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Ionic release of dental cobalt-chromium based alloys

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Abstract

Background: Since the 1980s, as the cost of noble metals has increased, more base metal alloys have been used in fixed and removable prostheses. Cobalt-chromium (Co-Cr) alloys are one of the most widely used base metal alloys in the prosthetic dental department and have several clinical uses. Co-Cr alloys are frequently used as having excellent biocompatibility, great strength, good resistance to tarnish, corrosion, and wear, as well as being heat-resistant and non-magnetic. **The objective** of this study was to compare the influence of two different production processes by utilizing five groups with varying amounts of Co-Cr alloy in each group on the release of metal ions in artificial saliva. **Materials and Methods:** For the ion release test, seventy specimens of a cobalt-chrome alloy disc with dimensions of 5 mm in diameter and 3 mm in thickness were created. They were divided into five groups, each of which had 14 specimens, based on the manufacturing method as follows: new cast alloy group; selective laser melting group (3D printer specimens); once recast alloy + old selective laser melting group; new cast + once recast alloy group; once recast alloy group. **Result:** The outcomes showed that there were no statistically significant differences in ion release in any of the groups examined (P>0.05).**Conclusion**: The production technique and alloy composition have a slight influence on ion release. A positive clinical response is anticipated, since it was found that every group met the ionic release criteria of the international standards.

Keywords: new casting; recasting; selective laser melting; ion release; artificial saliva.

Introduction

Since the 1980s, as the price of noble metals has risen, the use of predominantly base metal alloys in fixed and removable prosthetics has increased, One of the most popular base metal alloys in dentistry, cobalt-chromium (Co-Cr) alloys, has a variety of useful clinical applications **(Al Jabbari, 2014)**. Co-Cr alloys are often considered of as alloys with high strength, good resistance to wear, corrosion, and tarnish, as well as being heat-resistant and non-magnetic. They have great biocompatibility **(Viennot et al., 2005)**, and their high modulus of elasticity gives them the necessary strength and stiffness without requiring them to have large cross-sections, so allowing a lighter metal substructures **(Marti, 2000)**. Corrosion is the degradation of materials caused by the harsh action of the environment, including oral secretions and the atmosphere **(Denizoğlu et al., 2004)**. The corrosion resistance of alloys and their biocompatibility are intimately connected. The amount of metallic ions released into the oral cavity as a result of corrosion determines how poisonous dental casting alloys are **(Jayaprakash et al., 2017)**. The presence of saliva, acidic bacterial plaque, alterations in pH and temperature caused by the ingestion of food and beverages, as well as the effects of various drugs, make the oral environment an ideal place for corrosion **(Lucchetti et al., 2015)**. Despite the frequency of oral mucosa allergies, chromium allergies have been recorded in the general community, with typical values between 3% (women) and 10% (men) (Greig, **1983)**. Cobalt is a is an essential trace element, and forms part of the active site of vitamin B12, which is necessary for DNA synthesis, the production of red blood cells, and neurological and immune system function **(Sengupta et al., 2014)**. The alloy's composition and structure have a significant impact on its biocompatibility. When Co, Cr, and Mo are released from Co-Cr alloys, the surrounding tissue may undergo inflammatory responses, discoloration, and hyperplasia **(Karimi and Alfantazi, 2014).**The casting process is used to create most dental restorations, which produces poor accuracy and adequate quality **(Dolgov et al., 2016)**. Lost-wax traditional casting techniques were primarily used to create dental metal restorations. The classic techniques, including casting, plastic deformation, and numerous other stages with significant handmade components, form the foundation of these traditional technologies. Significant efforts have been made over the past few decades to create alternative manufacturing technologies that overcome the issues with traditional fabrication techniques. The production of dental products has seen a constant progression from conventional techniques, such as casting, to computer-aided design and manufacturing techniques, which require an even higher level of technological expertise. To make Co-Cr dental prostheses, a variety of production processes, including computer-aided design and manufacturing (CAD-CAM) milling, selective laser melting (SLM), and direct metal laser sintering (DMLS), are commercially accessible **(Padrós et al., 2020).** SLM improves production quality by decreasing operator error and casting defects **(Xin et al., 2014).** But the limitations of selective laser melting are its slower processing and higher price **(Zaharia et al., 2017).** Many researchers suggest using 50% of the already cast metal alloy buttons that have been taken out of the castings **(Thopegowda et al., 2014).** For financial reasons, the button can be recycled to produce a high-quality casting, with the production of castings that appear clinically **acceptable (Agrawal et al., 2015)**.Several important secondary elements that were present in trace amounts in the basic alloy compositions may be lost during the casting process through volatilization or oxidation during remelting processes, even though the explanations for not reusing already cast metal have not been thoroughly studied and documented. It has also been demonstrated that recasting metals changes their mechanical properties, resistance to corrosion, and biocompatibility **(Thopegowda et al., 2014)**. The manufacturing processes determine the degree of metal released **(Hedberg et al., 2014).** The study's main objective was to compare the effects of two different production processes on the metal ion-release behaviors in artificial saliva at 37°C, evaluated using five groups that included various combinations of Co-Cr alloy percentages.

