group 2 (which is bur surface treatment only for titanium abutment) and group 3 (which is plasma surface treatment for titanium implant abutment) had higher tensile strength than group 1 (which is control that without surface treatment for abutment). There were statistical differences between control and other groups that lead to refuse the null hypothesis, which holds that various methods of titanium surface treatments have no effect on the tensile bond strength with (5)Y zirconia crown.

Low tensile bond strength between titanium and zirconia is the outcome of titanium without surface treatment, according to Smielak *et al*.,(2015) research. This outcome is in line with the current investigation, which found that the control group 1 (which did not apply any surface treatment to titanium) had the lowest bond strengths and tended to produce specimens with adhesive failure patterns between the resin cement and titanium abutment (31). The fracture pattern analysis indicates that the bonding architecture is most vulnerable in the vicinity of the titanium surface. After that, the authors focused on how to modify titanium surfaces to make the bond stronger (32).

Our study observed that group 2 (which is bur surface treatment of abutment) had a higher value of tensile bond strength among other groups and less than group 4 (which combines bur and plasma surface treatment for abutment), these results agree with research of Sethi et al. (2020) which concluded that there was enhancement in retention of cemented-retained prosthesis to implant abutment by using diamond bur treatment on abutment (33).

Another study done by Shrivastav (2018) used diamond bur to treat surface of short abutments and found an increase in the retention of cement-retained prosthesis this is in line with our study results, because bur cause roughening the surface of titanium, which increases its wettability and surface area, it also allows for mechanical interlocking with resin cements, improve the Titanium-resin cement bonding (28). Ganbarzadeh, et al. (2012) found that retention of metal copings on titanium abutments increases with a diamond bur (34). In a study by Badawi, et al. (2015) the surface treatment of implant abutment by circumferential grooves with diamond bur was found an effective method of enhancing the retention of crowns cemented with non-eugenol temporary cement (35). This was similar to the finding of Sahu, et al.(2014) (36). Cements failed cohesively means cement failed within itself, and residual cement on both the abutment and the internal surface of crowns (29) .

In group 3 (which is plasma treatment for titanium abutment only) tensile bond strength was more than group 1 (control group) but less than other groups. The Plasma surface treatment process leads to the formation of strong chemical bonds, enhances wettability, and will produces sites of chemically active the adhesion to other molecules. these results agree with Seker, et al. (2015) revealed that, when compared to a control group, atmospheric plating treatment given to a titanium surface, bond strength increased without any structural change in titanium surface compared to bur and sandblast that changes in the morphology of Ti surface, and the roughness value same as that of the control group (37). Also our result agree with Ozyetim et al. (2023) who that found atmospheric plasma treatment significantly increased the retention value between the abutment and the crown compared to the control group ($P < .05$) (38).

The ability of Cold Atmospheric Plasma (CAP) to modify the titanium surfaces' physico-chemical characteristics without compromising their microstructure, its efficacy to reduce the in vitro water contact angle (WCA) of treated titanium surfaces and resulting in an improvement of hydrophilic surface features (39).

El-Helbawy et al. (2016) found in their study the formation of ($TiO_2$) layer after Oxygen plasma treatment for titanium abutment, this ($TiO_2$) layer increases the roughness of the

titanium surface but with more time of plasma exposure this oxidation process becomes stable and effect of plasma to smooth surface (40). Foest, et al. (2005) indicated that exposure to plasma will alter the surface energy and the chemistry because the high concentration of reactive species ($O_2$) generated on the treated surface that responsible for the chemical bond with the resin cement, so the adhesive type mode of failure occur in this group because resin cement adheres to the zirconia copings (41).
Group 4 (which is combine bur and plasma surface treatment for titanium abutments) had the best tensile bond strength due to the utilization of both mechanical and energetic surface treatments (plasma and bur) on titanium abutments. These two techniques strengthen the link between the abutment and resin cement, resulting in a cohesive failure mode.

## Conclusion

Within the limitations of this in vitro study, the following conclusions were made:

- Different methods for surface treatment of Ti-abutment had positive effect on the tensile bond strength in compare to smooth surface without treatment.
- Using of bur for treatment of Ti-abutment increased bond strength by causing rough surface and improve wettability and adhesion with resin cement and zirconia crown.
- Plasma treated method is effective and non-invasive technique for increasing tensile bond strength between Ti-abutment and zirconia crown.

