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Flexural Strength of Co-Cr Alloys for Porcelain-Fused-to-Metal Restorations

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Abstract

Cobalt-chromium (Co-Cr) alloys remain a fundamental material in prosthetic dentistry due to their high strength, durability, and corrosion resistance. The evolution of manufacturing technologies, including subtractive and additive methods, has introduced variations in the mechanical performance of these alloys.

Aim. This study aimed to evaluate and compare the flexural strength of Co-Cr alloys fabricated using three different techniques: conventional casting, CAD/CAM milling, and selective laser melting (SLM), using a classical three-point bending test.

Materials and Methods. Fifteen standardized specimens divided into three groups (n = 5 per group) were fabricated using casting, milling, and SLM. Flexural strength was evaluated using a three-point bending test under standardized conditions. Flexural strength test was carried out using a stand type MultiTest 2,5-i (Mecmesin Ltd, UK), calculating the force required to break the test bodies, following standard testing specifics. Statistical analysis was performed using one-way ANOVA followed by a post hoc LSD test at a significance level of $p < 0.05$.

Results. Statistically significant differences were observed among the groups ($p < 0.001$). The highest flexural strength was recorded in the PRINTED group (1422 MPa), followed by the CASTED group (903 MPa), while the lowest values were found in the MILLING group (670 MPa). Significant differences were identified between all groups.

Conclusion. Manufacturing technique has a significant influence on the flexural strength of Co-Cr alloys. Additive manufacturing demonstrated superior mechanical performance, followed by casting, while milling exhibited the lowest values.

Keywords: Co-Cr alloys, flexural strength, casting, milling, selective laser melting

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Introduction

Cobalt-chromium (Co-Cr) alloys are widely used in contemporary dentistry, particularly in the fabrication of fixed and removable prosthetic restorations, due to their high strength, corrosion resistance, and biocompatibility. Their favorable mechanical properties, including high elastic modulus and wear resistance, make them suitable for long-term clinical applications (1,2).

Traditionally, Co-Cr dental frameworks have been fabricated using the lost-wax casting technique. However, this method is associated with several limitations, such as porosity formation, microstructural heterogeneity, and casting defects, which may negatively affect mechanical performance (3,4).

With the advancement of digital technologies, CAD/CAM milling and additive manufacturing (AM) techniques, particularly selective laser melting (SLM), have emerged as reliable alternatives. These methods allow improved control over material composition and microstructure, resulting in enhanced mechanical properties (5,6).

Several studies have demonstrated that SLM-fabricated Co-Cr alloys exhibit finer microstructures, reduced porosity, and improved mechanical properties compared to cast alloys (7,8). Milling, on the other hand, ensures high material homogeneity due to the use of pre-fabricated industrial blanks, although its mechanical performance may vary depending on processing conditions (2,6).

Flexural strength is a critical parameter in dental materials, as it reflects the material's resistance to deformation and fracture under functional loading conditions. Previous studies have shown that the manufacturing technique significantly influences the flexural strength of Co–Cr alloys, with additively manufactured materials often demonstrating superior performance compared to conventionally cast alloys (5,9,10).

Despite the increasing use of digital manufacturing methods, comparative data on flexural strength among casting, milling, and additive manufacturing remain limited. Therefore, further investigation is required to better understand the influence of fabrication techniques on the mechanical behavior of Co-Cr alloys.

Aim

This study aimed to evaluate and compare the flexural strength of Co-Cr alloys fabricated using three different techniques: conventional casting, CAD/CAM milling, and selective laser melting (SLM).

Materials and Methods

A total of 15 Co-Cr specimens were fabricated and divided into three groups (n = 5) according to the manufacturing method:

- Casted
- Milling
- Printed (SLM)

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All specimens were standardized in dimensions for length, width, and height: 25x3x0.5 mm, and subjected to identical surface treatment. Flexural strength was evaluated using a three-point bending test performed under standardized conditions.
The test for determining three- point bending strength was performed on a MultiTest 2.5i stand (Mecmesin Ltd, UK) under the following testing conditions:

- Inter-support distance - 20 mm
- Crosshead speed – 1 mm/min
- Ambient temperature – 23°C

The inter-support distance of the fixture for positioning the sample is specifically recalculated and adjusted before experimental loading. The collection of test results starts from the initial contact of the loading and continues until a visibly sustained decrease in the resistance force of the test specimen.

The flexural strength (σ) was calculated using the formula:
$\sigma = 3FL / 2bh^2$

- F - maximum load (N)
- L - span length (mm)
- b – width of the test specimen (mm)
- h - thickness of the test specimen (mm)

The null hypothesis stated that there is no difference in flexural strength between the manufacturing methods.

The statistical methods used in the present study included:

- Descriptive statistics:
  - Mean value (Average) – a measure of central tendency;
  - Standard deviation (SD) – a measure of data dispersion;
  - Absolute frequency (N) – indicating the number of observations;
- Inferential statistics (hypothesis testing):
  - A parametric test for comparison of k independent groups (one-way ANOVA);
  - A post hoc test (based on the Least Significant Difference test) to determine between which of the k independent groups statistically significant differences exist.

All hypothesis tests were conducted at a significance level of 5% ($p < 0.05$).
Statistical analyses were performed using IBM SPSS Statistics 26, while graphical representations were created using Microsoft Excel 2010.

Results

The results demonstrated clear differences in flexural strength between the groups. The highest mean value was observed in the PRINTED group (1422 MPa), indicating superior mechanical performance compared to the other methods. This was followed by the CASTED group with a mean value of 903 MPa, while the lowest flexural strength was recorded in the MILLING group (670 MPa) (Fig. 1).

