Original Article

Effect of Posts Material on Stress Distribution at the Endodontic Treated Canine Tooth: A 3D Finite Element Analysis

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Abstract

Introduction: In case of severe destruction or total coronal loss of tooth structure the retention of the core is achieved by embedding a post into the root canal. There are different prefabricated posts for buildup of coronal tooth structure. There is no same opinion about which post is more effective for root canal treatment (RCT) tooth. The aim of this study is to determine the effect of post material on the stress distribution of RCT maxillary canine by finite element analysis (FEA). **Methods:** A canine tooth was mounted inside a resin. A 3D scan of the mounted tooth was prepared by cone-beam computed tomography (CBCT) method. The Mimics Medical and Solidworks software was applied to provide an appropriate 3D model of the canine tooth. Post core crown restorations with three different types of prefabricated post, glass fiber, zirconia, and titanium, were considered for the restoration. An oblique load of 100 N was applied on the cusp and then FEA was performed by ABAQUS software**. Results:** The results of FEA showed that in all models the maximum principal stress occurred at the crest area. The stress decreased in dentin and increased in the post and cement interface by increasing of post elastic modulus. **Conclusion:** In according to FEA results it could be deducted that the post stresses are increased, by increasing of post elastic modulus, as well as the post material has a small contribution to the stress of the cervical area.

Keywords: Canine, Finite elements analysis, Prefabricated post, Stress, CBCT.

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Introduction

All efforts and expenses of the root canal treatment (RCT) and rebuilding of the tooth with post-core and crown are to restore the tooth function for a long time. In the RCT teeth, the most important factor in determining the type of restoration is the extent of coronal destruction and the type of the tooth, a larger amount of residual crown provides more retention for restoration. Therefore, the restoration should be such a way that the tooth structure is preserved as possible during the preparation of the tooth. In cases where the tooth completely loses its coronal structure, the core retention is provided from the root canal space by cementing a post. Although, the main function of the post is to provide sufficient support for the core and the crown, the post also improves the distribution of stresses in the restored tooth by spreading functional forces over a larger area of the remaining root (1-3). However, restoration is one of the most important factors that affect the endodontic treatment. Restoration of endodontically treated teeth with extensive decay is usually done with post-core and crown by consideration its aesthetic effects and strength (4-6). Higher failure risk of RCT teeth than intact teeth show that, excess lost tooth tissue due to dentin or enamel decay, extensive restorations, occlusal problems, and intracanal preparation to obtain retention from the canal all contribute on the failure risk of RCT teeth (7,8). Dentists and dental materials manufacturers conclude that the difference between the elastic modulus of dental materials and the tooth is an important parameter in the transmission of functional forces. Therefore, which restorative material or technique is more suitable and effective for the RCT teeth, is also a matter that has not yet been precisely determined (9).

A review of previous studies is shown that the stiffness of posts is an effective parameter in determining the distribution of stresses at roots and interfaces. Rigid posts such as metal posts lead to concentrate stresses at the post-root interfaces due to the high difference in mechanical properties with the root but, they own good flexural resistance against deformation which leads to reducing stresses at the root compared to FRC posts. On the contrary, FRC posts have good compatibility with root tissue but have low flexural resistance; therefore, they decrease the stress at the interfaces and increase the stresses at the cervical region (10-13). There are various methods for investigating the effect of post material on the concentration of stresses in RCT teeth. One of these methods is finite element analysis (FEA). In the FEA method, the effect of forces can be simulated by using mathematical modeling and just one sample is enough (11). The use of the FEA method in dentistry is common and if the data imported into the computer be precise and correct, the error will be so small (14,15). As it is clear from previous studies, there is no consensus on which type of restoration is suitable for the treatment of RCT teeth. The effect of post type on the canine teeth has been studied by the FEA method on imprecise models, that is two dimensional or axisymmetric models. The aim of this study is to determine the effect of post-material on the stress distribution of the maxillary canine tooth. A 3D precise model was created and analyzed by the FEA method to achieve more reliable results.

