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Precision of polyether ether ketone (PEEK) or cobalt-chrome implant bar fit to implants after mechanical cycling

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ABSTRACT

Based on its mechanical properties, PEEK (polyether-ether-ketone) might be useful in restorative procedures. In oral rehabilitation, its viability has been studied mainly for prostheses and dental implants. ***Aim:*** *The aim of this study was to evaluate the fit accuracy of dental implant bars made of either PEEK or cobalt-chrome submitted to cycling mechanics.* ***Materials and Method:*** *This was an experimental in vitro study, where units were treated with two implants and mini-abutments, joined by cobalt-chrome or polyether-ether-ketone PEEK bars. A total 20 bars were prepared (n=10 per group) and subjected to mechanical cycling tests (1 million cycles on the distal cantilever of the bar in the vertical direction, 120N and sinusoidal loading, at a frequency of 2Hz). The fit at the abutment/implant interface was measured before and after cycling, and the counter-torque of the vertical screw of the mini abutments was measured after cycling, using a digital torquemeter. Data were analyzed by three-way ANOVA and Tukey's test at 5% significance level.* ***Results:*** *No statistically significant interaction was found among the three factors considered (bar material, implant positioning and mechanical cycling) (p = 0.592). No significant difference was identified in the interaction between bar material and implant positioning (p = 0.321), or between implant positioning and mechanical cycling (p = 0.503). The association between bar material and mechanical cycling was statistically significant (p = 0.007), with the cobalt-chrome bar resulting in greater misfit with mechanical cycling. There was no difference in counter-torque values between groups.* ***Conclusions:*** *The PEEK bar provided better fit of the mini abutments to the implants, even after mechanical cycling. The counter-torque of the screws was similar in all scenarios considered.*

Keywords: *PEEK - Dental prosthesis - Mouth rehabilitation.*

Precisão da adaptação de barras tipo protocolo confeccionados em polyetheretherketone (PEEK) ou cobalto cromo sobre implante após ciclagem mecânica

RESUMO

O PEEK (Poli-éter-éter-cetona) é um material considerado para uso em procedimentos restauradores devido às suas propriedades mecânicas. Na reabilitação oral, sua viabilidade tem sido estudada principalmente para uso em próteses e implantes dentários. ***Objetivos:*** *O objetivo deste estudo foi avaliar a precisão da adaptação de duas barras diferentes do tipo protocolo confeccionadas em PEEK ou Cobalto-Cromo, após serem submetidas à mecânica ciclística.* ***Materiais e Método:*** *As unidades experimentais foram constituídas por barras confeccionadas em Poli-ether-ether-Ketone (PEEK) e em Cobalto-Cromo (Co-Cr). Trata-se de um estudo experimental, in vitro, onde verificou-se unidades constituídas por dois implantes e mini pilares unidos com barras de Cobalto-Cromo ou PEEK. Foram confeccionados um total de 20 barras (n=10 em cada grupo) e as barras foram submetidas a ensaios de ciclagem mecânica (1 milhão de ciclos no cantilever distal da barra no sentido vertical, 120N e carregamento senoidal, a uma frequência de 2Hz). Antes e após a ciclagem realizou-se a mensuração da desadaptação na interface pilar/implante e após a ciclagem foi medido o contra-torque do parafuso vertical dos mini-pilares através de torquímetro digital TQ 8800 (LT Lutron, Taiwan). Os dados foram submetidos a ANOVA a três critérios e teste de Tukey ao nível de significância a 5%.* ***Resultados:*** *Constatou-se que não houve interação estatisticamente significativa entre os três fatores estudados, ou seja, entre o material da barra, o posicionamento do implante e a ciclagem mecânica (p = 0,592). Também não se identificou diferença estatística significativa da interação entre o material da barra e o posicionamento do implante (p = 0,321), nem entre o posicionamento do implante e a ciclagem mecânica (p = 0,503). Já a associação entre o material da barra e a ciclagem mecânica foi estatisticamente significativa (p = 0,007), onde a barra de Cobalto-Cromo resultou em maior desadaptação com a ciclagem mecânica. Não houve diferença nos valores dos contra-torques entre os grupos.* ***Conclusões:*** *Conclui-se que a barra de protocolo fabricada em PEEK proporcionou melhor adaptação dos mini pilares aos implantes mesmo após a ciclagem mecânica. Por fim, o contra-torque dos parafusos foi semelhante em todos os cenários avaliados.*

