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Influence of sintering technique on fracture load of monolithic zirconia with different thicknesses

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ABSTRACT

Aim This work aims to investigate and measure different fracture loads produced by two different sintering procedures (high-speed and traditional sintering) on different thicknesses of zirconia crowns.

Materials and methods Zirconia blanks (Vita/zahnfabrik diameter 98mm x 12 mm height, Germany) were used to fabricate 48 molar crowns (N = 48, divided into 2 groups of 24) which were constructed in three different occlusal thicknesses (1.5, 2.0, 2.5 mm) using two methods: conventional sintering (1,450°C) and high-speed sintering (1,550°C). Crowns were bonded to CoCr die. Fracture load was tested after all crowns were underwent 5,000 timesthermocycling test (between 5°C and 55°C).

Result ANOVA analysis has been used to compare the fracture load of different groups, and results showed that high-speed sintering required significantly more force and load than conventional sintering (p-values 0.001).

Conclusion Time and money-saving technology showedencouraging results that with zirconia crowns resulted in high-speed sintering and greater fracture loading values than the control group (conventional technique); also, fracture load increased with increase of thickness of zirconia crown. Therefore, it is recommended to increase occlusal thickness with high-speed sintering to obtain better resistance to chewing force.

KEYWORDS Zirconia; Layer thickness; Fracture load; High-speed sintering.

INTRODUCTION

As a result of the ever-increasing esthetic demands, all ceramic restorations are becoming increasingly popular in dentistry. Glass ceramics, such as zirconium, have excellent esthetic results in fixed restorations. In areas highly exposed to mastication, the preferred material is zirconium (zirconium dioxide, ZrO2) (1,2).

Zirconia restorations are now often made with CAD/CAM technology. Pre-sintered blocks are milled into soft zirconia structures, resulting in white-stage specimens that require final sintering. Since the grain size is determined by the sintering conditions, they have a significant effect on the final product's stabilization and mechanical properties, with a higher firing temperature, the grain size becomes bigger (4,5). However, this link is only available up to 1600°C sintering temperatures, after which flexural capacity begins to degrade. In addition to influencing the mechanical properties of zirconia, sintering parameters have been demonstrated to influence optical properties such as translucency (6,7).

The speed sintering process has recently emerged as an effective alternative to the conventional sintering process, which takes 4-12 hours to finalize and require a high cost and emotional commitment. High-speed sintering uses a temperature of 1580°C, and requires 30 minutes, while speed sintering requires 30–120 minutes at 1510°C. According to the first research, high-speed sintering produces equal or even greater strength than conventional sintering, for the conventional sintering process (5,6); another critical consideration for evaluating the mechanical efficiency of a material is its external force opposition that can be measured by calculating fracture force. Zirconia has shown excellent performance in terms of fracture toughness and flexural resistance (3).

Of course, fracture load is heavily influenced by the thickness of a material's layer: to withstand masticatory stress, zirconium crowns usually need in the occlusal region, a minimal thickness that must be at least 1 mm-1.5 mm. Zirconium materials are a relatively new addition to the industry. New manufacturing methods, such as high-speed sintering, may provide useful information about these materials' potential applications (7).

The aim of this study was to investigate and measure fracture loads related to two different sintering procedures (high-speed sintering and traditional

sintering) on zirconia crowns of different thickness.
As the performance of a restoration is determined by three significant factors, i.e. fracture tolerance, aesthetic value, and marginal accuracy, several studies have examined the clinical performance of monolithic all-ceramic restorations and discovered that technological problems are uncommon. However, the reduction of axial wall thickness was not discussed in these studies. As a result, the impact of this aspect is still unclear (8).

MATERIALS AND METHODS

Zirconia crowns (diameter 98. x 12 mm height - Vita HT, Germany) in various occlusal thicknesses were sintered utilizing different sintering processes and evaluated after thermocycling testing machine (Fig. 1, Table 1).

Fabrication procedure of master metal die with base

Resin maxillary left first molars (Nissin Dental Products, Kyoto Japan), were prepared with deep chamfer finishing line of 0.8 mm, and 2 mm reduction occlusally with axial reduction of 1.5 mm was used for the construction of a master metal die (Fig. 1).
So, then a metal die was fabricated by using a CAD/CAM machine to simulate a tooth prepared to receive the two types of zirconia crowns.

