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Strain gauge evaluation of bone microstrain in full-arch implant-supported prostheses: cobalt-chromium and fiberglass materials

Avaliação extensométrica de microdeformações ósseas em prótese implanto-suportada de arco completo: materiais cobalto-cromo e fibra de vidro

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ABSTRACT

Objective: This study addresses the strain gauge evaluation of bone microstrain in full-arch implant-supported prostheses using two distinct materials: Cobalt-Chromium (CoCr) and Fiber Reinforced with Composite (FRC). **Material and methods:** By employing strain gauge analysis, this study compares the mechanical properties of CoCr and FRC, noting that FRC bars exhibit significantly smaller microstrain under load, suggesting a more balanced strain distribution. **Results:** This finding may be attributed to the intrinsic material properties of each, where FRC offers relative flexibility and a modulus of elasticity closer to that of human bone tissue, promoting harmonious integration with peri-implant tissue. Additionally, the potential toxicity of CoCr alloys is addressed, emphasizing the importance of alternative materials that minimize health risks. **Conclusion:** This study contributes to the field of implant-supported rehabilitations, suggesting that FRC may offer significant mechanical and biocompatible advantages over CoCr. However, it underscores the need for further research to validate these findings.

KEYWORDS
Cobalt-chromium alloys; Dental prosthesis, Implant-supported; Elastic modulus; Fiberglass; Osseointegration.

RESUMO

Objetivo: Este estudo aborda a avaliação do extensômetro da microdeformação óssea em próteses implanto-suportadas de arcada completa utilizando dois materiais distintos: Cobalto-Cromo (CoCr) e Fibra Reforçada com Compósito (FRC). **Material e métodos:** Ao empregar análise de extensômetro, este estudo compara as propriedades mecânicas do CoCr e do FRC, observando que as barras do FRC apresentam microdeformação significativamente menor sob carga, sugerindo uma distribuição de tensão mais equilibrada. **Resultados:** Esse achado pode ser atribuído às propriedades intrínsecas do material de cada um, onde a FRC oferece relativa flexibilidade e módulo de elasticidade mais próximo ao do tecido ósseo humano, promovendo integração harmoniosa com o tecido peri-implantar. Além disso, é abordada a potencial toxicidade das ligas de CoCr, enfatizando a importância de materiais alternativos que minimizem os riscos à saúde. **Conclusão:** Este estudo contribui para o campo das reabilitações implanto-suportadas, sugerindo que a FRC pode oferecer vantagens mecânicas e biocompatíveis significativas sobre o CoCr. Porém, ressalta a necessidade de mais pesquisas para validar esses achados.

PALAVRAS-CHAVE
Ligas de cobalto-cromo; Próteses dentárias, Suportadas por implantes; Módulo de elasticidade; Fibra de vidro; Osseointegração.

INTRODUCTION

Oral rehabilitation with implant-supported prostheses has revolutionized treatment for edentulous patients, offering solutions that significantly improve quality of life. Since the introduction of the concept of osseointegration by Brånemark [1], dentistry has witnessed significant advances in the design and selection of materials for prostheses, aiming to optimize their longevity and functionality. The selection of material for prosthesis infrastructure is important, given its direct influence on load distribution and structural integrity of oral rehabilitations [2,3].

The introduction of alternative materials in the manufacturing of infrastructures for implant-supported prostheses has been a field of intense research in recent years. The growing interest in materials such as fiber-reinforced composite (FRC) is due to its unique properties, including excellent mechanical strength and lower thermal conductivity compared to traditional metals like cobalt-chromium (CoCr). Recent studies [4] highlighted the potential of FRC in the manufacture of prosthetic bars, demonstrating its ability to efficiently distribute masticatory loads while minimizing strains transmitted to peri-implant bone.

