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Impact on Shear Bond Strength of Ceramic to Castable Nickel Chromium Beryllium-Free Alloys Following Lanthanum Addition: An In-Vitro Study

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KEYWORDS

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ABSTRACT:

Introduction: Metal-ceramic restorations are crucial in dental prosthetics, but adhesive failures between ceramic and metal frameworks can weaken their effectiveness and longevity. Nickel-chromium (Ni-Cr) alloys, routinely utilized in these restorations, might encounter adhesive bond strength and biocompatibility issues. This study explores adding lanthanum to Ni-Cr beryllium-free alloys to enhance the alloy's microstructure and strengthen the metal-ceramic bond, aiming to improve restoration durability and efficiency.

Objectives: The purpose is to test the shear bond strength of castable Ni-Cr beryllium-free alloy to porcelain after adding lanthanum by weight (0.07%) and assess its impact on bond strength.

Methods: Sixty cylindrical wax patterns (5 mm diameter, 15 mm height) were fabricated and divided into two groups: Group A (control group, Ni-Cr alloy without lanthanum) and Group B (with 0.07% wt. lanthanum micro-particles added during casting). The wax patterns were induction cast, then trimmed, polished, and measured. Ceramics sintering measuring 5 mm in height and 5 mm in diameter were built on top of a metal cylinder. A universal testing machine was used to evaluate shear bond strength. The statistical analyses were carried out using SPSS software version 29.0.

Results: The mean shear bond strengths (MPa) for Group A was 30.64 (SD = 7.803), while Group B had a mean of 48.35 (SD = 7.803). Statistical analysis utilize the Student's t-test demonstrated a significant difference between the groups ($P < 0.05$). This finding indicates that the addition of lanthanum significantly improved the shear bond strength of the nickel-chromium beryllium-free castable alloy.

Conclusions: The addition of 0.07% lanthanum significantly improved the bond strength between Ni-Cr beryllium-free alloy and ceramic thereby enhancing restoration durability, biocompatibility, and patient satisfaction.

Introduction

The development of dental restorations has been a crucial aspect of dentistry, with the primary goal of restoring the function and aesthetics of teeth. Dental restorations, such as Metal–ceramic and all ceramic crown & bridges, have gained popularity due to their aesthetic appeal, biocompatibility, and durability. However, the bond between metal and ceramic

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restoration and the underlying tooth structure is crucial for the long-term success of the restoration. In the late 1970s, a significant surge in the price of gold provoked a notable shift towards the use of nickel-based alloys for Ceramic-to-metal restorations. These alloys, composed predominantly of nickel (60-82%), chromium (11-20%), molybdenum (0-9%), and beryllium (0-2%) by weight, which gained widespread popularity.[1] At present, the Ni-Cr alloy, whether with or without beryllium, dominates as the primary base metal alloy utilized in clinical applications.[2] In light of the frequent instances of Ceramic chipping and the escalating importance given to enhance shear bond strength between metal and Ceramic,[3] there is a growing demand for alternative alloys that promise enhanced compatibility and durability in dental prosthetics. There exists a contemporary inclination to substitute the commonly utilized Ni-Cr alloys, employed in conjunction with dental ceramics, with Co-Cr alloys, perceived to possess superior biocompatibility.[4] In accordance with a research investigation, chromium and beryllium emerge as the most toxic component in dental alloys, with nickel exhibiting a moderate level of toxicity.[5] Beryllium manifests toxicity as both a dermal irritant and an inhalation hazard, capable of inducing dermatitis, acute pneumonitis, and chronic pulmonary disorders.[6] Lanthanum oxide nanoparticles are widely acknowledged for their biocompatibility and have undergone scrutiny for prospective biomedical applications.[7] In 2019 an in vitro investigation by Yanan Zhou et al. examined the impact of Lanthanum on the bond strength between dental casting Co-Cr alloys and ceramics. The conclusions emphasized the amplified bond strength resulting from the incorporation of La, primarily attributed to an augmentation in the thickness of the oxide and diffusion layers.[8]

Objectives

The primary objective of this research is to investigate the influence of lanthanum addition, in weight percentage, on the shear bond strength between castable Nickel Chromium beryllium-free alloy and porcelain, a prevalent material in dental applications. Specifically, the study aims to elucidate the effect of lanthanum on the bonding characteristics of Nickel Chromium beryllium-free alloy with porcelain and ascertain whether the incorporation of 0.07% lanthanum by weight enhances the bond strength. By examining the integration of lanthanum into dental alloys, this investigation endeavours to provide scholarly contributions towards advancing the development of dental materials and refining clinical practices to ultimately benefit patient care.