Materials and Methods

Creating an accurate and 3D model of the tooth is difficult due to its irregular geometry. One of the reasons why the most previous FEA studies have been limited to 2D or axisymmetric 3D models might be this irregularity of tooth geometry and the complexity of modeling. In this study, the cone-beam computed tomography (CBCT) method was used to simulate a computer model of maxillary canine. In order to achieve the anatomical dimensions of the tooth, a canine tooth with normal anatomical shape and dimensions was selected and mounted at the center of a beaker. The mounting process was performed in such a way that the longitudinal axis of the tooth and the beaker were in the same direction. Then a 3D scan of the mounted tooth was prepared using the CBCT method. The CBCT model was exported into Mimics Medical 20.0 software to separate the dentin, enamel, and pulp in this software (Figure 1). In Mimics software, the tooth was separated from the mount material. Then, the model was exported from the Mimics software into the SolidWorks software (Solidworks ® premium 2019 ×64 Edition SP4.0) to prepare a suitable model for FEA, Solidworks software is a suitable tool for preparing suitable models for FEA and it is also capable of simulating every restoration on the tooth. The thickness of periodontal ligament (PDL) tissue varies with age and depth between 0.15 and 0.25mm, so in this study, an average thickness of 0.20 mm was considered for the PDL. (Figure 2).

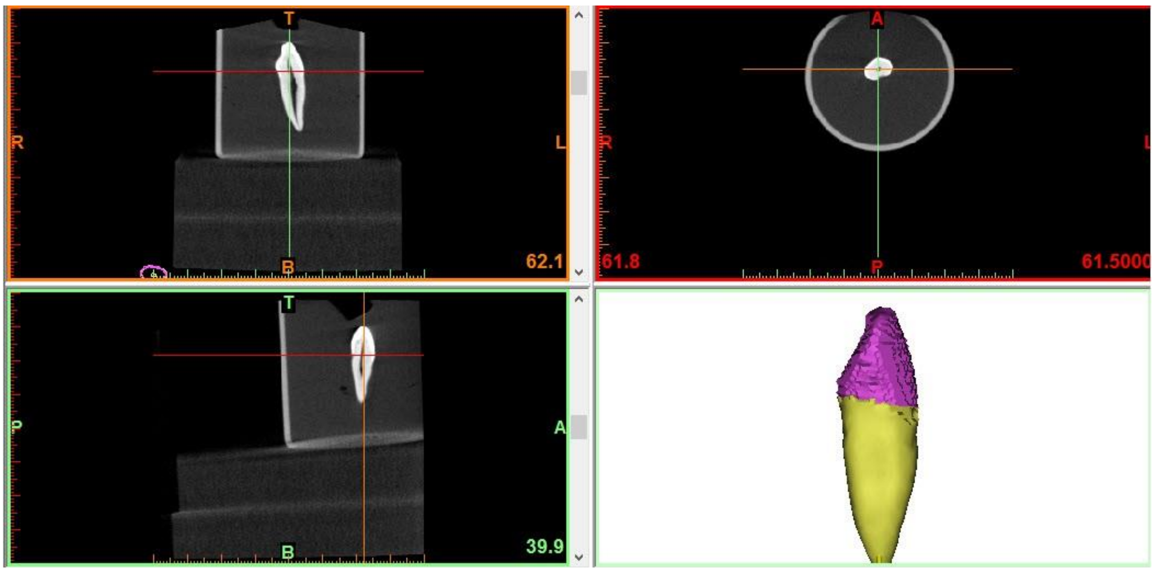

Figure 1. CBCT scan in the Mimics software

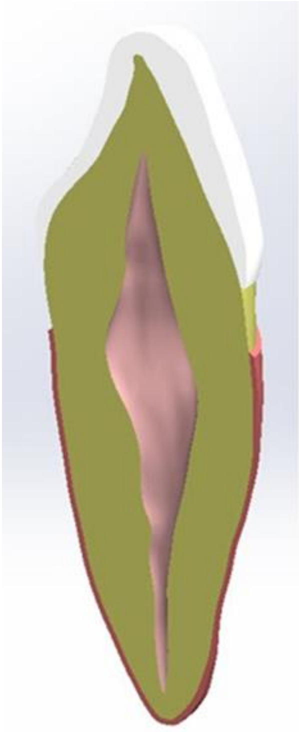

Figure 2. Bacco-lingual section of intact canine tooth modeled in Solid works software.

