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Biomechanical effect of inclined implants in fixed prosthesis: strain and stress analysis

Efeito biomecânico de implantes inclinados em prótese fixa: analise das tensões e deformações

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Resumo

Introdução: A inclinação dos implantes pode ser corrigida através de mini-pilares de diferentes angulações. **Objetivo:** Analisar a influência de implantes com hexágono externo em diferentes inclinações (3 níveis) na distribuição de microdeformações geradas em torno de três implantes. **Método:** Um modelo geométrico de osso foi criado através do *software* CAD Rhinoceros (versão 5.0 SR8, Mcneel North America, Seattle, WA, EUA). Três implantes (4,1 × 13 mm) foram modelados e inseridos no interior do substrato em três diferentes inclinações: 0º, 17º e 30º. Em seguida, todos os grupos receberam mini-pilares cônicos, parafusos de fixação e prótese simplificada. A geometria final foi exportada em formato STEP para *software* de análise e todos os materiais foram considerados homogêneos, isotrópicos e linearmente elásticos. Uma carga axial (300N) foi aplicada no centro da prótese. Um estudo *in vitro* foi conduzido com as mesmas condições e grupos para validar o modelo tridimensional. **Resultado:** A concentração de tensão ocorreu na área externa dos implantes, em contato com o osso cortical e o hexágono externo. Para o simulador ósseo, a deformação aumentou na região peri-implantar de acordo com o aumento da inclinação do implante. A diferença entre os grupos foi significativa (p = 0.000). O grupo de 30º apresentou maior concentração de tensão e deformação. **Conclusão:** O aumento da microdeformação e das tensões ao redor dos implantes aumenta diretamente proporcional ao aumento do ângulo de instalação.

Descritores: Análises de elementos finitos; implante dentário; prótese fixa.

Abstract

Introduction: Implant inclinations can be corrected using mini abutments at different angulations. **Objective:** To analyze the influence of external hexagon implants in different inclinations (3 levels) on the microstrain distribution generated around three implants. **Method:** A geometric bone model was created through Rhinoceros CAD software (version 5.0 SR8, Mcneel North America, Seattle, WA, USA). Three implants (4.1 × 13 mm) were modeled and inserted inside the substrate at three different inclinations: 0º, 17º and 30º. Next, all groups received mini conical abutments, fixation screws and a simplified prosthesis. The final geometry was exported in STEP format to analysis software and all materials were considered homogeneous, isotropic and linearly elastic. An axial load (300N) was applied on the center of the prosthesis. An *in vitro* study was conducted with same conditions and groups for validating the tridimentional model. **Result:** Stress was concentrated on the external area of the implants, in contact with the cortical bone and external hexagon. For the bone simulator, the strain increased in the peri-implant region according to the increase in the implant's inclination. The difference between groups was significant (p = 0.000). The 30º group presented higher stress and strain concentration. **Conclusion:** The microstrain and stress increase around implants directly proportional to the increase of the installation angle.

Descriptors: Finite element analyses; dental implant; fixed prosthesis.

INTRODUCTION

In clinical situations where dental implants are inclined inside bone tissue, the use of angulation-correcting abutments may be an alternative for prosthesis installation[1-3]. Although the use of these abutments solves part of the prosthetic complications, masticatory load dissipation will be modified when this set enters into function[4].

Load transmission to the peri-implant bone is directly linked to the prognosis of favorable remodeling or not for maintenance of the implant in position[5,6]. Despite the possibility of reducing the treatment longevity due to implant's inclination the clinician will need this arrangement several times due to anatomical accidents and bone disposition which restricts installation sites[7]. The decision to install an inclined implant can be scientifically based on several articles that evaluated inclined implants in anterior regions, with reduced occlusal load and contact on the prosthetic crown's palatine face[8-10]. These studies mostly express a common clinical situation and provide the dentist with an initial basis that inclined implants aggravate the strain generated around the supporting tissue, but the physiological limit is still maintained[9]. However, there are components in various angles without manufacturer restrictions on the regions in which they can be used. Also, there are no reports in the literature of more extensive situations in which all implants were angled and their angulation was corrected by these prosthetic pieces.