Crown fabrication

CAD/CAM software (Exocad, Germany) was used to create molar crowns with different occlusal thicknesses (1.5, 2.0, 2.5 mm; in total N = 48, n = 24 per group; n = 8 per subgroup) (Fig. 1). A coated diamond disk (144080; Komet, Germany) was used to cut the connectors, and a diamond bur for smoothing (918PB; Komet, Germany).

FIG. 1 Metal die.

Specimens were sintered by two different methods: high-speed sintering at 1550°C (study Group) and conventional sintering at 1450°C (control Group).
Exocad software was used to design the crown, the same design was used for both groups of CAD/CAM zirconia crowns (Fig. 2).
Zirconia blanks (Vita Zirconia HT, Germany) were inserted into a 5-axis milling machine (Exocad, Germany). The crowns were milled with a 20% enlargement as specified by the manufacturer to compensate for the sintering shrinkage.

Sintering process

After the milling process, the crowns were inserted in a high temperature sintering furnace (their color was chalky-white). So they needed dense sintering process, which was done in a sintering furnace (Imes-Icore GmbH, Germany). The crowns were placed on the firing stand directly in such a way that the inner surface of the crowns faced downward. The sintering was programmed according to the instructions of Imes-Icore sintering

Temp.	Holding time	Pre –heating	Cooling off	Time
1450°C	120 min	17°C\min	100%-200%	9 hours, 50 minutes
1550°C	25 min	17°C\min	100%-200%	2 hours, 55 minutes

TABLE 1 Programs of high speed and conventional sintering group.

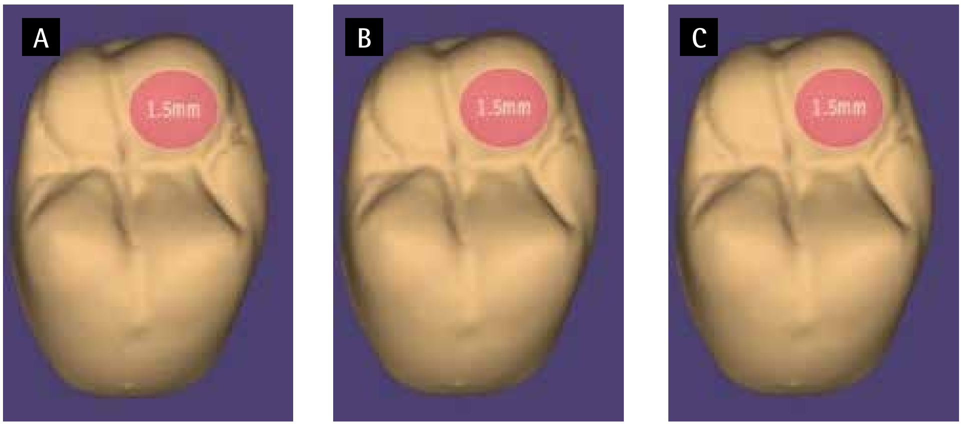

FIG. 2 Different thickness of crowns.
A: 1.5 mm occlusal thickness.
B: 2.0 mm occlusal thickness.
C: 2.5 mm occlusal thickness.

program as follows.

- Conventional cycle (Control Group, C): Crowns were located over the sintering beads in the sintering tray which was loaded into the furnace at room temperature, then the temperature was gradually increased till reaching the sintering temperature (1450°C) which was held for 120 minutes, after that the crowns were cooled down to room temperature. The total cycle time was 9 hours and 50 minutes.
- High Speed cycle (Study Group, H): Crowns were sintered at 1550°C sintering temperature that was held for 25 minutes. The total cycle time was 2 hours and 55 minute's (Table 1, Fig. 3).

Cementation

Following sintering, the two groups of zirconia molar crowns were bonded to standardized abutments (metal dies) using Selfcem adhesive resin cement (Medicept Selfcem 3M ESPE, USA) with a 360-chamfer preparation of 1 mm cast from a CoCr alloy finishing line (Fig. 4). Then, using the specimen-holding mechanism, a static stress of 5 Kg was exerted for 6 minutes according to the manufacturer's recommendations to force the standard to paste all specimens uniformly. Before final polymerization, excess material was scraped with a fine microbrush (Fig. 5). The crowns were then kept in distilled water at 37°C for 24 hours in an incubator (Thermo Scientific Heratherm 150, USA) and then tested 24 hours after cementation (Fig. 6).