Palavras-chave: *PEEK - Prótese dentária - Reabilitação bucal.*

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INTRODUCTION

Science and technology are increasingly investing in implant dentistry, which is one of the main specialties requiring innovative materials[1]. One of these materials is PEEK (polyether-ether-ketone), an aromatic semicrystalline polymer developed in England in the late 1970s. PEEK is a high-performance thermoplastic material being researched in dentistry[2-5].

PEEK has been considered for use in restorative procedures due to its mechanical properties[6]. In oral rehabilitation, its viability has been studied mainly for prostheses and dental implants. In Implantology specifically, it is studied as a potential alternative to titanium and zirconia, considering its biocompatibility and physical properties such as elasticity, resistance and radiolucency[7-9].

PEEK has high resilience, resistance to fracture and corrosion and shock absorption, and low transmission of forces to the adjacent bone[10], which can prevent abutment screw fractures, transmission of occlusal overloads to the marginal bone around dental implants, and bone loss[10].

PEEK has an elastic modulus similar to that of bone, so it can absorb mechanical shocks. Prosthetic abutments and dental implants made from PEEK can therefore absorb and foster dissipation of masticatory loads to the peri-implant bone, thereby preventing implant failures[10]. Its main disadvantages are that it is bioinert, which may be a problem for osseointegration, and susceptible to stress deformation[9-10]. In thermal cycling with artificial saliva, PEEK has low retention in prostheses, especially at very acidic or very alkaline pH values[11-12]. There are few randomized controlled clinical studies to ensure effectiveness in its clinical use[9-10].

Passive fit is one of the most important prerequisites for maintaining the implant-bone interface. To achieve a passive fit or stress-free framework, the framework should theoretically not induce stress on the implant components or surrounding bone in absence of external load application[13]. However, according to the available literature, it is practically impossible to achieve completely passive fit[13]. Prosthetic complications such as loosening or fracture of the prosthetic abutment screw, infrastructure and ceramic covering have been documented and may be related to poor fit of the framework[13]. In bone tissue, complications such as infections, oronasal communication or peri-implantitis are quite rare[14].

In implant-supported bars, there is a direct relationship between the amount of deformation and the force of occlusion, while there is an inverse relationship with the modulus of elasticity of the framework material of the implant-supported bar[15]. The most usual techniques for making bars for protocol-type prostheses ultimately produce heavy structures and use laboratory procedures requiring extensive execution time, fostering failures in their manufacture. In this regard, PEEK could be an alternative material. However, due to the scarce evidence and protocol-type prostheses, further studies are required. Considering as a null hypothesis that PEEK promotes fit similar to that of cobalt-chrome, which is the material traditionally used, the aim of this study was to evaluate the fit accuracy of PEEK and cobalt-chrome implant bars, after being submitted to cycling mechanics.

MATERIALS AND METHOD

Experimental design

This was an experimental in vitro study. Experimental units consisted of two implants and mini abutments seated on them, numbered as mini abutment I and mini abutment II, the latter being closest to the cantilever. The mini abutments were connected with bars that had two levels, one made of cobalt-chrome and other made of PEEK. The positioning of the implant/mini prosthetic abutment and bars was measured before and after dry mechanical cycling. As a dependent variable, there was an assessment of the mismatch between mini abutments I and II to cylinders made of Co-Cr alloy and PEEK and the counter-torque of the screws of the mini abutments after the dry mechanical cycling test.

Sample and master model preparation

Twenty solid rectangular bars were prepared, half of them (n=10) made of polyether-ether-ketone (PEEK), and the other half (n=10) of cobalt-chrome, to be used as a control group.

Aluminum molds 30 mm long x 6.97 mm wide x 12.60 mm tall were made for fixing the implants. To guide the positioning of the two external hexagon implants (3.75 x 11mm) and 4.1mm platform (Neodent), a lathe was used to make perforations 3.5 mm in diameter in the aluminum mold.

