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Different protocol bar designs made of polyether ether ketone (PEEK) and metal: an analysis of mechanical behavior

Diferentes designs de barras de protocolo em Poli-éter-éter-cetona (PEEK) e metal: análise do comportamento mecânico

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ABSTRACT

Objective: To assess the flexural strength (FS) of protocol bars on implants made of polyether ether ketone (PEEK) and metal. **Methods**: Thirty PEEK bars and thirty metal bars (control) were manufactured in three different cross-sectional designs (n = 10): rectangular solid bar (R); T-shaped bar (T); and inverted-T shaped bar (T-inv). The 30 cm bars were screwed onto Cone Morse implants measuring 3.75 x 11.0 mm and subjected to FS test on a universal testing machine (0.5 mm/min), with load applied to the pontic. Then, the counter-torque (CTorque) was measured on the screws following the test. **Results**: Both the PEEK and metal bars showed the highest FS values for the R-type design, followed by the T and T-inv designs. On average, FS values of PEEK bars for the T and T-inv designs were, respectively, 32.5% and 47.2% smaller than the R-shaped bars. On metal bars, the T and T-inv designs showed values 19.9% and 30.5% smaller than that found for the R design. However, regardless of design, the Ni-Cr bars showed consistently higher FS values. CTorque was not affected by material, but the R design showed higher values. **Conclusion**: The bar design influences FS. Regardless of design, metal bars show higher FS relative to PEEK. On the other hand, CTorque was not affected by material; in terms of design, the R-shaped bars showed lowest CTorque and T and T-inv showed no statistical difference.

Keywords: Dental implants. Polymers. Prosthesis design. Torque. Bar.

RESUMO

***Objetivo**: Avaliar a resistência à flexão (RF) de barras de protocolo sobre implantes, confeccionadas em poli-éter-éter-cetona (PEEK) e em metal (NiCr). **Métodos**: Foram confeccionadas trinta barras em PEEK e trinta em metal (controle), em 3 desenhos de secção transversal (n=10): barra maciça retangular (R); barra em T (T); e barra em T invertido (T inv). As barras com de 30 mm de comprimento foram parafusadas em implantes Cone Morse de 3,75x11,0mm e submetidas ao ensaio de RF em máquina de ensaios universal (0,5 mm/min), com a carga aplicada no pôntico. Após o ensaio, foi mensurado o contratorque (CTorque) dos parafusos. **Resultados**: Para os dados de RF, tanto a barra em metal ou em PEEK, revelaram valores significativamente mais elevados em R, seguidos por T e por último* a T inv. De fato, quando utilizado PEEK, em média, a RF de barras em T e T inv foram, respectivamente, 32,5% e 47,2%

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menores em relação à R. Já nas metálicas, as barras em T e T inv apresentaram valores de 19,9% e 30,5% menores que os encontrados para as R. Contudo, quaisquer dos desenhos mostraram valores significativamente mais elevados em barra em Ni-Cr. Já nos dados de CTorque, o tipo de material não o afetou de forma estatisticamente significativa. Já as barras R apresentaram valores de CTorque estatisticamente maiores que as demais. ***Conclusão****: O desenho da barra influencia em sua RF. Para quaisquer dos desenhos, barras em metal possuem maior RF que as mesmas em PEEK. Já o tipo de material das barras não afetou o CTorque. E o desenho das barras em T e T inv não diferiram entre si, porém apresentaram valores de CTorque menores que os das R.*

Palavras-chave: *Dental Implants; Polymers; Prosthesis Design.*

INTRODUCTION

Protocol-type prostheses over implants are frequently used on full arch rehabilitations. Metal alloys such as Co-Cr and Ni-Cr are employed in the manufacture of the prosthesis bars for years, but there are some limitations [1,2].

The search for new materials to be used on protocol bars that improve aesthetical and functional features, as well as new and improved designs are an important line of research.

Polyether ether ketone (PEEK), a linear thermoplastic polymer, has been targeted by research due to its lighter weight, good mechanical strength, and elasticity module similar to the bone's [3-5]. Shows excellent physical properties, stability at high temperatures, and resistance to chemical damage [6,7]. Because it is biocompatible and bioinert [8], it is an option for patients allergic to metals [3].

The technology Computer Aided Design and Computer Aided Manufacturing (CAD CAM) enables the manufacturing of bars with good quality in a shorter time [8] and allows milling in different designs and materials [2].

The design of a protocol-type bar is associated with the rehabilitation success since it optimizes the physical and mechanical properties of the material used. However, a high incidence of fractures is observed in conventional metal infrastructures with solid design [9]. Several designs have been proposed [10] seeking for lighter weight, and better dissipation of stresses while keeping the ability to resist loads.