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In terms of variability, all three manufacturing methods exhibited relatively low standard deviations, indicating consistent mechanical behavior within each group.

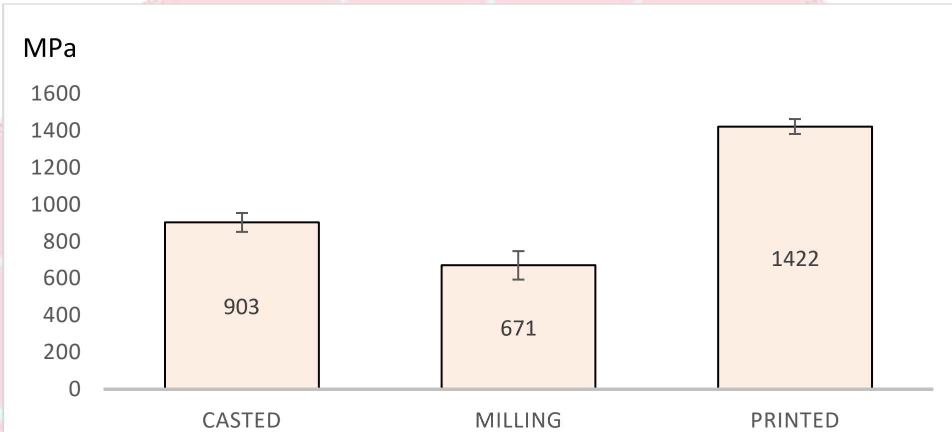

Figure 1. Results of the Analysis of Flexural Strength

Whether a significant difference exists among the three manufacturing methods was determined through hypothesis testing. The null hypothesis stated that the different manufacturing methods do not result in differences in flexural strength, whereas the alternative hypothesis stated that the manufacturing methods lead to differences in flexural strength.
The distribution of flexural strength values was evaluated using the Kolmogorov–Smirnov test, which demonstrated that the data for all groups followed a normal distribution. Therefore, the statistical analysis was performed using one-way analysis of variance (ANOVA) to compare the independent groups.

To determine more specifically between which manufacturing methods the differences were statistically significant, a post hoc test was performed. The analysis revealed statistically significant differences between all manufacturing methods. This indicates that the PRINTED method demonstrated significantly higher flexural strength compared to the other methods, followed by CASTED, and finally MILLING (Table 1).

Table 1. Flexural strength values for the three manufacturing methods

Experimental group / Measured parameter	Properties	Tested methods		
		CASTED	**MILLING**	**PRINTED**
Flexural strength	Mean	903 ^{A}	671 ^{B}	1 422 ^{C}
	SD	± 51	± 77	± 40
	N	5	5	5
ANOVA test	**P-value**	**p<0.001**		

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The level of significance obtained from the analysis ($p < 0.001$) is lower than the accepted error risk of 5%; therefore, the alternative hypothesis is accepted, stating that different manufacturing methods result in different flexural strength values.
These conclusions can be stated with a confidence level of 95%.

Discussion

The present study demonstrated that the manufacturing method has a statistically significant influence on the flexural strength of Co-Cr alloys, confirming the rejection of the null hypothesis. The PRINTED group exhibited the highest flexural strength, followed by CASTED and MILLING, with statistically significant differences observed between all groups.
The inferior performance of the cast specimens can be attributed to the inherent limitations of the casting process. It is well documented that casting introduces microstructural defects such as porosity, dendritic structures, and elemental segregation, which act as stress concentrators and reduce mechanical strength (3,4,11).
The relatively low flexural strength observed in the milling group in the present study is noteworthy. Although CAD/CAM milling is generally associated with improved homogeneity and reduced internal defects, several studies have reported variability in mechanical properties depending on the characteristics of the prefabricated alloy blocks and machining-induced stresses (6,12,13).
The superior performance of the PRINTED group is consistent with current literature on selective laser melting. Additive manufacturing produces a fine-grained, dense microstructure due to rapid solidification, which enhances mechanical properties such as strength and hardness (7,8).
Previous studies have reported that SLM-fabricated Co-Cr alloys exhibit significantly higher flexural strength compared to cast alloys, with values often exceeding 1900 MPa (5,9). These findings support the results of the present study, where the PRINTED group demonstrated the highest mechanical performance.
The statistically significant differences observed between all groups emphasize the critical role of manufacturing technology in determining the mechanical behavior of Co-Cr alloys. The improved performance of additively manufactured materials is primarily attributed to reduced porosity, improved microstructural uniformity, and enhanced interlayer bonding (14,15).
From a clinical standpoint, increased flexural strength is associated with improved fracture resistance and long-term durability of dental prostheses. Therefore, the use of SLM-fabricated Co-Cr alloys may provide significant clinical advantages, particularly in high-load applications.
Nevertheless, the present study has limitations, including the small sample size and the evaluation of a single mechanical property. Additionally, factors such as build orientation, heat treatment, and post-processing procedures were not considered, although they are known to influence the mechanical performance of additively manufactured materials (14,15).
Future research should focus on comprehensive mechanical characterization, including fatigue behavior and fracture toughness, as well as long-term clinical studies.

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Conclusion

The manufacturing method has a significant influence on the flexural strength of Co-Cr alloys. The highest values were observed in the PRINTED group, followed by CASTED, while MILLING showed the lowest flexural strength. All differences were statistically significant. Additive manufacturing demonstrates superior mechanical performance and represents a promising alternative to conventional fabrication methods.

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