Methods

In this investigation, sixty cylindrical wax patterns (5 mm base diameter, 17 mm height) were meticulously crafted utilizing Stick Inlay wax (GC Corporation in Tokyo, Japan). The precision of these dimensions was validated using a digital Vernier Calliper (Cobra Metal Productions, Ontario, Canada). The patterns were systematically assigned into two distinct groups: Group A, designated as the control, featured a Nickel Chromium beryllium-free castable alloy (Star Alloy N Dentsply Sirona Germany) without Lanthanum addition. Whereas Group B with precisely measured 0.07% weight of Lanthanum micro particle incorporated in Nickel Chromium beryllium-free castable alloy during casting procedure. Subsequently, the patterns were fixed to a Crucible Former, and a Ring Liner was placed inside the Casting Ring. Prior to investment, a debubblizer (Waxit Evonik Degussa GmbH, Germany) was applied, and investment was manually mixed & poured in the casting ring and allowed to set. After that casting was executed using an Induction-Casting Machine (Ducatron Series 3; Ugin Dentaire, France). Post-casting procedures include trimming, polishing, and precise measurements by a digital Vernier caliper. Followed by sandblasting with airborne-particle 110-μm aluminum oxide, and then thorough ultrasonic cleaning (Vitasonic II; VITA Zahnfabrik, Germany) was performed. The ceramic (Ceramco 3 Dentsply Sirona Inc) sintering or layering was performed using the Vacumat 40 furnace (VITA Zahnfabrik), adhering strictly to the manufacturer's precise recommendations and dimensions of 5mm length and 5mm diameter (Figure 1). After this the samples were ready for testing. To evaluate shear bond strength variations among lanthanum concentration groups, shear bond tests were performed using an Instron universal testing machine. The machine was loaded at a crosshead speed of 1.0 mm/min and 200 Kgf of load with a circular shape shear-tip. Bond strength was determined until fracture

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occurred. The resulting data underwent statistical analyses utilizing SPSS software.

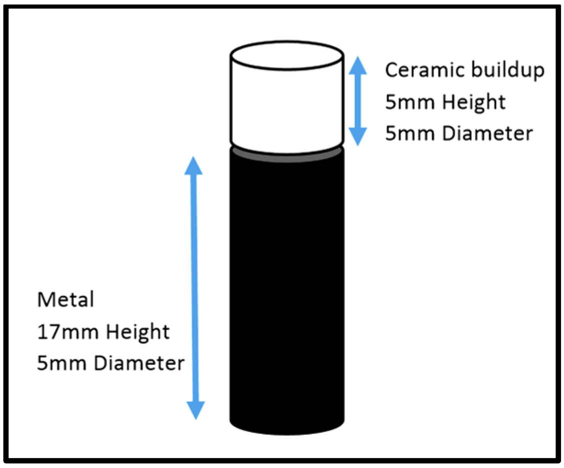

Figure 1- Describes dimensions of samples

Results

The results indicated statistically significant differences between the groups, where $P < 0.05$. By applying descriptive analysis on SPSS software Table II depicted that group B exhibited a superior mean bond strength compared to group A. The mean bond strengths (MPa) for Group A were 30.64 and for Group B 48.35 with Standard Deviation of 7.803. Graph I illustrate difference in mean of both groups. Results of student T-test results Table III demonstrates that the mean paired difference between the groups is not equivalent to zero. Stereomicroscopic Visual examination reveals that Group B exhibit higher cohesive fractures than adhesive (Picture1). Homogeneous distribution of samples and groups names is listed in Table I.