Given this scenario and the importance of comparing new materials with metals well-established in the literature and clinical practice, it is relevant to assess, through a flexure test, the mechanical behavior of three different designs of protocol-type bars manufactured in polyether ether ketone (PEEK) and metal (Ni-Cr).

MATERIALS AND METHODS

Test base

A rectangular metal matrix was manufactured in stainless steel (48x38x15mm). Two holes were drilled on the top of the matrix with 4.9 mm of diameter and 7.8 mm of depth, equidistant, parallel and vertically aligned.

Two implants Titamax CM ExAcqua 3.75 x 11mm (Neodent, Curitiba, Brazil) were attached to the holes using high viscosity epoxy resin to avoid displacement. The distance between abutment centers in the implant was 18 mm. A mini straight CM abutment was installed on top of each implant with a 1.5mm strap (Neodent, Curitiba, Brazil), with torque applied as per the manufacturer's recommendation.

Test specimens

The prosthetic components were scanned using a Dental Wings 3Series (Dental Wings, Montreal, Canada) scanner to generate a virtual model. Based on this model, a digital project was created with three protocol-type bar designs to connect the implants installed on the metal matrix. The project was created using 3D Geomagic (Geomagic, Morrisville, USA).

Based on the digital project, the PEEK bars were milled using a Victrex PEEK disk (Polifluor, São Paulo, Brazil) measuring 98.0 x 16.5 mm that was machined with a four-axis milling machine Zenotec Mini (Wieland Dental, Sttutgart, Germany).

Thirty PEEK bars were manufactured: 10 solid bars with rectangular cross-section, 10 T-shaped bars, and 10 inverted T-shaped bars. All bars measured 30 x 4 x 6 mm, and cantilevers measured 9mm in length (figure 1).

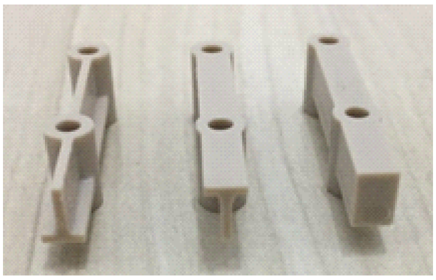


Figure 1. Three different designs of bars made of PEEK.

Based on the same digital project, a calcinable acrylic disk Burnout Vipiblock VBW (Vipi Produtos Odontológicos Ltda, Pirassununga, Brazil) was subjected to the same process to produce ten bars for each design with same dimensions as above to obtain 30 Ni-Cr metal bars. The milled bars were later subjected to induction casting using the metal alloy Liga N NiCr (Vipi Produtos Odontológicos Ltda, Pirassununga, Brazil). These were considered the control group (figure 2).

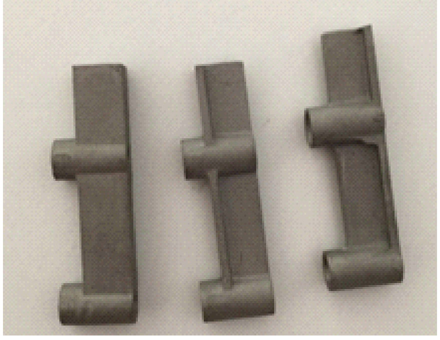


Figure 2. Three different designs of metal bars.

The bars were attached to the mini abutments using 3 mm prosthetic screws (Neodent, Curitiba, Brazil), with torque of 20N (as per manufacturer's instructions) applied with the digital torque-meter TQ 8800 (LT Lutron, Taiwan). The same torque-meter was used to measure the countertorque after the test.

The insertion torque was first applied to the screw next to the cantilever, then to the opposite screw in all test specimens – PEEK and metal. The same procedure was used for the countertorque.

Flexural mechanical test

The flexural mechanical test was conducted on a universal testing machine EMIC DL2000 (EMIC, São Paulo, Brazil) with load cell of 2000 kgf and actuator speed of 0.5 mm per minute.

During the test, a cylindrical shaft with straight tip was used to apply force, vertically, to the center of the bar's pontic, between implants. Flexural strength was registered in MPa. The test was terminated when the bar deformation reached 1.5mm or the force applied reached the equivalent to 200kg (figure 3).

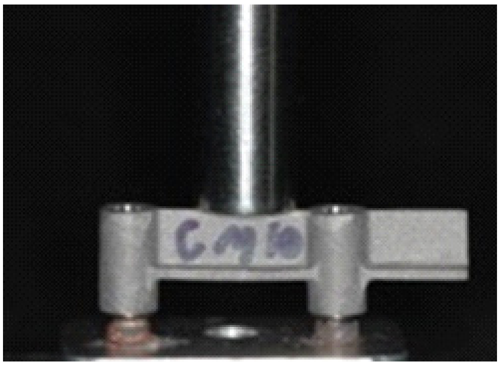


Figure 3. Mechanical test.