Furthermore, biocompatibility is an increasingly considered factor in the choice of materials for implant-supported prostheses. The literature shows that FRC-based materials offer additional advantages in these aspects, favoring a more harmonious integration with peri-implant tissue and not undergoing oxidation or releasing ions or byproducts into the body. The use of FRC in prosthetic infrastructures not only meets functional requirements but also promotes a favorable environment for the maintenance of peri-implant health [5], as corroborated by Pesce et al. (2019) [6], who demonstrated the favorable mechanical properties and biocompatibility of fiber-reinforced composites.

The choice of material for prosthesis infrastructure is fundamental for the success of oral rehabilitation. Al Jabbari (2014) [7] extensively explored the mechanical properties and biocompatibility of CoCr alloys, noting their exceptional strength and durability. However, the rigidity of these materials may result in a less-than-ideal load distribution, leading to adverse microstrain in the surrounding bone tissue. In contrast, Ferreira et al. (2014) [8] investigated the use of FRC, emphasizing its ability to offer a more favorable load distribution due to its relative flexibility and modulus of elasticity closer to that of natural bone.

Therefore, this study aimed to evaluate bone microstrain in edentulous jaws rehabilitated with four internal connection Morse cone implants, supporting hybrid prosthesis infrastructures made of CoCr and FRC. The objective is to investigate if there are significant differences in strain distribution between the two different protocol prosthesis infrastructures, hypothesizing that the distinct material properties of CoCr and FRC will influence the bone microstrain.

MATERIAL AND METHODS

For this study, a synthetic bone model simulating an edentulous jaw with mild atrophy was used, manufactured from polyurethane and endowed with elastic properties similar to human bone tissue [9,10]. Four cylindrical Morse cone implants (Torque Hard, Conexão Sistemas de Prótese, Arujá, São Paulo, Brazil) with a diameter of 4.0mm and length of 13mm each, were used. Additionally, prosthetic abutments (Solid Micro Units) manufactured by the same company, with Morse cone connection and a transmucosal height of 2.5mm, were employed.

The installation of the implants in the mandible model (Polyurethane) was carried out freehand taking care so that they were equidistant and parallel to each other. Then, they were fixed in the resin to simulate osseointegration. The scanning and design phase of the infrastructures was carried out using an intraoral scanner and CAD software, allowing the prosthetic infrastructures to be designed and manufactured to fit precisely to the previously installed implants (Figure 1).

The prosthetic infrastructures included Protocol-type bars made of CoCr (n=5) and FRC (n=5). These infrastructures were digitally designed using an intraoral scanner and Computer-Aided Design (CAD) software and subsequently manufactured using subtractive and additive manufacturing technologies, respectively, and had dimensions of 4.3x7x65mm (Figure 2). The design of the bar in its bilateral distal portion was made in an airplane wing shape. The length of the cantilevers was 12mm.

The bars were screwed onto the jaw model and the torque used was the torque suggested by the manufacturer.

For the evaluation of bone microstrain, strain gauges (PA-06-060BA-120-L (Excel Sensores Ind. Com. Exp. Ltda, Taboão da Serra, Sao Paulo, Brazil, resistance 120 Ω; gauge length: 1.5 x 1.3 mm) were fixed on the surface of the jaw model according to the spaces available between the implants (Figure 3), and their output channels and connection to the data acquisition machine were identified through colors. Red and yellow strain gauges were placed on the distal surfaces of the posterior and anterior implants on the right side, respectively. Green and blue strain gauges were placed on the distal surfaces of the posterior and anterior implants on the left side, respectively. The prosthetic infrastructures manufactured in CoCr and FRC were then subjected to static vertical loads of 100N at the end of the right cantilever, near the red strain gauge, to simulate masticatory forces. A load application device (LAD), developed by Nishioka et al. (2015) [11], was used (Figure 4).

The electrical cables were identified with colored tapes according to the previous description of the strain gauge group and

Figure 1 - Polyurethane prototype resembling an edentulous mandible with a flat base and borders with Conexão Torque Hard implants and prosthetic abutments installed.

Figure 2 - Top view of Cobalt-chromium and Fiberglass bars in the finalization process.