In order to analyze the stress generated around the implants, the correlation of two or more methodologies can reduce erroneous inferences, and thus increase the clinical validity of the study[11,12]. Finite element analysis (FEA) is widely used as a methodology to study dental implants and allows for tridimensional simulation of occlusal loads in the implant structure[13,14]. Associated with FEA, Strain Gauge (SG) can validate the tridimensional model *in vitro*, and thus certify that the responses generated by the software have real behavior.

The purpose of this study was to analyze the influence of mini abutments at different inclinations (3 levels: 0°, 17° and 30°) on the microstrain distribution generated around three external hexagon implants. The null hypothesis was that abutment's angulation does not interfere in the mechanical behavior of implants or peri-implant tissue.

METHOD

Three-Dimensional Models

Pre-processing

A tridimensional (3D) rectangular model (95 × 16 × 20 mm) was created from Rhinoceros CAD software (version 5.0 SR8, McNeel North America, Seattle, WA, USA) to simulate geometric bone tissue[14]. Then, three implants were modeled following the manufacturer's dimensions (4.1 × 13 mm) containing an external hexagon of 0.7 mm. Implants were arranged in a linear way with 3.0 mm between them. The implants were replicated and new groups were created with inclinations of 17° and 30°. Mini-abutments with a height of 3.5 mm were modeled for each implant in all groups with a fixation screw and a prosthetic screw. For groups with inclined implants, the abutments were modeled with an angled platform to correct the prosthetic insertion trajectory (Figure 1). The three groups were inserted into identical bone tissue simulator blocks and received a fixed prosthesis.