The perforations were equidistant and parallel, with precision of one micrometer (1 µm), and numbered I and II. The implants were subsequently placed using

a ratchet, and standardized with torque of 60 N.cm (Fig. 1).
HE 4.1 mini conical abutments (Neodent, Curitiba, Brazil) were installed on the implants with a regular transmucosal height of 1 mm and torque 32N.cm, as recommended by the manufacturer. Then, protocol-type bars were made, a PEEK-type polymeric disc (Juvora Dental Discs, Cleveleys, UK) and a wax disc (Vitazanfabrik, Bad Säckingen, Germany) were positioned on a five-axis milling machine for machining the bars (Juvora Dental Discs, Cleveleys, UK).
After installing all the implants in the master molds with their respective mini abutments, they were scanned with a 3shape scanner, and an adapted solid body protocol-type bar project[16] was executed in the Dental System 3Shape program (Fig. 2). Ten PEEK polymer bars and ten wax bars were made in the same design, as a quadrilateral figure with dimensions 30 mm long x 6.97 mm wide x 12.60 mm tall. The wax bars were subjected to the induction casting process. The passivity of all bars was tested by visual verification in their respective metallic molds. The metal bars and polymer (PEEK) bars were screwed into the mini abutments on the implants with torque of 10N.cm, as recommended by the manufacturer, and then submitted to the dry mechanical cycling test.

Mechanical cycling
The cyclic load tests were performed in a device for mechanical cycling (MSFM, Elquip, São Carlos, SP, Brazil), dry and at room temperature, applying 1 million cycles on the distal cantilever of the bar in the axial direction, which simulates 50 years[17]. The cylinder drive speed and frequency were controlled by the control box that moved the pistons located inside these cylinders, compressing the specimens with a controlled force of 120N and sinusoidal loading, at a frequency of 2Hz[18] (Fig. 3).

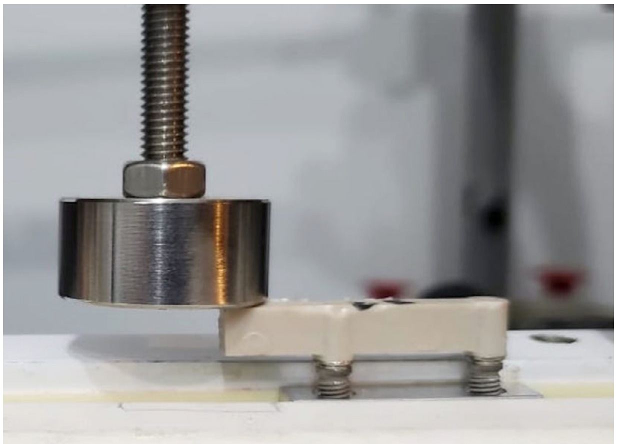

Fig. 1: Master die. Dimensions: 12.60 mm high x 30 mm long x 6.97 mm thick. The distance between implants I and II was 15.24 mm.

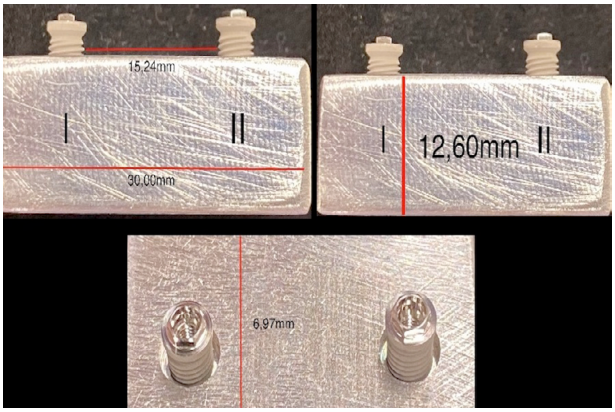

Fig. 2: Digital design of the bars to be milled. Dimensions: 6.07 mm high x 33.3 mm long X 4.03 mm thick.