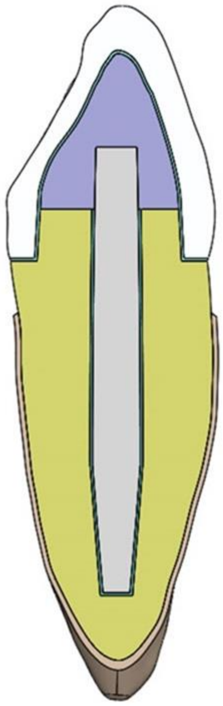

Figure 3. Bacco-lingual section of the post-core crown restoration and PDL tissue

Figure 4. meshed model of canine tooth

In order to achieve the aims of this study, four situations were considered for FEA:

1. Intact tooth as a control sample

2. Root canal treated canine tooth restored with glass fiber posts

3. Root canal treated canine tooth restored with zirconia post

4. Root canal treated canine tooth restored with the titanium post

In post-core crown restorations, a prefabricated tapered post with a maximum diameter of 1.85 mm was considered for it. The dimensions of the core and crown were simulated by consideration of 1 mm thickness in the cervical margins and 2 mm thickness at the cusp region for the crown. The outer surface of the artificial crown was considered according to the anatomical surface of the enamel. In the clinical condition, the outer surfaces of the core are made convergent, to facilitate the seating of the crown on the core. Therefore, the outer surface of core walls was sloped three degrees to the longitudinal axis of the tooth, a totally of six degrees to each other to close the modeling into clinical conditions. (Figure 3).

After the modeling is completed, the models were exported into the commercial software of FEA (Abaqus/CAE 6.13) to perform a finite element analysis for the prepared models. In FEA software all materials except FRC post were considered homogeneous and isotropic with linear elastic behavior according to Table I. The mechanical properties of FRC posts are transversally isotropic and their mechanical properties are different from longitudinal to transverse direction. The mechanical properties of glass fiber posts are also presented in Table II. The behavior of PDL was considered linearly in this study; linear behavior for PDL was considered to simplify the FEA. In fact, the elastic modulus of the PDL changes according to the load, i.e., its elastic modulus is low for low loads and increased by increasing the load. The constant elastic modulus of PDL which was considered in this study is a suitable approximation for functional loads that uses in many articles. In all models, LuxaCore was considered for core and cement as well as ceramic material for the crown.

Table I. Mechanical properties of materials used in the finite element analysis

Materials	E^* (GPa)	ν^*	Ref.
Enamel	84.1	0.33	13
Dentin	18.6	0.31	4, 9,13
Cement (Luxa core)	8.8	0.30	16
Core (Luxa core)	8.8	0.30	16
Titanium post	112	0.33	11
Zirconia Post	200	0.33	11, 17
Ligament	0.0689	0.45	9, 12, 18
Crown (Chinese)	69	0.28	17, 18

*E: modulus of elasticity, ν: Poisson ratio

Table II. Mechanical properties of glass fiber post (9)

E_1=E_2 (GPa)	E_3 (GPa)	ν_{21}	ν_{23}	ν_{31}	G_{21} (GPa)	G_{23} (GPa)	G_{31} (GPa)
11	40	0.32	0.07	0.26	4.2	4.2	4.2

E, elastic modulus; G, shear modulus; ν, Poisson ratio; 1 and 2, lateral directions of post; 3, longitudinal direction of post

A distributed load of 100 N at an angle of 45 ° to the longitudinal axis of the tooth was applied to a small area of the cusp to simulate functional loads (18). All contacts were considered completely banded. The models were meshed with 10-node tetrahedral elements. The appropriate size of elements obtained from mesh sensitivity analysis and totally all models approximately meshed with 260,000 elements and 400,000 nodes (Figure 4).

After determining the boundary conditions and meshing of the samples, FEA was performed and the results were displayed as stress contours. Since dentin, cement, and ceramics are classified in the category of brittle materials, so the maximum tensile stresses (principal stresses 1) were calculated to compare the samples.

Results

Finite element results showed that in all situations the maximum principal stress occurred at the crest edge. As the elastic modulus of post increased, the stress in the dentin decreased and in the post-cement interface increased. Post material did not much effect on the concentration of stresses in the cervical margins. Also, as the elastic modulus of post increased, the stress in the post was increased. Figure 5 shows the maximum principal stresses in the different areas of the restored canine tooth.