Thermocycling test

All crowns were mechanically loaded and cycled 5,000 times between two water baths, 5°C and 55°C

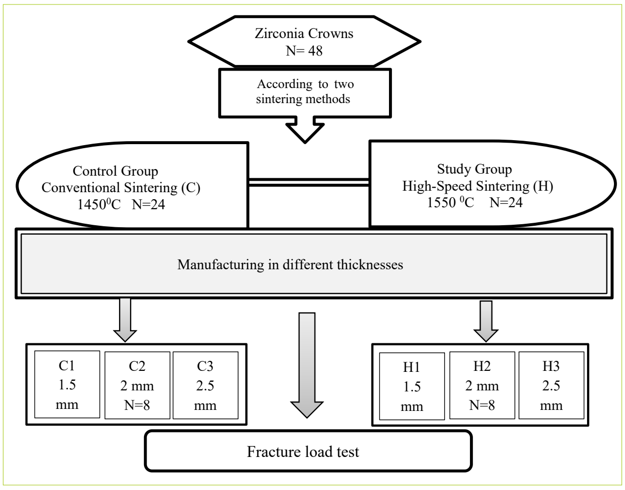

FIG. 3 Study design grouping samples.

FIG. 4 All crown fixed on the die with cement.

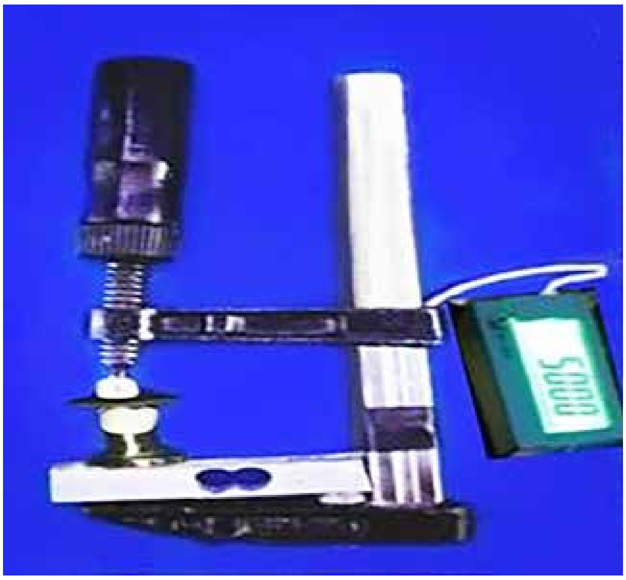

FIG. 5 The device holding the samples.

FIG. 6 Samples in the incubator at 37°C.

(Thermocycling system, Karl Kolb, Germany). Each loop took 60 seconds in each bath and 10 seconds to switch between baths (Fig. 7).

Fracture load test

the universal testing machine (Instron 1195, Germany) was used to measure the fracture load of specimens treated with thermocycling. A 6 mm diameter testing stamp (chrome-nickel steel; Deutsche, Witten, Germany) was utilized with a 1 mm/min cross head speed (Fig. 8). To prevent force peaks, each crown had the stamp placed on the occlusal surface and a 0.1 mm tin foil (Dentaurum, Germany) was placed between the stamp and the crown.

Statistical analysis

Following that, the findings were statistically evaluated using SPSS TM tools (Version 23, IBM, USA). The mean and standard deviation (SD) values were used to present the data. Student's t-test, One-way ANOVA, analysis was used to compare the fracture resistances of different groups. The test was used to compare the groups several times. There were a lot of substantial variations between the groups that were studied. Both p values less than 0.001 were considered statistically significant. The findings are more important when the p value is small.