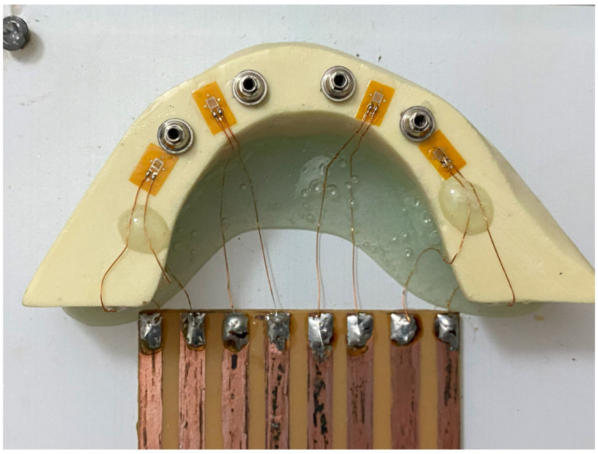

Figure 3 - Strain gauges fixed on the models.

Figure 4 - Test specimen finished with Cobalt-Chromium bar subjected to static compression with a force of 100N on the right cantilever end.

soldered to a copper electronic plate, connecting them directly to flexible electrical conductors with a diameter of 1.5 mm each, which in turn were connected to a data acquisition machine (ADS 2000 - Lynx Tecnologia Eletrônica Ltda. - SP - Brazil) through a base with identified connectors to minimize manipulation to the connectors of the Data Acquisition machine. This machine is responsible for receiving the signals resulting from the variation of the electric current flowing through the strain gauges, amplifying them, and converting them into digital signals. These signals were then sent to the computer, providing data on the microstrain ($\mu\varepsilon$/a) suffered by the test specimen (TS), through the AqDados7.2 software (Lynx Tecnologia Eletrônica Ltda. - SP - Brazil).

The statistical analysis of the data collected through the strain gauges was performed using ANOVA (Tables I and II) and Tukey's post-hoc test (Table III), aiming to compare the Strain distribution between the infrastructures manufactured from the two different materials and determine the existence of statistically significant differences between them.

RESULTS

In this study, it was observed that the FRC and CoCr bars exhibited distinct patterns of microstrain under a static axial load of 100N. The FRC bars demonstrated a more balanced distribution of strain, with significantly lower average microstrain values compared to the CoCr bars, as evidenced by ANOVA and Tukey's test statistical analyses, which revealed statistically significant differences between the materials ($p < 0.05$).

Specifically, the FRC bars exhibited lower microstrain on the Yellow and Blue strain gauges,

Table I - One-way ANOVA (Fischers's) statistical test for FRC and CoCr bars obtained through Jamovi computer software (Version 2.3)

	FRC	CoCr
F	34.3	17.4
df1	3	3
df2	96	96
p	<0.01	<0.01

Note: df = degree of freedom.

Table II - Descriptive table of means, standard deviation, and standard error of the tests performed on FRC and CoCr samples, obtained through Jamovi computer software (Version 2.3)

	FRC				CoCr			
	Red	Yellow	Blue	Green	Red	Yellow	Blue	Green
N	25	25	25	25	25	25	25	25
Mean	565.4	162.8	59.8	242.5	530.4	470.6	898.9	82.5
SD	280.2	156.1	67.3	178.3	138.0	345.4	704.3	81.3
SE	56.0	31.2	13.5	35.7	27.6	69.1	140.9	16.3

Note: Red = posterior implant on the right side; Yellow = anterior implant on the right side; Green = posterior implant on the left side; Blue = anterior implant on the left side.

Table III - Tukey's Post-Hoc statistical tests comparing the extensometers associated with Fiberglass and CoCr bars, obtained through Jamovi computer software (Version 2.3)

		Red-FRC	Yellow-FRC	Blue-FRC	Green-FRC
Red-CoCr	Mean difference	-35.0	–	–	–
	p-value	0.578	–	–	–
Yellow-CoCr	Mean difference	–	308	–	–
	p-value	–	<0.001	–	–
Blue-CoCr	Mean difference	–	–	839	–
	p-value	–	–	<0.001	–
Green-CoCr	Mean difference	–	–	–	-160
	p-value	–	–	–	<0.001

Note: Red = posterior implant on the right side; Yellow = anterior implant on the right side; Green = posterior implant on the left side; Blue = anterior implant on the left side.

suggesting a better capacity for load absorption and distribution. On the other hand, the CoCr bars showed higher microstrain values, particularly on the Blue strain gauge, indicating a possible concentration of strain and a less favorable load distribution, which may negatively influence bone integrity and long-term implant stability.