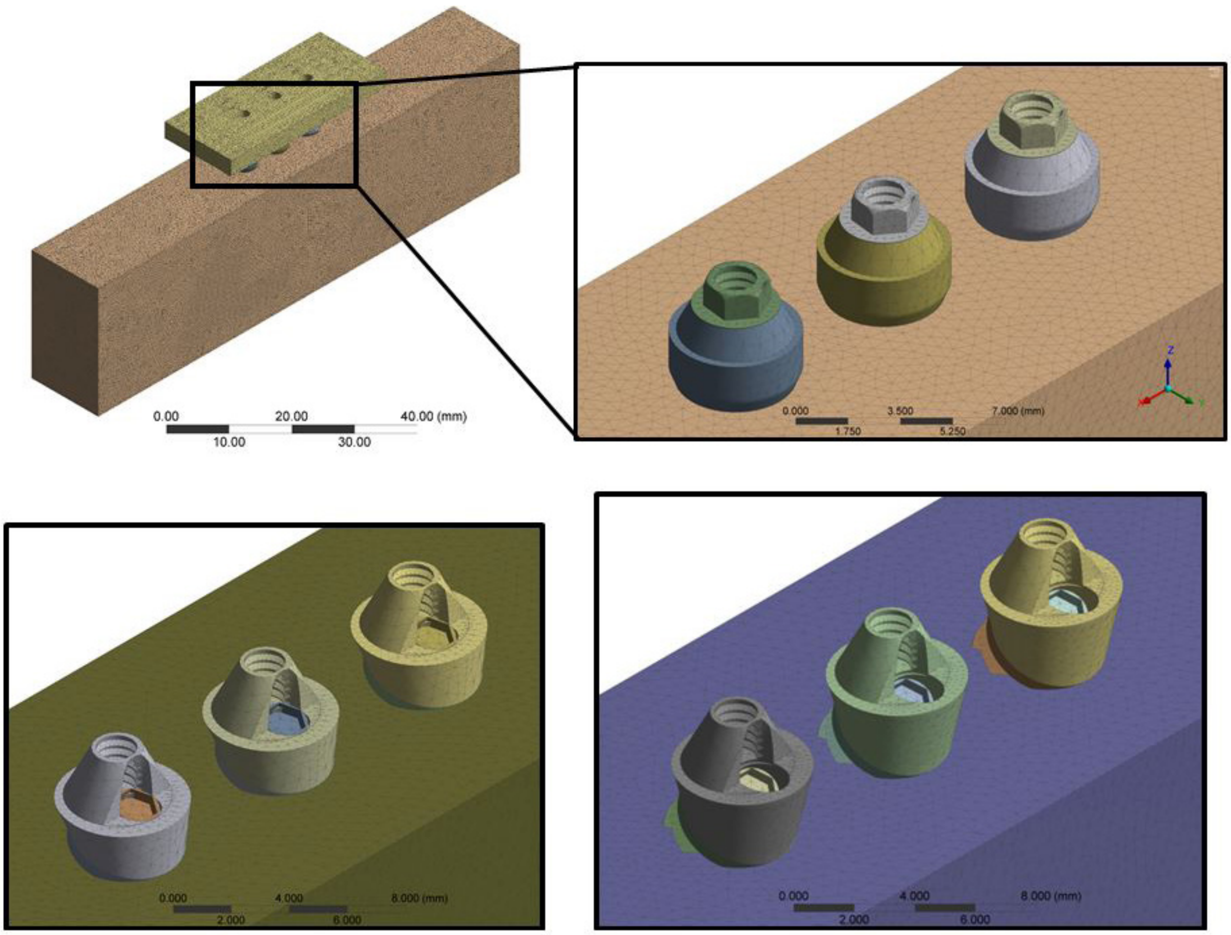

Figure 1. Group geometries exported to software analyses.

The bodies were imported in STEP format into Ansys software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA) and mechanical properties of each were reported based on the literature[15-17], following a previously published methods[12,14]. The Meshes were created based on convergence test (10%) and the size of 0.3 mm was selected for each element[14]. 754,936 nodes with 440,893 elements were created for the block with perpendicular implants, 732,375 nodes with 428,219 elements for the block with the inclined implant at 17°, and 733,412 nodes with 430,217 elements for the block with the inclined implant at 30°.

FEA loading and fixation

The fixation was located on the external lower surface of the model. The loading point (2 mm, diameter) was located at the center of the fixed prosthesis. Load was defined as the vector in the Z axis with 300 N in an apical direction. The required solutions were: Von Mises stress for implants and elastic strain for peri-implant tissue. Results were placed on an identical values scale to allow visual comparison through color charts.

Validation of 3D Model

Samples confection

Three polyurethane (Polyurethane F16 Axson, Cercy - France) blocks were created with exact measurements of the initial 3D model (95 × 45 × 40 mm) using a metal die. The blocks' surfaces were regularized with granulated sandpapers of #220 to #600 (3M ESPE, St. Paul, USA), and then three implants were installed in each block following a conventional drilling protocol (AS TECHNOLOGY TITANIUM FIX, São José dos Campos, Brazil). Metallic devices were used to standardize the perforations according to the "inclination" factor of the study (0º, 17º and 30º). Mini conical abutments (AS TECHNOLOGY TITANIUM FIX, São José dos Campos, Brazil) were positioned on each implant platform. The prosthetic abutments were installed with a torque of 20 Ncm with the aid of a manual torquemeter. Simplified fixed prostheses (N=30, n=10) were melted in nickel-chromium (Wironia Light Bego, Bremen, Germany) following the same dimensions of the 3D model.

Block surfaces were cleaned with isopropyl alcohol and seven linear strain gauges (Model KFG-02-120-C1-11, Kyowa Eletronic Instruments Co., Ltd-Tokyo-Japan) were attached to each block with cyanoacrylate adhesive (Super Bonder Loctite, São Paulo, Brazil) in 7 different areas (Figure 2). Next, the calibration of each extensometer was performed using a multimeter device (Minida ET 2055: Minida São Paulo - Brazil). Variations of electrical resistance were converted to microstrain units through an electrical signal conditioning apparatus (Model 5100B Scanner - System 5000 - Instruments Division Measurements Group, Inc. Raleigh, North Carolina - USA). Data recording was performed using Strain-smart software.