RESULTS

From the descriptive analyses (Table 2) it resulted that the highest mean value of fracture load was 6197.375, recorded in H3 subgroup (high speed sintering with 2.5 mm thickness), while the lowest was 4517.875, recorded in C1 subgroup (conventional sintering with 1.5 mm thickness), as shown in the bar chart (Fig. 9).
One-way ANOVA test was used to determine if the difference in the mean value for all groups was statistically significant (Table 3). It was shown that the differences between the two sintering techniques in fracture load of zirconia crowns (Vita) with three

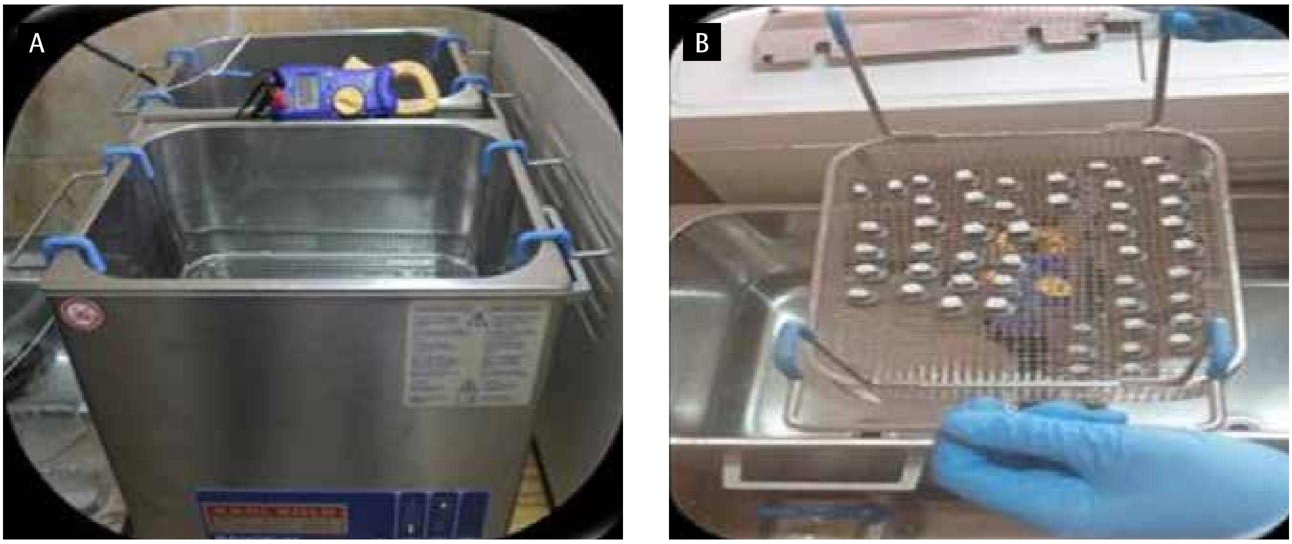

FIG. 7 A: Thermocycling machine. B:Water dipping and transfer of samples from 5 °C to 55°C for 5000 cycles.

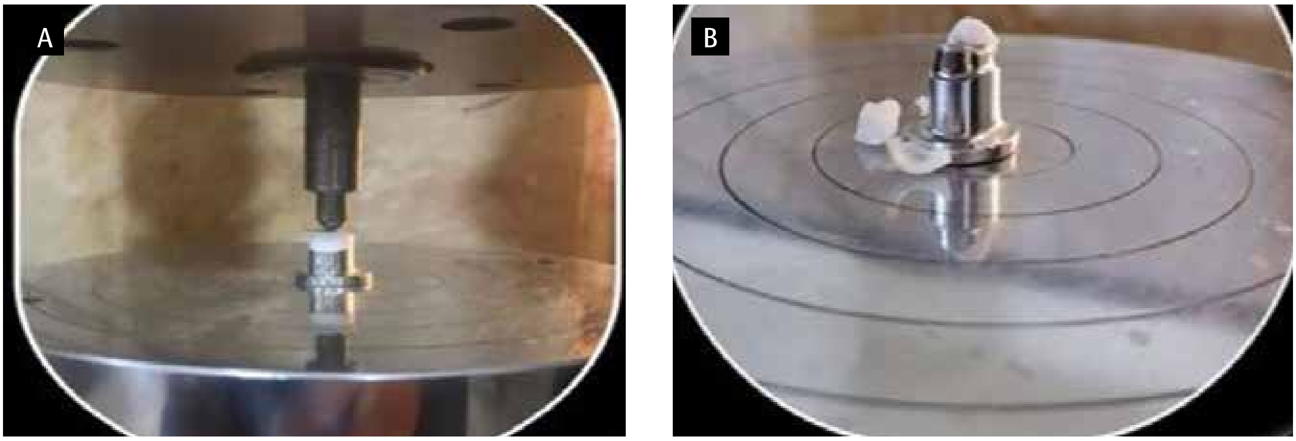

FIG. 8 The tested specimens' CAD/CAM design in universal testing machine. A: During testing B: After testing.