The distribution of stresses in the dentin, crown cement, post cement, and post in all situations are illustrated in Figures 6-9 respectively.

Figure 10 shows the distribution of stresses in the intact tooth. The maximum stress created in the roots of the intact tooth was 51.19 MPa, which was almost equal to restoration with glass fiber post. The intact tooth does not have an interface, a weaker area for failure, and its strength is more than restored teeth with post-core crown. Therefore, lower stresses at the root of restorations with titanium and zirconia post compared to the intact tooth, does not mean the superiority of these restorations over intact tooth because failure depends on both stress and strength.

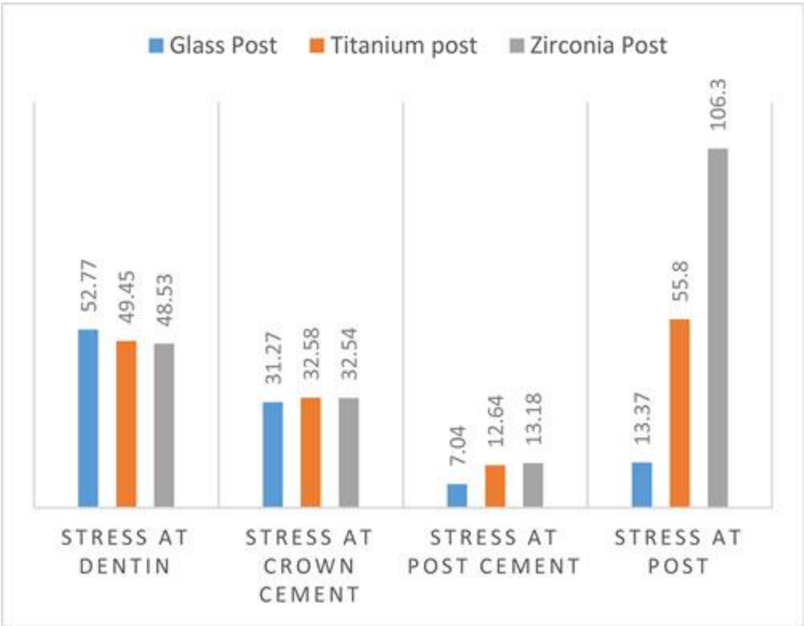

Figure 5. Maximum principal stresses verses post material (MPa)

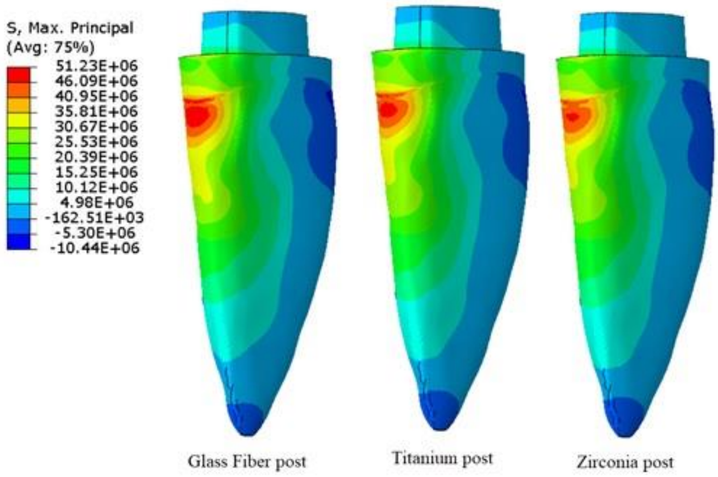

Figure 6. Maximum principal stresses in the root of post-core and crown restoration verses post material

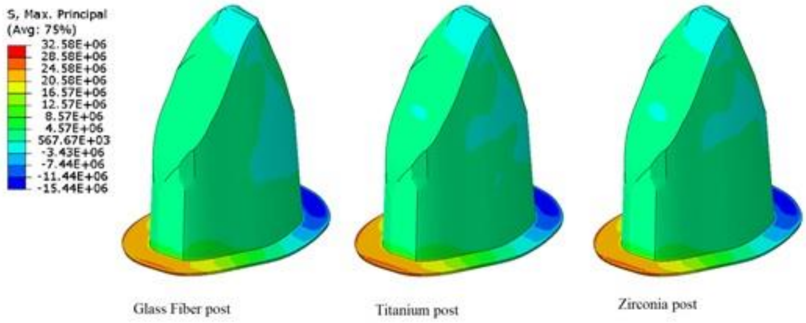

Figure 7. Maximum principal stresses in the crown cement of post-core and crown restoration verses post material