Materials and Methods

1. Study Specimens' Design and Grouping

70 specimens of a cobalt-chrome alloy disc with a diameter of 5 mm and a thickness of 3 mm were produced **(Thopegowda et al., 2014)**, and they were classified into five groups according to the production process, each group contain 14 specimens as follows:

1. New cast alloy group.
2. Selective laser melting group (new 3D printer specimens).
3. (Old cast alloy+ old 3D printer) group.
4. (New cast+ old cast) alloy group.
5. Old cast alloy group.

2. Specimens Preparation

a. Selective laser melting specimen's preparation (new 3D printer)

Disc form data was designed utilizing the program (Autodesk 3ds max 2022, USA) to fabricate the specimens **(Choi et al., 2014).** Adding Co-Cr powder to the Selective Laser Melting (SLM) machine (SHINING 3D EP-M150, Hangzhou, China) with the chemical composition listed in Table 1. In accordance with the manufacturer's specifications, the following parameters are employed with an SLM system that uses Ytterbium fiber with a wavelength of 1060–1100 nm: laser beam diameter of 0.1 mm, powder layer thickness of 0.03 mm, laser output of 195 W, scan speed of 1200 mm/s, and track spacing of 0.09 mm. The SLM framework was stripped of its manufacturing platform. The platform was scrubbed with a bristle after emptying the powder that hadn't yet been utilized. A suitable oven with a temperature of 650 °C was used to host the removable part of the manufacturing platform carrying the produced specimens. The temperature increased by 800 °C in 12 minutes and stayed there for 15 minutes. Later, the temperature was decreased to 550°C. The platform was then moved from the oven. Tweezers were employed to remove the specimens from the platform after it had been heated to relieve stress and cooled. Then, at a pressure of 3bar, 250 µm aluminum oxide particles were sandblasted onto each specimen **(Choi et al., 2014)**

Table (1): Composition of (Mediloy S-Co, BEGO, Germany) Co-Cr alloy used according to manufacturer's instruction.

Component	Weight percentage (wt. %)
Co	63.9
Cr	24.7
W	5.4
Mo	5.0
Si	1.0

b. Cast specimens preparation

Pre-designed specimens were converted to a three-dimensional system (Asiga MAX UV, 3D printer, Sydney, Australia) and castable modeling resin was used to fabricate them.

The cast specimens were divided into four groups as follows:

The first group was 100% new cast alloy, the second group was 50% old cast alloy+50% spruse of selective laser melting, the third group was 50% new cast alloy+50% old cast alloy, and the fourth group was 100% old cast alloy. The disc-shaped specimens were created using phosphate-bonded investment material (XACT, Dentify, Germany), and they were cast using a Co-Cr metal alloy (Wirobond SG, BEGO, Germany), which has the elemental composition listed in Table 2. For the first group, burnout was done using an electrical burnout furnace and casting was done using an induction casting machine. The procedures were completed in accordance with the manufacturer's instructions, which required cooling at room temperature, divesting, and sandblasting with 250µm aluminum oxide particles at 3 bar pressure with a 20 mm gap and a 45° angle between the specimens' surface and the nozzle **(Choi et al., 2014)**.