Groups	No.	Mean	Median	Std Dev.	Min. Value	Max Value
C1	8	4517.875	4450	210.339479	4289	4869
C2	8	5161.125	5096	244.3483681	4854	5662
C3	8	5740.25	5687	248.2422492	5342	6149
H1	8	5173.75	5198	207.6822779	4843	5502
H2	8	5752.125	5613.5	305.0018443	5393	6360
H3	8	6197.375	6160	227.8777476	5973	6686

TABLE 2 Descriptive statistics of the different groups measured in N.

different thickness were highly statistically significant (p values < 0.001).

DISCUSSION

Zirconia is widely used in dentistry because it has metal-like strength and a pleasing aesthetic appearance. When compared to other ceramic restorations, zirconia coping allows for a smaller margin like metal. Restorations' color is also more compatible than porcelain fused to metals. Biocompatibility is excellent as well. As a result, there have been numerous studies on zirconia-ceramic restoration Compared to metal coping that is cast, zirconia coping made with CAD/CAM technology has better marginal fit and has fewer mistakes.

Zirconia crowns can be constructed to look like natural teeth, and the laboratory process can be simplified, reducing laboratory error. In comparison to existing ceramic restorations, complete zirconia crowns require less tooth reduction (14).

With the introduction of new materials and procedures, monolithic all-ceramic restorations with lower thicknesses are now possible; it is critical to determine the minimum restoration thickness that ensures a successful restoration (9). Therefore the goal of this investigation was to see how long full-anatomical zirconia (VITA) crowns made with two sintering techniques could withstand fracture load at varying occlusal thicknesses (1.5, 2.0, and 2.5 mm).

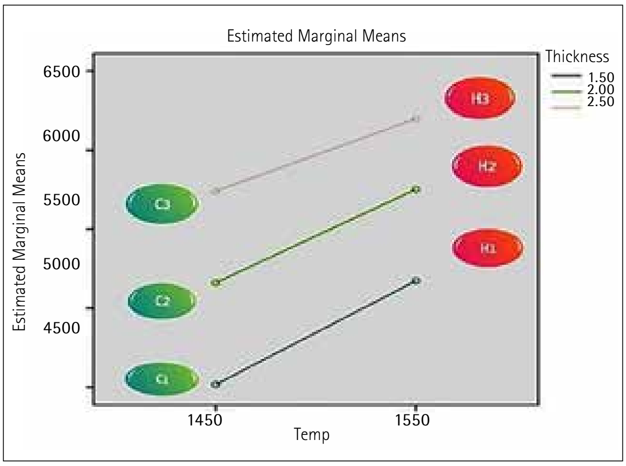

FIG. 9 Mean values of groups measured in N.

The ability of a material to resist fracture load is an essential factor of its mechanical properties. In examining the impact of changing sintering techniques on mechanical properties of zirconia crown, the majority of the researchers focused on flexural strength. For this reason, this study had to evaluate and compare the effect of two sintering processes (high speed sintering and conventional sintering) on fracture load of different thicknesses of zirconia crowns.

Additionally, zirconia crowns were cemented with adhesive resin cements owing to studies that reported higher fracture load in ceramic restorations. All ceramic crowns displayed a greater fracture load when the

Group	ANOVA	Sum of squares	d.f.	Mean Square	p-value	Sig.
Conventional sintering group	Between Groups	5982285	2	2991142.6	0.000	(HS)
	Within Groups	1159011	21	55191.012		
	Total	7141297	23			
High Speed Sintering group	Between Groups	4214862	2	2107431.1	0.000	(HS)
	Within Groups	1316604	21	62695.44		
	Total	5531467	23			

TABLE 3 ANOVA test of all groups.

occlusal thickness was 2.5 mm in high-speed sintering, while a lower fracture load was reported in the control group with an occlusal thickness of 1.5 mm.