S.No.	**Groups**	**Lanthanum (LA) %**	**Number of samples**(n)
1	Group-A	0% of weight Lanthanum	**0**
2	Group-B	0.07% of weight Lanthanum	**30**
Total			**60**

Table 1- Division of test groups according to Different Lanthanum concentration in Nickel Chromium beryllium free alloy

S.No.	**Groups**	**Minimum**	**Maximum**	**Mean**	**SD**	**SE**
1	Group A	26.18	34.60	30.64	2.707	0.494
2	Group B	38.40	61.50	48.35	6.461	1.179

Table 2 – Mean bond strength between the test groups n=60

Pair	**Paired Differences**					**t**	**df**	**P value**
	Mean Difference	**SD**	**SE**	**95% Confidence Interval**				
				Lower	**Upper**			
Group 1 & Group 2	**-17.717**	**7.803**	**1.4247**	**-20.6316**	**-14.8037**	**-12.436**	**29**	**0.00***

Table 3- Mean difference between both the groups by applying Student's paired T- test

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Figure 2- Stereo-microscopic picture at 80x magnification showing cohesive fracture in Group B

Discussion

The widespread adoption of metal-ceramic restorations in dentistry persists, even as significant attention is directed towards advancing metal-free alternatives. A pivotal aspect of the efficacy of metal-ceramic restorations lies in establishing a reliable bond between the veneering ceramic and the alloy.[9] Various factors, such as thermal coefficients, micro-cracks in the Ceramic, and exposure to occlusal loads or trauma, can contribute to the breakdown of the metal-Ceramic bond. Ceramic detachment from the metal surface is the second most common reason for replacing metal-ceramic restorations.[10] Microscopic analysis identifies the metal-ceramic bonding mechanism as involving chemical bonding, mechanical bonding, compressive bonding, and Van der Waals forces. Chemical bonding, influenced by reactions at the metal-ceramic interface, relies on interactions between metal oxides and amorphous glass phases. Mechanical bonding is influenced by alloy surface treatments and wettability between the alloy and ceramics.[11] Drawing from various conducted studies, the decision to utilize 110 µm aluminium oxide particles for sandblasting of all alloys demonstrated highest mechanical bond strength values.[12-14] Concerns arise regarding the castability and porcelain bond strength of alloys when beryllium free Ni-Cr is used. Incorporating beryllium into the Ni-Cr alloy aims to improve its wettability during melting and enhance castability.[15-17] Rare earth (RE) element, lanthanum, plays a significant role in metallurgy, contributing to strengthening, melt purification, and grain refinement.[18,19] Exceeding the specified values for La additions will result in excessive oxidation, leading to a darkening of the surface colour and posing a health hazard.[8] Consequently, the maximum La addition in this study was limited to 0.07 wt.%. Previous studies highlight the crucial role of oxides in the chemical mechanism of metal-ceramic bonding. Oxidation at different temperatures results in the identification of oxides of various elements, with nickel oxide (NiO) and chromium oxide (Cr2O3) being prevalent at elevated temperatures. Lanthanum exhibits a pronounced chemical affinity towards oxygen and reacts with oxides, leading to the formation of lanthanum oxide (La2O3) during Ceramic firing.[20] This alters the oxide layer's composition, including NiO, Cr2O3, and La2O3, enhancing mechanical bonding. Lanthanum's reaction with Chromium Oxide (Cr2O3) and Aluminium Oxide (Al2O3) modifies the oxide layer's permeability at interface, facilitating atom diffusion and promoting chemical bonding between metals and ceramics. Simultaneously, La addition enhances resistance to high-temperature oxidation.[21] Weathering Steel formulations containing lanthanum have demonstrated improved malleability, wettability, impact resistance, reduced corrosion, reduce thermal coefficient and ductility.[22-25] Hammad IA and Stein RS contributed to the development of circular interface shear bond tests, emphasizing a consistent testing methodology for assessing shear bond strength.[23] The reported mean shear bond strength between a nickel-chromium alloy and ceramic materials falls within the range of 21 to 33 megapascals (MPa),[26-28] the present study investigated the bonding strength between a dental ceramic and a nickel-chromium beryllium-free castable alloy containing lanthanum, resulting in a reported mean shear bond strength of 48.35 MPa. Statistically significant differences between the groups, where found the $P<0.05$. In Group B, the mode of failure predominantly exhibited cohesive characteristics within the ceramic (Figure 2).

Conclusion

Consequently, according to the findings acquired, the Ni-Cr-La alloy shows promise for effective utilization with the porcelain systems employed in this investigation, thus offering potential benefits for hypersensitive patients. However, the favourable

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compatibility observed between the Ni-Cr Lanthanum alloy and the porcelain in this study underscores the necessity for additional research to address long-term clinical trials.

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