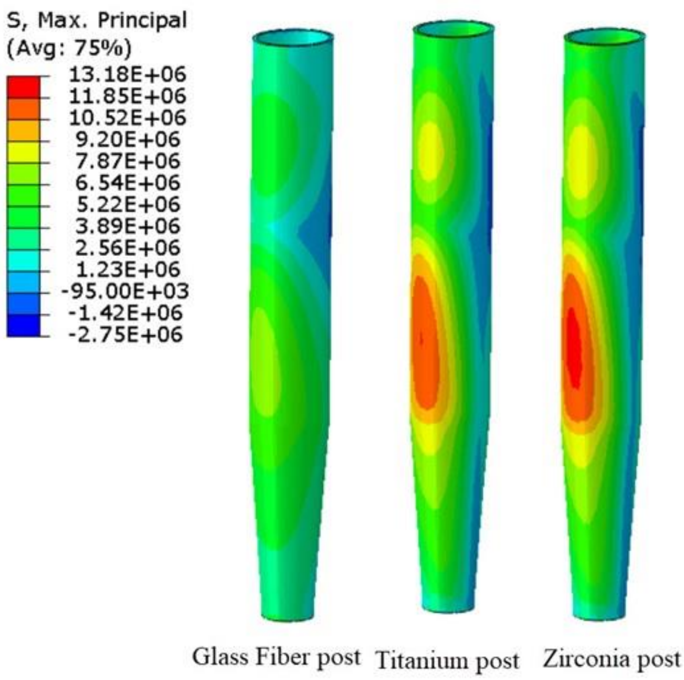

Figure 8. Maximum principal stresses in the post cement of post-core and crown restoration verses post material

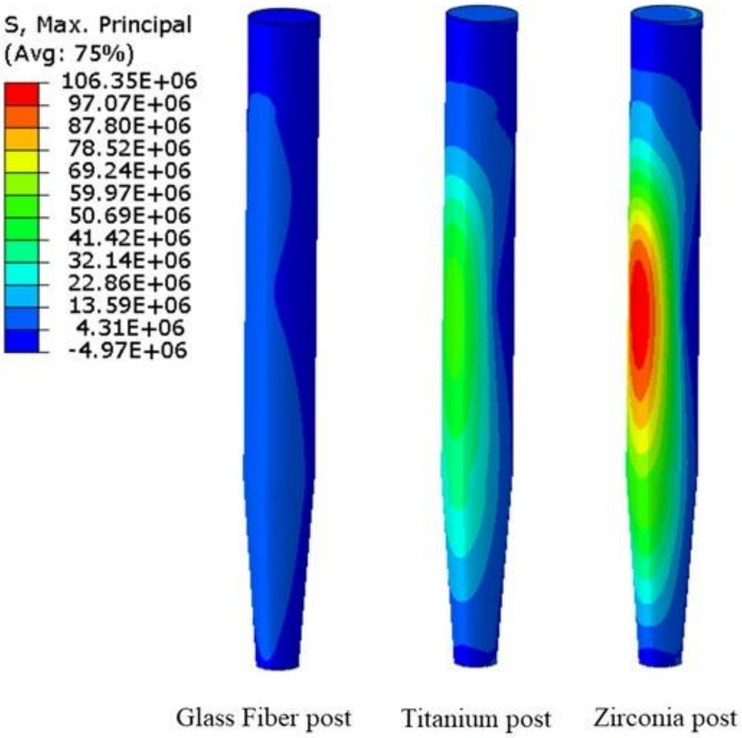

Figure 9. Maximum principal stresses in the post of post-core and crown restoration verses post material