Table 2: Composition of (Wirobond SG, BEGO, Germany) Co-Cr alloy used according to manufacturer's instruction.

Component	Weight percentage (wt. %)
Co	63.8
Cr	24.8
W	5.3
Mo	5.1
Si	1.0

To facilitate the casting process , the recasting was performed using a cylindrical wax model **(Nandish et al., 2020)**.The second group was created by combining 50% Co-Cr alloy that had previously been cast once more in a cylindrical model with 50% sprues of finished specimens of selective laser melting. Third group of specimens was made by combining 50% of Co-Cr alloy that had just been received from manufacture with 50% of Co-Cr alloy that had previously been recasted from the cylindrical model. And the fourth group of specimens was made entirely from Co-Cr alloy that had previously been recasted from the cylindrical model. All groups were processed using the same procedure as group one.

All metal specimens of each five groups were washed with alcohol (ethanol 97%) and rinsed with distilled water for 5minutes (**Nejatidanesh et al., 2005**).

3. Artificial Saliva preparation

The artificial saliva was made with the following ingredients: combine 0.22 g of K_2HPO_4, 1.19 g of KCI, 0.29 g of KSCN, 0.26 g of Na_2HPO_4, 0.69 g of NaCl, 1.49 g of $NaHCO_3$, and 1.49 g of urea and lactic acid then mixed with 1000 ml of distilled water to produce a 6.8 pH artificial saliva solution **(Padrós et al., 2020)**

4. Testing Procedure

The specimens were immersed in a polypropylene test tube filled with 10 ml of artificial saliva solution, which was held in a tubes rack and incubated at 37 C for 30 days (**Jayaprakash et al., 2017**).

After 30 days of immersion, 0.5 ml of the immersion solution was taken from each test tube, and Co and Cr ion concentrations were detected using an analytical method for elemental analysis known as inductively coupled plasma optical emission spectrometry (ICP-OES). According to the manufacturer's instructions, ICP-OES uses inductively coupled plasma that provides an analytical technique used for elemental detection. Each reading was used to determine the average concentration of the different elements in parts per million released from the alloy.

5. Statistical Methods

The data were analyzed with the use of the software program SPSS, which performed descriptive statistics and one-way ANOVA test to compare among the test groups.

6. Results

Generally, there wasn't any Cr ion release for any of the tested groups, and there was no Co ion release for the old cast group. The remaining tested groups showed releases of Co ions at different concentrations. As shown in Table 3 and Fig. 1.

Table (3): Descriptive statistics of the Ion release test for the studied groups (Cobalt ion)

Studied Groups	N	Groups	Mean of CO.	SD	Min.	Max.
New Cast	14	**Group A**	.0608	.010076	.044	.077
New (3D) Printer	14	**Group B**	.0564	.009070	.039	.068
Old Cast + Old 3D Printer	14	**Group C**	.0557	.014121	.033	.074
Old Cast + New Cast	14	**Group D**	.0546	.008345	.043	.070