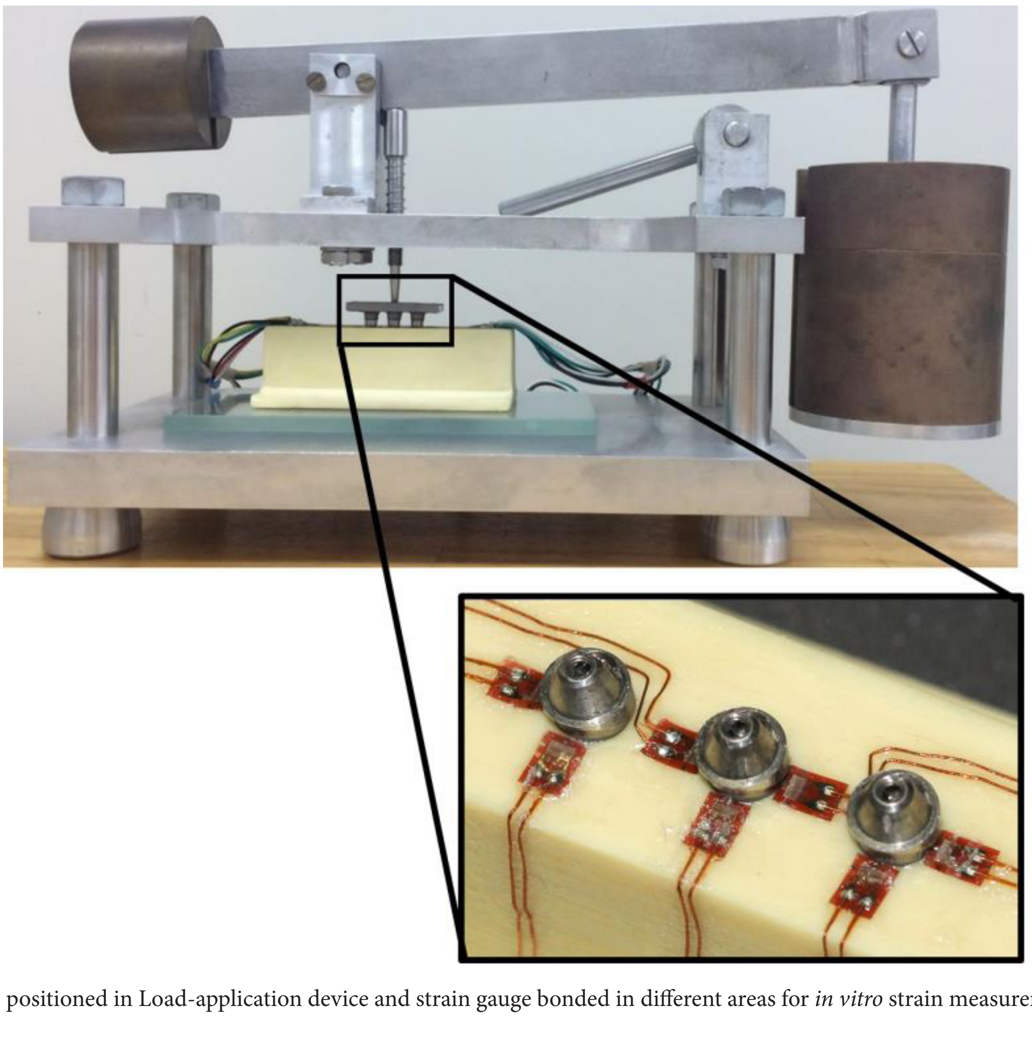

Figure 2. Sample positioned in Load-application device and strain gauge bonded in different areas for *in vitro* strain measurement.

Load aplication

Constant static loading (30 kgf, 10 s) was promoted by a device with a 2 mm rounded tip (Figure 2) which allowed three loading repetitions on the center of the prostheses (n = 10)[12].

Data analysis

Qualitative stress results obtained by the computational mathematical model were analyzed according to colored scales. The strain results are presented in graphs. Descriptive statistics consisted of means and standard deviations, and inferential statistical analysis consisted of a 95% confidence interval one way ANOVA analysis using MINITAB software (Minitab, version 16.1.0, 2012).

RESULT

After computational simulation, the MPa results of stress generated on each implant's were photographed with the same representative color scale. The hottest points represent areas with the highest concentration of positive values (traction), while the cooler zones represent zones with smaller values (compression). In this regard, the increase in stress concentration was proportional to the increase of the implants' inclination (Figure 3). Maximum strain found on the bone's surfaces and peri-implant tissue exhibited similar behavior to implants (Figure 3). Values of strain were compared with SG results (Table 1). Statistical analysis showed that the "inclination" factor was significant (p = 0.000) for the *in vitro* results; and the mechanical behavior of the 3D model is assumed valid, as both methodologies corroborated the results.