In this research, the use of different sintering techniques statistically significantly affected fracture load. These results lead to the conclusion that different sintering protocols would affect fracture load resistance of zirconia crowns submitted to thermocycling depending on occlusal thickness.

Effect of crown occlusal thickness on fracture load

With the demand for more conservative restorations, monolithic all-ceramic restorations with reduced thicknesses became possible with the advent of new materials and techniques; it was essential to determine the minimal restoration's thickness that ensures a successful restoration (9).

In the current study, monolithic crown wall thicknesses was 1.0 mm while the occlusal thickness was 1.5, 2.0, and 2.5 mm in both groups.

In all groups, full-contour zirconia crown restorations without porcelain overlay were used to give crowns with sufficient mechanical strength to withstand fracture load while preserving excellent esthetics and biocompatibility. As a result, changes in mechanical behavior and fracture incidence should be expected.

Monolithic zirconia crowns are machined straight to the entire anatomical crown without the requirement for porcelain veneering, eliminating the necessity for a second fire cycle. These findings might be attributed to the anatomical blanks of zirconia material specific composition compared to that of zirconia as core materials (10). Thus, all ceramic restorations have been associated with some technical problems, including ceramic chipping, veneering ceramic fracture, framework fracture, loss of retention, and marginal discolorations. Veneering porcelain chipping has been found to be a regular occurrence, and the research indicates that it occurs more frequently with zirconia-based crowns than with other all-ceramic crowns.(11). Monolithic crowns are, thus, well-suited for clinical use in areas of high stress (12).

In our study, fracture load values exceeding 4500 N are considered acceptable because they are higher than the chewing force of physiological occlusion; crowns with a thickness of 1.5 mm can be recommended to allow acceptable strength and, if increased to 2.5 mm, to allow more aesthetics, and resistance to bear the fracture. This result corresponds with those of Abdulmajeed et al. (13), who demonstrated that increasing thickness significantly increases the fracture load resistance of zirconia. Also, our findings are consistent with those of Jang et al. (14), who concluded that fracture strength of zirconia crown increased with increased thickness.

While the metal alloy abutments may erroneously enhance fracture load estimates, more research is needed to validate these preliminary findings.

Effect of the different sintering process on fracture load resistance

In our work, when comparing high-speed sintering and conventional sintering of zirconia crowns with the same thicknesses, high speed sintering of monolithic zirconia crowns showed the highest fracture load. This could be due to differences in the sintering process between the two groups of zirconium crowns; in conventional sintering temperature is 1450°C and the holding time is 120 minutes, while the sintering temperature of high speed sintering zirconia is 1550°C and the holding time is 25 min.

Our study agrees with Wiedenmannet et al. (7) who investigated the effect of high-speed sintering and layer thickness on fracture load, which showed that increasing layer thickness in high sintering groups lead to increase of fracture load.

The variations in sintering process of zirconia can directly affect microstructure and properties of zirconia, this may be related to crystal structure maturation, elimination of defects on grain boundaries, and grain size expansion. This is accomplished by either increasing the sintering temperature or reduce the holding time. The properties of monolithic zirconia are determined by the microstructure and crystalline phases of zirconia, which are affected by increasing sintering temperature. The sintering process eliminates inter-particle porosity in granular materials by facilitating atomic diffusion driven by capillary forces. When the sintering temperature is increased, the zirconia particles have a greater ability to bind together, which tends to minimize porosity on grain boundaries during solid-state diffusion and allows for increased material density which lead to increasing strength of zirconia (3). This is one of the main reasons why groups with higher sintering temperatures have higher flexural strength than those with lower temperatures. The findings of this study are consistent with those of previous research (3, 5, 16).

The results of another study by Juntavee and Attashu (15) indicated that modifying the sintering parameter of monolithic zirconia has a substantial effect on its strength. It shows the comparison in the sintering process quite clearly, resulting in the strengthening of zirconia, as well as the change in grain size. Lower sintering temperature, on the other hand, may decrease flexural strength, leading to a brittle restoration while higher sintering temperatures increase grain size, which improves mechanical characteristics and strength.

CONCLUSION

Time-saving and cost-effective technologies have shown encouraging results. With zirconia crowns high-speed sintering resulted in higher fracture load resistance than the conventional sintering.

The fracture load increased with the increase of thickness of zirconia crown.

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