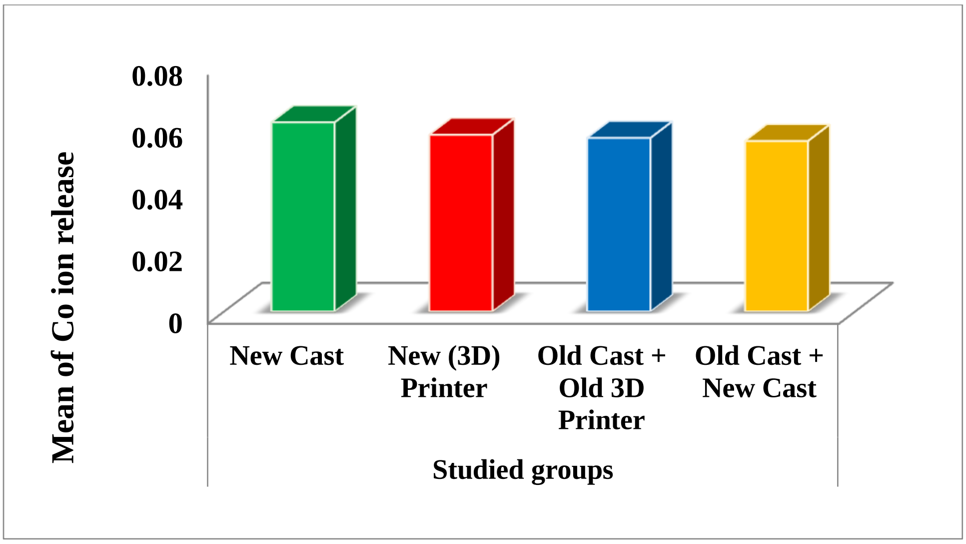

Figure 1: Bar chart showing the mean distribution of Co ion release of the studied groups

Table 4 shows the difference in Co ion release values using one-way ANOVA test in which there is no statistically significant differences (P>0.05) between each of the studied groups.

Table (4) Statistical analysis (ANOVA) to compare the difference in average Ion release test between different studies groups (Cobalt ion)

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	3	.000	.916	.440 (NS)
Within Groups	.006	52	.000		
Total	.006	55			

*** The mean difference is significant at the 0.05 level**.

7. Discussion

The aim of this research is to examine the effects of two distinct manufacturing techniques on the metal ion-release in artificial saliva at pH of 6.8 at a temperature of 37°C. This was done using five groups with varied percentages of Co-Cr alloy in each group. Numerous variables, including composition, metallurgical state, surface conditions, and environment, have an influence on the rate of corrosion **(Schmalz and Garhammer, 2002)**.

According to the findings of the present investigation, there is no cobalt ion release in saliva at pH 6.8 for the old cast group. And the new cast group had the highest ion release but with no significant difference. For cast alloys, local differences in composition and the heterogeneous microstructure with the presence of carbides and multiple phases lead to lower corrosion resistance and increased ion release. Carbon is included in dental alloys in trace amounts (> 1%), but is typically not listed in the manufacturer's alloy composition. The presence of carbon near grain boundaries in the form of carbides may drain the region of potentially significant passive components, such as Cr, that might speed up corrosion in these regions (**Viennot et al., 2005)**. The structural discontinuities, microstructural differences, and chemical differences from the bulk grains are seen at grain borders and interdendritic areas. The corrosion behavior of the casting is impacted by these variations from the bulk (**Qiu et al., 2011)**. The chemical and microstructural properties of castings containing recast alloys altered, suggesting that the passive layer's composition and element release may have changed. A protective corrosion-product coating that is insoluble and passive forms on Co-Cr during corrosion. The corrosion response time is slowed to extremely low levels with the creation of metal oxide coating with restricted ionic conductivity. An alloy's corrosion behavior is greatly influenced by the consistency, homogeneity, thickness (<5 nm), composition, and integrity of this protective coating. Castings may exhibit active corrosion behavior and dissolve if the passive coating is damaged or dissolved due to mechanical or chemical conditions (**Davis, 2000)**. The average dietary intake of Cr is 280µg/day, skin sensitivity and dermatitis may be brought on by chromate salts, which are produced when base metal alloys corrode. According to reports, 3% of women and 10% of men have Cr allergy symptoms, respectively. In humans, the fatal dosage of Cr is thought to be between 50 and 70 mg/kg body weight **(Jayaprakash et al., 2017)**. None of the five study groups in the current investigation released any Cr ions. This may be due to the presence of passive film that may be more resistant to the transfer of metal ions if it contains a greater proportion of Cr_2O_3 and MoO_3 **(Saji and Choe, 2010).** The present study results disagree with Jayaprakash et al., who discovered that as the recasting numbers increase, the amount of ions released increases. This could be the result of a change in their chemical components brought on by the loss of a few elements during the remelting processes **(Jayaprakash et al., 2017).**

These oxide coatings are uniformly and densely dispersed over the surface. However, the microstructure generated by the manufacturing processes determines the stability and uniformity of these films **(Galo et al., 2014).**

Conclusion:

Within the scope of this study, ion release is negligible affected by alloy composition and manufacturing process. Since all groups were determined to meet the requirements of the international standards for ionic release, a satisfactory clinical performance is predicted.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

AGRAWAL, A., HASHMI, S. W., RAO, Y. & GARG, A. 2015. Evaluation of surface roughness and tensile strength of base metal alloys used for crown and bridge on recasting (recycling). *Journal of clinical and diagnostic research: JCDR,* 9**,** ZC01.