DISCUSSION

According to the results obtained in the present study, it was observed that the hypothesis was rejected because the implants' and the bone tissue's mechanical behavior were altered due to the implants' inclination.

In comparing both used methodologies, it is possible to observe that FEA shows values with more than 10% difference

Table 1. Mean of normal strain (dimensionless) measured by both methods

	Computational	Experimental
0°	540	567(± 120)^{A}
17°	1100	1288 (± 387)^{B}
30°	1550	1725 (± 417)^{C}

Legend: Different capital letters indicate statistically significant differences (Tukey's test α = 5%).

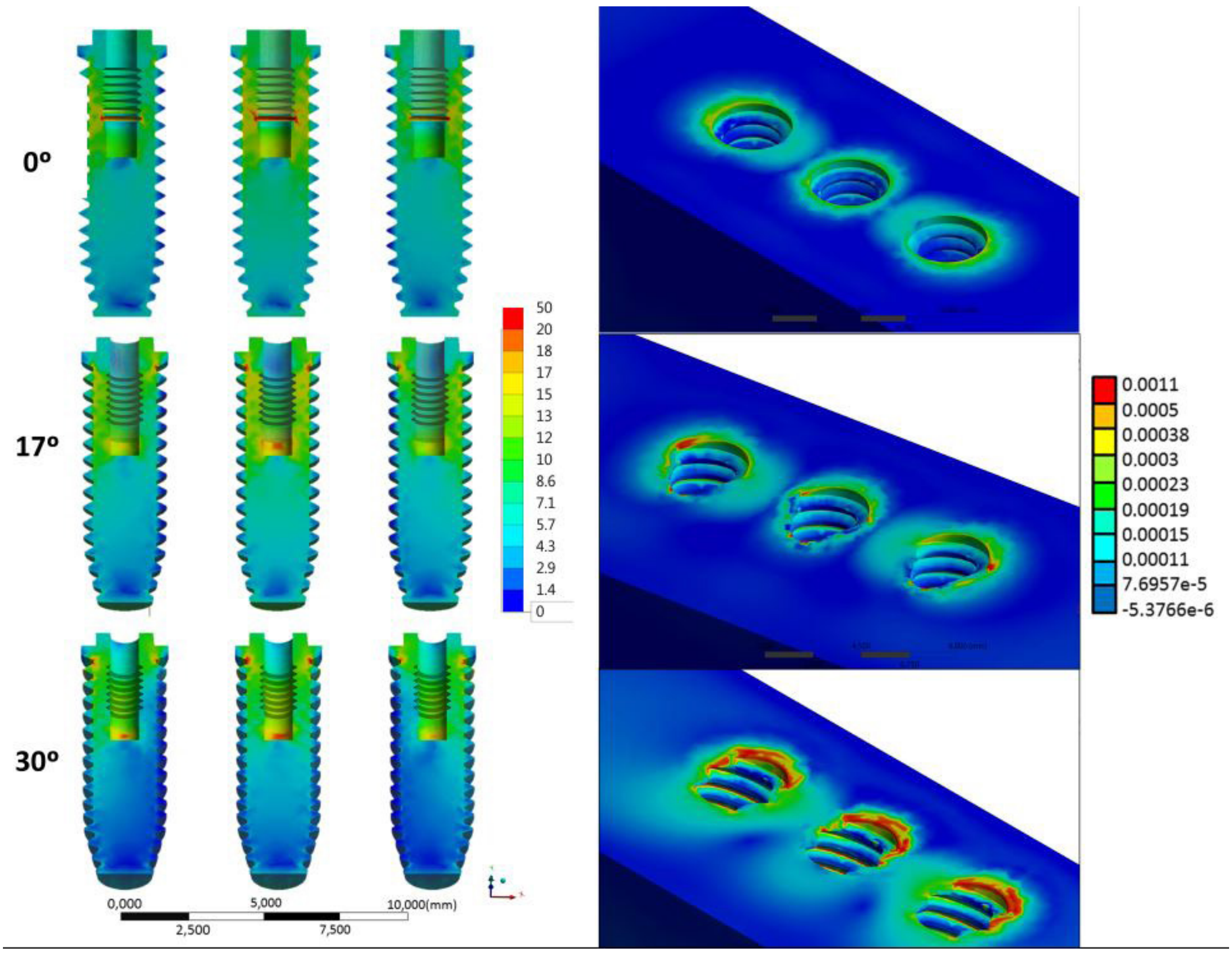

Figure 3. Von Mises Stress for the implant's threads in sagittal vision and Microstrain generated in peri-implant tissue for all groups.