Statistical analysis

Data on torque and detorque were analyzed with two-way variance analysis to investigate the effect of the independent variables – type of material and bar design. Flexural strength data, which were not normally distributed and lacked variance homogeneity, were analyzed with the tests of Kruskal-Wallis and Mann-Whitney.

Dunn's test was used for the multiple comparisons.

All statistical calculations were conducted on SPSS 23 (SPSS Inc., Chicago, IL, USA), with 5% of significance.

RESULTS

The two-way variance analysis showed no significant difference in torque between PEEK or Ni-Cr alloy ($p = 1.000$). There was also no statistical difference in torque when comparing the T-shaped, inverted T-shaped and rectangular bars ($p = 0.589$; table 1).

Although the type of material (PEEK vs metal) showed no effect on detorque ($p = 1.000$), T-shaped and inverted T-shaped bars, that lacked statistical difference in terms of detorque, showed significantly lower results relative to rectangular bars (variance analysis: $p < 0.001$; table 1).

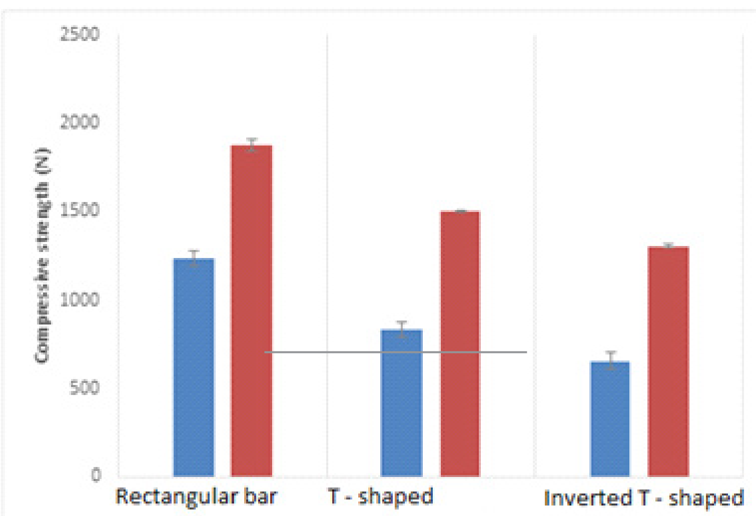
Caption: General averages followed by upper case letters indicate statistically significant difference between PEEK and Ni-Cr alloy, regardless of bar design. General averages followed by lower case letters indicate significant difference between bar design, regadless of material. Flexural strength averages followed by different upper case letters indicate significant difference between PEEK and Ni-Cr alloy considering the same bar design. Flexural strength followed by different lower case letters indicate significant difference between bar design considering same material.

Mann-Whitney's test showed higher flexural strength for Ni-Cr bars ($p < 0.001$) regardless of bar design. The Kruskal-Wallis's test showed that the rectangular design conferred higher strength than the T-shaped design, that, in turn, was higher than the inverted T-shaped, regardless of material ($p < 0.001$). On average, flexural strength of PEEK bars with the T-shaped and inverted T-shaped designs were 32.5% and 47.2% smaller than the rectangular design, respectively. On Ni-Cr alloy bars, T-shaped and inverted T-shaped designs showed 19.9% and 30.5% less resistance than the rectangular design, respectively (graph 1).

Table 1. Average and standard deviation of torque, detorque and flexural strength according to type of material and design of protocol-type bars.

Bar design		Type of material				General average	
		PEEK		Ni-Cr alloy			
Torque (N.cm	Rectangular	20.1	(0.2)	20.1	(0.2)	20.1 a	(0.2)
	T normal	20.2	(0.3)	20.2	(0.3)	20.2 a	(0.3)
	T inverted	20.2	(0.3)	20.2	(0.3)	20.2 a	(0.3)
	General average	20.2A	(0.3)	20.2A	(0.3)	–	
Detorque (N.cm)	Rectangular	10.9	(1.6)	10.9	(1.6)	10.9 a	(1.6)
	T normal	8.5	(0.9)	8.5	(0.9)	8.5 b	(0.9)
	T inverted	9.1	(1.5)	9.1	(1.5)	9.1 b	(1.5)
	General average	9.5A	(1.7)	9.5A	(1.7)	–	
Flexural strength(N)	Rectangular	1,234.68 (43.45)	Ba	1,874.68 (31.01)	Aa	–	
	T normal	832.88 (42.14)	Bb	1,501.87 (6.72)	Ab	–	
	T inverted	652.39 (47.10)	Bc	1,302.39 (8.78)	Ac	–	

Source: Own authorship.