Mini abutment/implant interface fit assessment
Before and after the mechanical cycles, the samples of the implant - mini abutment/bar set were positioned in a microhardness tester to measure the mismatch of the implant/prosthetic abutment interface and respective bars, with an increase of 100 times (Pantec, Campinas, SP – Brazil). Eight readings were performed, two on the anterior face and two on the posterior face of each implant/mini-abutment and bar set, totaling 80 measurements for each group of 10 sets. Two measurements were taken on each mini-plier, I and II, at the point where the bar was adapted to the mini-abutment. The other measurements were taken in exactly the same locations on the opposite side. Thus, four measurements were

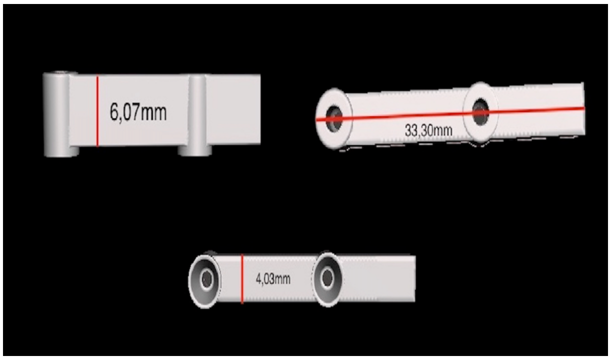

Fig. 3: Loading positioning during mechanical cycling.

taken on the anterior side and four on the posterior side, totaling eight measurements. An arithmetic mean of the measurements of each implant was used for analysis.

Counter-torque

Before and after the mechanical cycles, the samples of the implant - mini abutment/bar set were placed in a microhardness tester (Pantec, Campinas, SP, Brazil) to measure the mismatch of the implant/prosthetic abutment interface and respective bars, with an increase of 100 times. A TQ 8800 digital torquemeter (LT Lutron, Taiwan) was used to measure the counter-torque of the mini abutment screws after cycling and check the abutment/implant interface mismatch. All the analyses were performed by the same operator.

Statistical analysis

Fit data were checked for adherence to normal distribution. In order to investigate the effects of bar material, implant positioning and mechanical cycling, as well as the triple and dual interactions among these three factors, the three-way analysis of variance for repeated measures was used. For multiple comparisons, Tukey's test was used. For counter-torque values, the effects of bar material and implant positioning, non-parametric Mann-Whitney tests were used. Statistical calculations were performed using SPSS 23 software (SPSS Inc., Chicago, IL, USA), setting the significance level at 5%.

RESULTS

Table 1 summarizes the mean values and standard deviations of the fit between the mini abutments and the protocol-type cylinder made of PEEK or cobalt-chrome, before and after mechanical cycling. Three-way analysis of variance for repeated measurements showed that there was no statistically significant interaction among the three study factors (bar material, implant positioning and mechanical cycling) ($p = 0.592$). No statistically significant effect was identified between the bar material and implant positioning ($p = 0.321$), or between implant positioning and mechanical cycling ($p = 0.503$). The association between bar material and mechanical cycling was statistically significant ($p = 0.007$).

Table 2 shows the results of the statistically significant interaction. Both before and after mechanical cycling, the misfit was significantly greater with the cobalt-chrome bar than with the PEEK bar. Only cobalt-chrome resulted in greater misfit with mechanical cycling. For the PEEK bar, the misfit between the mini abutments and their cylinder was not significantly affected by mechanical cycling.

The Mann-Whitney tests showed no significant difference (Table 3) in the values of counter-torque in

Table 1. Means and standard deviations of the fit (µm) between the mini abutments and the cylinder of protocol-type bars made of PEEK or cobalt-chrome, before and after mechanical cycling.

Bar material	Before cycling		After cycling	
	Mini abutments I	Mini abutments II	Mini abutments I	Mini abutments II
PEEK	6.02 (0.93)	6.32 (1.24)	5.81 (1.48)	5.97 (1.10)
Cobalt-Chrome	7.35 (1.04)	7.17 (0.82)	10.62 (5.88)	9.17 (1.21)

Table 2. Means and standard deviations of misfit (µm) between the cylinder of protocol-type bars made of PEEK or cobalt-chrome and the mini abutments, without considering their positioning, before and after mechanical cycling.

Bar material	Before cycling*	After cycling*
PEEK	6.17 Aa (1.08)	5.89 Aa (1.27)
Cobalt-Chrome	7.26 Ba (0.92)	9.89 Bb (4.20)

* Not considering whether they were mini-abutments I or II.
Means followed by different capital letters indicate significant difference between materials (comparisons within each column).
Means followed by different lowercase letters indicate a significant difference before and after cycling (comparisons within each row).