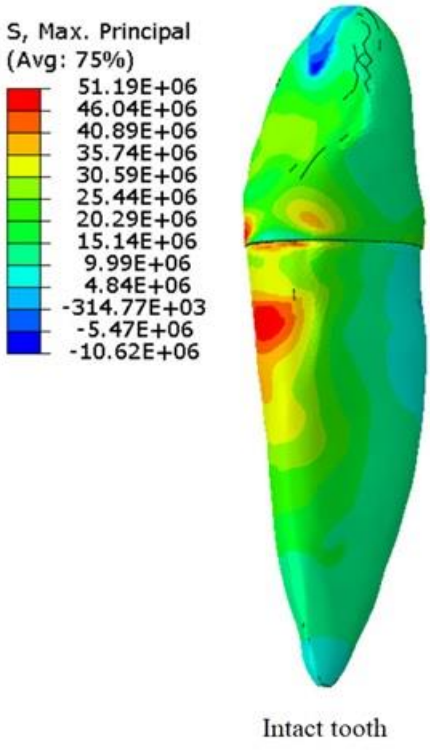

Figure 10. Distribution of stresses in the intact tooth

Discussion

Computers and their related softwares have been able to provide a model of the target that mimics the conditions of experiments. In this study, it was tried to eliminate the shortcomings of previous studies, modeling a precise 3D canine tooth by CBCT method, to investigate the effect of post material on the distribution of stresses in root canal treated canine tooth and achieved more reliable results. The use of the post is an essential component in the restoration of endodontically treated tooth that has lost a lot of its coronal tissue. A maxillary canine tooth was selected for analysis because the most lateral forces are applied to it in the maxillary anterior teeth. The use of an inappropriate post may lead to loss of post retention or post / root fracture. Although the loss of post retention is more common, the likelihood of root fracture is not zero (19). The FEA results presented in this study were based on maximum tensile and compressive stresses. Since the tensile and compressive strength of all materials were not available to predict the possibility of failure. Therefore, based on the brittleness of the dental tissues and restoration materials, the maximum principal stresses were calculated by FEA to compare the samples (2). In fact, the probability of failure is reduced as the stress in the samples is reduced (20,21). Cement failure is one of the reasons for debonding (22), therefore, the maximum tensile and compressive stresses in the bonding layers were also calculated to predict the risk of cohesive failure. The results of the present study showed that, in all situations, the maximum principal stress occurred at the crest edge, this result is consent with the finding of other like studies (23-26).

Piersnard et al. simulated a 3D model of an anterior tooth inside a cancellous bone and found that in the post-core crown restorations the tensile stresses concentrate in the supporting tissues at the cervical region (15). Other studies have also shown that the cervical area is a critical region, especially where the edges of the crown rest on the root (9, 11, 27). They are concurrent with the present study. According to FEA results as the elastic modulus of post increased, the stress in dentin is decreased and in the post-cement interface increased. Yaman et al. investigated the effect of the post without crown and stated that post does not reduce the effect of oblique forces but, reduces the effect of vertical forces by about 20% (28). Ho et al. also stated that metal posts reduce pressures in the cervical region by about 10-14% (24).

The results of the present study showed that post material had no significant effect on the concentration of stresses in the cervical margin, also, the stress in the post was increased as the elastic modulus of the post increased. The results of this study confirm the results of Uddanwadiker et al. who showed that there is no difference between carbon fiber and tapered glass fiber posts in terms of stress concentration at the root (29). Genovese et al. showed that the maximum stress in restorative teeth was not more affected by the type of post and its material, and the most stress occurs in the cervical region, which confirms this study’s results (30). According to FEA results post material had a more contribution on post stresses and insignificant effect on the stress of other components especially dentin tissue. The interpretation of these results in terms of mechanical view is that in the post-core crown restoration the maximum stress concentrates at the cervical region. The use of post inside the root canal treated tooth increases the flexural resistance of the tooth under occlusal loads. The deflection and consequently the mechanical stresses are reduced by increasing the flexural resistance. But, when the coronal structure of the tooth is enough the ferrule effect could reduce the effect of post material. Therefore, it can be deduced, in the presence of ferrule, the post material is not so effective in the dumping of destructive stresses.

Conclusion

Within the limitation of the FEA study, it can be concluded that in the root canal treated canine tooth which is restored by the post-core crown, the maximum principal stress is accumulated at the crest area. Additionally, as the elastic modulus of the post is increased, the post stresses are increased, as well as the post materials have a small contribution to the stress of the cervical area.

Conflict of Interest

None declared.

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