between groups, which exceeds the convergence test value of the mesh generation, and can be understood as significantly different (Table 1). In the same way, SG verified statistical difference between microstrain values found around straight compared to inclined implants (p=0.000). Thus, both methodologies indicate that the greater the inclination of the implants, the greater the generated bone deformation (Figure 3), which is according to the study of Clelland et al.[18] (1996). These regions where higher microstrain concentrations occurred are more susceptible to bone crest micro fractures around the implant[4]. When strain values exceed physiological bone tolerance, they cause irreversible damage at the bone-implant interface[19], and thus initiate a process of unwanted bone remodeling since it culminates in insertion loss[5].

The results of this present study did not show values above the physiological limit (Figure 3) as demonstrated by situations with prosthesis with a less number of elements[20]. Thus, although other factors may modify the peri-implant region[21], the stresses generated appear to be acceptable and the use of these components can be performed without initial problems. Considering that the study used a four-element prosthesis, it is believed that the center point is the region that would allow a better load distribution between implants, and this would explain the symmetry of the stress generated between the lateral implants, but the strain's physiological limit was achieved even in this situation. For the stress generated in implants, no values of critical tensile stress of titanium[12] were recorded (Figure 3). However, it is believed that in long term, the group with 30º angled implants would present possible failures due to fatigue since the stress accumulated in the metallic structures was larger with the same applied load.

The load used was 30.6 kgf. (300 N), being a mean load obtained in the first molar region[22]. The study did not consider the bone variations existing *in vivo* conditions due to the difficulty of standardization and reproducibility between two methodologies. Thus, polyurethane (an isotropic material previously validated in the literature) was used as a replacement of bone tissue for laboratory analysis[17].

The fixed prosthesis model was chosen considering that this configuration favors the load distribution on implants when compared with different configurations[23]. Other studies have been carried out with this prosthesis configuration in order to observe the behavior of microstrains around implants[14,24], but an evaluation of the biomechanical behavior of inclined implants has not been discussed in the literature.

The implants were installed linearly with angles of 0°, 17° and 30°, as previous studies showed that there was no statistical difference when compared to implants in a linear position or offset[24].

The prosthetic screw is one of the main regions of stress concentration and possible mechanical failure in the implant/prosthesis[25,26]. Thus, the concentration of stresses can be facilitated during incidence of oblique loads[6,21,24]. As the present study used a simplified fixed prosthesis, the generated stress inferences in the abutment and screw would not correspond to reality, as verified during the 3D model validation[14]. Nevertheless, the literature is rather concise in emphasizing possible damage on the prosthetic screw when used in inclined implants[6,8,14,21]. Future studies evaluating fatigue life and torque maintenance of prosthetic screws in straight and angled abutments should be performed to complement the available literature data.

The von-Mises stress is directly related to the ductile metals failure[25-28]. Therefore, restorative procedures that involve stress maps with greater magnitude show higher possibility of premature failure[6]. Considering the dental implants, studies that have evaluated this type of failure criteria during computational simulations are quite common in order to prevent critical damages in implant-supported prosthesis[24-28].

The use of abutments to correct implant position in fixed prostheses can provide a correct insertion trajectory facilitating the implant-supported prosthesis installation[6,21]. But, at the same time those abutments can make the biomechanics response more fragile due to the increase of stresses concentration in the implants and bone strain. Moreover, according to the figure 3, as the angulation increases the zones of stress concentration prevail in the implant cervical region, especially below the prosthetic platform before the first thread.

CONCLUSION

Within this study's limitations, it may be concluded that the microstrain and stress increase around implants directly proportional to the increase of the installation angle.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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