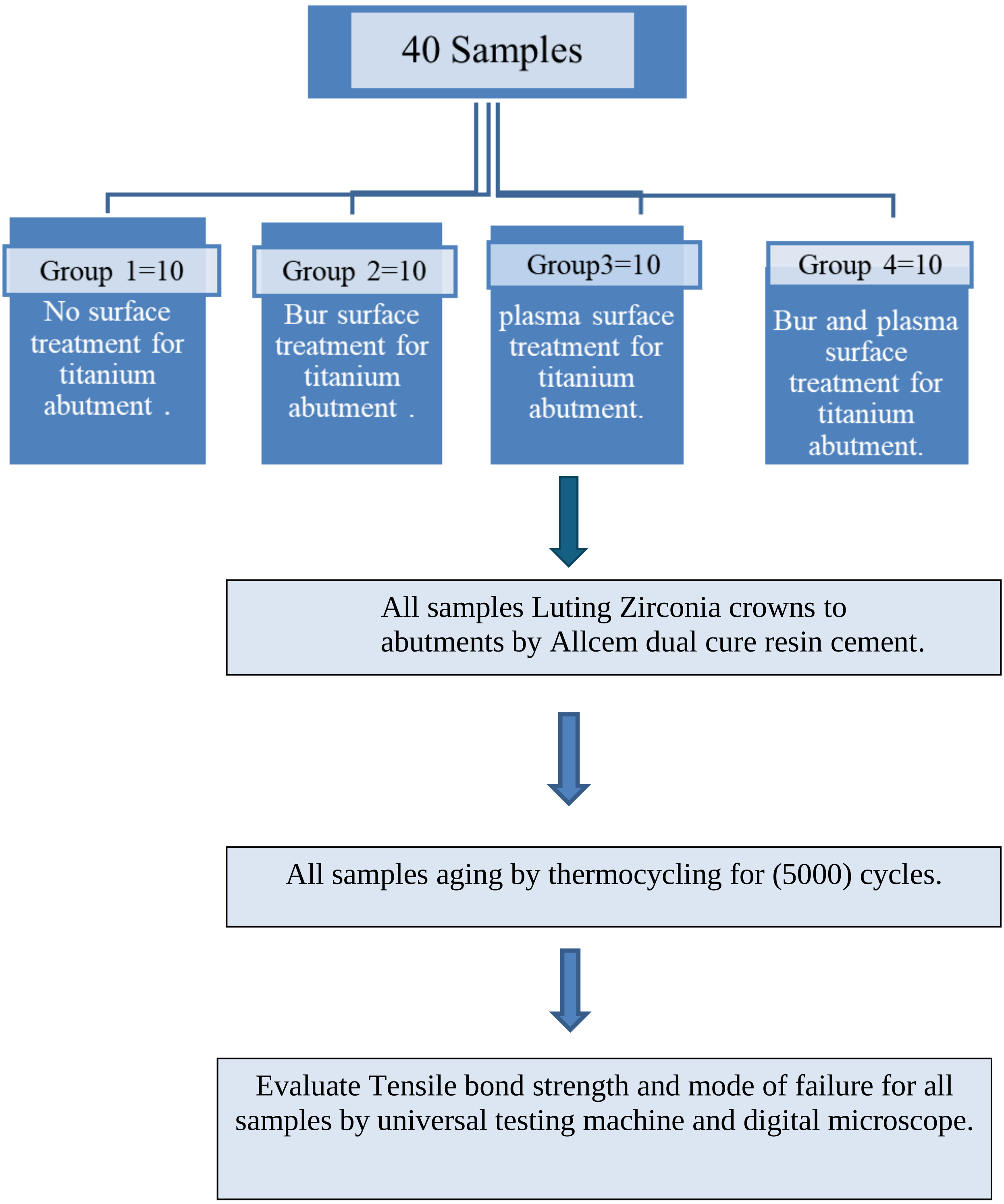


**Fig. (1): Diagram of study.**

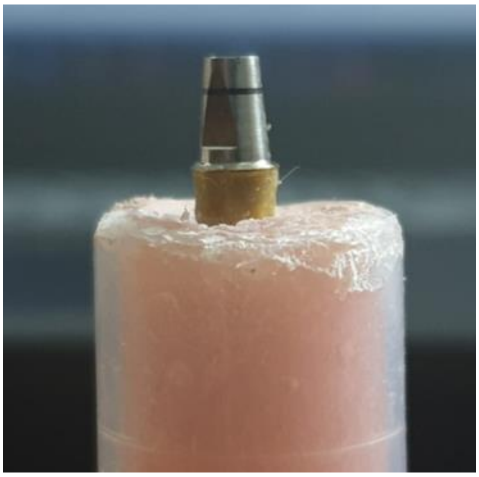

**Fig. (2): Implant analog with abutment seated in an acrylic resin mold**

**Fig. (3): abutment surface treatment with bur**

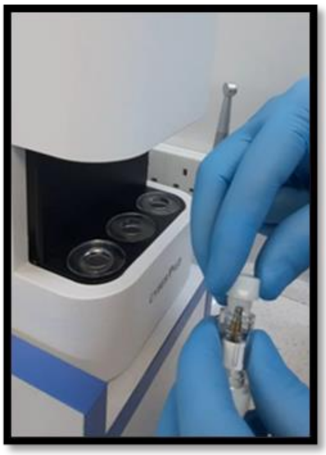

**Fig. (4): Titanium abutments treated by plasma with CORE plasma activator.**

**Fig. (5): Sample in Universal testing machine.**

**Table.1: Statistical analysis for all groups**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| control | 10 | 50.00 | 81.00 | 64.1000 | 9.84829 |
| bur | 10 | 410.00 | 475.00 | 438.5000 | 18.86355 |
| plasma | 10 | 127.00 | 150.00 | 143.2000 | 6.49444 |
| bur+plasma | 10 | 600.00 | 660.00 | 629.0000 | 19.69207 |

**Table. 2: One- way anova.**

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2062595.400 | 3 | 687531.800 | 3115.311 | .000 |
| Within Groups | 7945.000 | 36 | 220.694 | | |
| Total | 2070540.400 | 39 | | | |

**Table 3: Duncan test**

| codes | N | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| group1 | 10 | 64.1000 | | | |
| group3 | 10 | | 143.2000 | | |
| group2 | 10 | | | 438.5000 | |
| group4 | 10 | | | | 629.0000 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 |

**Table 4: Mode of failure.**

| Group | Adhesive | Cohesive | Mixed | Total |
|---|---|---|---|---|
| Group 1 | 10 | 0 | 0 | 0 |
| Group 2 | 0 | 10 | 0 | 0 |
| Group 3 | 10 | 0 | 0 | 0 |
| Group 4 | 9 | 0 | 1 | 0 |

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