DISCUSSION

Long-term clinical success largely depends on the appropriate choice of materials and prosthetic infrastructure design, which should optimize load distribution and minimize strains transmitted to peri-implant bone [12].

The significant difference in microstrain between FRC and CoCr bars can be attributed to intrinsic material properties. FRC, with its modulus of elasticity closer to that of human bone tissue, allows for a more homogeneous load distribution and reduces the risk of concentrated strain points, which are detrimental to osseointegration and implant stability. This finding is corroborated by previous studies [4,13] which highlighted the mechanical superiority and biocompatibility of FRC in dental applications. Thus, when compared to other bar materials like titanium and CoCr, the fiber-reinforced resin bar exhibited lower weight and reduced approximately 25% of the generated strains [14].

On the other hand, the greater microstrain observed in CoCr bars can be explained by the rigidity of this material, which, despite its strength and durability, may lead to inadequate load distribution. This observation is consistent with the literature, which emphasizes the importance of the relative flexibility of the prosthetic material for favorable load distribution [7]. Additionally, the potential toxicity of CoCr raises additional concerns about its biocompatibility, especially considering the release of metallic ions into the oral environment, which can trigger adverse tissue reactions [15,16].

The choice between FRC and CoCr should not be based solely on mechanical considerations but also on biological, aesthetic, and financial criteria. While FRC bars have demonstrated mechanical and biocompatible advantages in this study, clinical experience, ease of handling, and cost are also relevant factors in clinical decision-making [17].

This study used the strain gauge method to measure and analyze the biomechanical behavior of two different material bars. It measures localized surface strain through changes in electrical resistance, offers high precision, and real-time data acquisition, and is relatively simple and cost-effective to implement [11]. Finite Element Analysis (FEA), a numerical method that subdivides structures into finite elements, allows for comprehensive internal strain analysis across complex geometries and conditions. Although highly versatile, FEA requires sophisticated software, and significant computational power, and depends heavily on model accuracy [3]. Photoelasticity employs polarized light to visualize stress distribution in transparent materials, providing full-field, non-intrusive stress patterns. However, it is predominantly qualitative and limited to specific materials [13].

Although a single operator performed the experimental work to ensure a standardized process, our data must be cautiously extrapolated to the clinical setting, as the complex biothermal mechanical factors of the oral environment are not considered in vitro testing.

This study contributes to the understanding of the biomechanical implications of different infrastructure materials in implant-supported rehabilitations, suggesting that FRC may offer a promising alternative to CoCr alloys. However, additional clinical studies are needed to validate these in vitro findings and explore the long-term clinical impact of these observations.

CONCLUSION

This study showed that FRC bars exhibited significantly smaller microstrain under load compared to CoCr. The behavior suggests that FRC is superior in force absorption and distribution when used for full-arch implant-supported prostheses. However, the importance of conducting further research, including clinical studies, to fully understand the impact of these results and improve oral rehabilitation techniques using implants, is emphasized.

Author's Contributions

WSO: Conceptualization, Methodology, Writing – Original Draft Preparation, Writing – Review & Editing. MSO: Writing – Original

Draft Preparation, Writing – Review & Editing, Translation. ASC: Methodology, Writing – Original Draft Preparation, Writing – Review & Editing. GSFAS: Supervision, Writing – Review & Editing. MAB: Supervision, Writing – Review & Editing. LNJ: Conceptualization, Supervision, Writing – Review & Editing.

Conflict of Interest

The authors have no conflicts of interest to declare.

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Regulatory Statement

None.

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