Graph 1. Bar chart of average flexural strength according to type of material and design of protocol-type bars.

DISCUSSION

Currently, Co-Cr and Ni-Cr alloys with ceramic or acrylic coating are the most commonly used material in rehabilitations of protocol-type prostheses with metal structure [11]. This type of alloy has gained attention in the global market due to its excellent physical properties and low cost. However, despite the long-standing use and acknowledgement in the scientific literature and clinical practice, metal bars present some limitations [1,2]. Among those are reports of hypersensitivity [12], risk of metal ions release into the blood [1], casting issues, porosity [13], aesthetical deficiency, and poor absorption and dissipation of stresses [6,14]. In addition to that, they are thick and heavy, which favors the occurrence of fractures and the need for repairs due to the use of welding [15]. With this in mind, new metal-free materials are being investigated as alternatives that offer good performance, aesthetical features and less long-term risks to the patient.

One such alternative to metal is polyether ether ketone (PEEK), an organic synthetic polymer that offers the advantages of being ultralight [16], presenting elasticity similar to the bone's [14], no corrosion, minimal water absorption, radiotransparency, and being non-allergenic [17,18]. This new material has been researched in the medical field since the 1990's [7,19] and has shown promising mechanical properties and great versatility. It is biocompatible, stable at high temperatures, has great physical properties and good resistance to chemical damage [6,7] and abrasion [20]. Besides, PEEK bars can be manufactured in shorter time without loss in quality using the CAD CAM system [8] with different designs [2].

These features have contributed to the choice of PEEK as a study material against metal bars. By comparing their performance and different designs, it is possible to establish PEEK as an alternative to metal in protocol-type bars [21,22].

Fracture or deformation of a protocol bar are complications that may occur when a protocol-type prosthesis is placed into function [23]. However, the bar design and a larger cross-sectional surface area can minimize flaws and avoid fractures [24]. The design of the bars seeks to optimize physical and mechanical properties [15]. Hence, the present study corroborates results previously found that the bar design affects its flexural strength.

The flexural strength is a key parameter since it provides an estimate of the clinical performance of materials when subjected to occlusal forces. Here, the three types of bars studied showed different behaviors in the flexural mechanical test, regardless of material.

According to the literature, the bar design affects resistance and minimizes flaws [2]. This study references the choice of designs used here; however, here, force was applied to the pontic instead of the cantilever region. In both cases, the rectangular design conferred greater resistance to the bar, followed by the T-shaped design, and inverted T-shaped design with the lowest resistance result, both for metal and PEEK bars. The poor performance of the inverted T-shaped design might be due to a smaller surface area where force is applied, generating a point load with larger incidence of stress. However, some authors point out that solid bars transfer more load to the implants [2].

In the present study, PEEK bars showed smaller flexural strength than Ni-Cr alloy bars, with the rectangular design showing the largest resistance among the three. In agreement with some authors, PEEK should be considered as protocol bar material for the rectangular design, as it showed results that combine good ability to absorb load and adequate resistance for a good biomechanical performance of prosthetic structures [2]. Comparing the flexural strength of three high performance polymers (PEEK, Polyethersulfone - PES and Polyvinylidene Fluoride - PVDF), PEEK shows the largest flexural and creep strength [25].

Some studies report that protocol-type bars manufactured with resilient materials increase the stress between the retaining abutment screws [26]. However, the present study does not corroborate this finding since type of material (PEEK or metal) showed no effect on countertorque. Another study found that the distribution of stresses on the abutment is affected by the bar's design, the loading conditions acting on the mandible and, in a lesser degree, the coating material properties [27]. In the present study, the T-shaped and inverted T-shaped designs did not differ in terms of countertorque but showed significantly smaller values than the rectangular one.

Considering the results discussed above and because PEEK is a new material, further tests of resistance and behavior, including new methods and thermocycling, are needed to provide more evidences and a better understanding of the possibilities offered by this material.

CONCLUSIONS

Based on the results of this study, it is possible to conclude that:

- The bar's design influences its flexural strength. For both materials analyzed (metal or PEEK), the rectangular design conferred larger resistance than the T-shaped, which, in turn, showed more resistance than the inverted T-shaped design;

- Regardless of design, metal bars are more resistant to flexure than PEEK bars;

- Type of material (PEEK or metal) did not affect countertorque;

- The T-shaped and the inverted T-shaped designs did not differ in terms of countertorque but rendered significantly lower values than the rectangular bars.

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