Table 3. Medians, means and standard deviations of the counter-torque (N.cm) of mini abutment screws, according to their positioning and the material used in making the protocol-type bar.

Bar material	Mini abutment I	Mini abutment II
PEEK	3 Aa 2.50 (1.4)	2 Aa 1.90 (1.4)
Cobalt-Chrome	4 Aa 2.3 (5.36)	1 Aa 0.40 (3.9)

Medians in the first line of each group. Means and standard deviation in the second line of each group. Medians followed by the same capital letters indicate no significant difference between materials (comparisons within each column). Medians followed by different lowercase letters indicate a significant difference between mesial and distal miniscrews (comparisons within each row).

the screws of the mini-abutments I and II with either cobalt-chrome ($p = 0.257$) or PEEK ($p = 0.473$) bars.

DISCUSSION

The search for alternative materials for implant-supported bars is justified by the concern about a possible release of metals from cobalt-chrome alloys into the bloodstream[3]. The present study sought to evaluate the properties of PEEK by comparing fit accuracy between PEEK and conventional Co-Cr bars. The findings refuted the null hypothesis because the experimental bar had lower misfit values.

The results demonstrated that the interaction between the bar's composition material and the performance of mechanical cycling affected the marginal fit of the mini abutment. In this context, PEEK bars achieved better marginal fit before and even after mechanical cycling. This might be explained by the fact that PEEK has a lower modulus of elasticity and absorbs more tension, distributing the load on the bar more evenly[18-20].

These findings complement existing evidence for use in dentistry, which point to aesthetic feasibility[21], biocompatibility and elasticity[10], with several studies suggesting optimistic results regarding physical, chemical and mechanical properties[19-21]. In the present study, the cantilever region was chosen because it is the most affected by masticatory forces, as noted in other studies[16,23]. Room temperature was used without impact on the results since the critical temperature to modify the properties of PEEK is above 75 °C[24].

PEEK is limited to use in healing abutments or prosthetic dental devices. Further, more complex investigations are needed, including histopathological studies investigating how to improve osseointegration, since PEEK is bioinert[9,10-25]. However, it has been proven that osseointegration occurs in implants with PEEK[26], and surface modification with laser, bioactive materials or chemical treatments has been proposed [27].

The need for further research on protocol bars is confirmed by the fact that the literature is mainly related to overdentures. Corroborating the results of the present research, other studies have reported that structures made of PEEK provide better retention, and lower stress concentration or misfit than those made of Co-Cr alloy[20,28,29]. Clinical and longer-term studies have shown good outcomes and patient satisfaction with PEEK[30]. Despite the lack of studies with protocol bars, the findings mentioned above suggest that PEEK is a promising material for implant dentistry.

In other situations, for example, when the All-on-Four® technique was used, the stress peak was higher for PEEK bars than conventional bars[31]. For zygomatic implants, there was no difference in tension between PEEK and the cobalt-chrome alloy[32]. Compressive strength was lower in PEEK bars than in nickel-chrome bars[16].

The results of this study support the use of PEEK as an alternative for protocol bars, since it promoted a smaller misfit, being a functionally viable option, in addition to being a good aesthetic option, according to other studies[31,33]. The differences between PEEK and cobalt-chrome bars can be explained by their surface features, regarding which the influence of particle size and uniformity, as well as the mechanical properties, have been reported[3]. Moreover, evidence is emerging that PEEK bars improve mastication performance, bite force capacity and occlusal pattern, in addition to providing greater patient satisfaction[34].

The "counter-torque" response variable did not indicate any difference between materials. It is speculated that PEEK promoted the same passivity as the cobalt-chrome alloy, protecting the screw similarly.

Like the current study, most studies on PEEK in oral rehabilitation are still experimental. Despite the need for larger long-term clinical studies, it is important to reinforce the evidence of experimental studies that support and increase the safety of using the material in clinical practice, which reinforces the relevance of the present study.

It is concluded that the PEEK protocol bar provided better fit of the mini abutments to the implants, even after mechanical cycling. The counter-torque of the screws was similar in all evaluated scenarios.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

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