AL JABBARI, Y. S. 2014. Physico-mechanical properties and prosthodontic applications of Co-Cr dental alloys: a review of the literature. *The journal of advanced prosthodontics,* 6**,** 138-145.

CHOI, Y.-J., KOAK, J.-Y., HEO, S.-J., KIM, S.-K., AHN, J.-S. & PARK, D.-S. 2014. Comparison of the mechanical properties and microstructures of fractured surface for Co-Cr alloy fabricated by conventional cast, 3-D printing laser-sintered and CAD/CAM milled techniques. *The Journal of Korean Academy of Prosthodontics,* 52**,** 67-73.

DAVIS, J. R. 2000. *Corrosion: Understanding the basics*, Asm International.

DENIZOĞLU, S., DUYMUŞ, Z. Y. & AKYALCIN, Ş. 2004. Evaluation of ion release from two base-metal alloys at various pH levels. *Journal of international medical research,* 32**,** 33-38.

DOLGOV, N., TS, D., DZH, D., PAVLOVA, D. & SIMOV, M. 2016. Mechanical properties of dental Co-Cr alloys fabricated via casting and selective laser melting. *Materials Science. Non-Equilibrium Phase Transformations.,* 2**,** 3-7.

GALO, R., ROCHA, L. A., FARIA, A. C., SILVEIRA, R. R., RIBEIRO, R. F. & DE MATTOS, M. D. G. C. 2014. Influence of the casting processing route on the corrosion behavior of dental alloys. *Materials Science and Engineering: C,* 45**,** 519-523.

GREIG, D. 1983. Contact dermatitis reaction to a metal buckle on a cervical headgear. *British dental journal,* 155**,** 61-62.

HEDBERG, Y. S., QIAN, B., SHEN, Z., VIRTANEN, S. & WALLINDER, I. O. 2014. In vitro biocompatibility of CoCrMo dental alloys fabricated by selective laser melting. *Dental materials,* 30**,** 525-534.

JAYAPRAKASH, K., SHETTY, K. H. K., SHETTY, A. N. & NANDISH, B. T. 2017. Effect of recasting on element release from base metal dental casting alloys in artificial saliva and saline solution. *Journal of Conservative Dentistry: JCD,* 20**,** 199.

KARIMI, S. & ALFANTAZI, A. M. 2014. Ion release and surface oxide composition of AISI 316L, Co–28Cr–6Mo, and Ti–6Al–4V alloys immersed in human serum albumin solutions. *Materials Science and Engineering: C,* 40**,** 435-444.

LUCCHETTI, M. C., FRATTO, G., VALERIANI, F., DE VITTORI, E., GIAMPAOLI, S., PAPETTI, P., SPICA, V. R. & MANZON, L. 2015. Cobalt-chromium alloys in dentistry: An evaluation of metal ion release. *The Journal of prosthetic dentistry,* 114**,** 602-608.

MARTI, A. 2000. Cobalt-base alloys used in bone surgery. *Injury,* 31**,** D18-D21.

NANDISH, B., JAYAPRAKASH, K., SHETTY, H. K., RAO, S., GINJUPALLI, K., CHANDRASHEKHAR, H. R. & PRABHU, S. 2020. The effects of recasting on the cytotoxicity of dental base metal casting alloys. *Journal of Conservative Dentistry: JCD,* 23**,** 412.

NEJATIDANESH, F., SAVABI, O. & YAZDANPARAST, A. 2005. An investigation on metallic ion release from four dental casting alloys. *Frontiers in Dentistry***,** 168-173.

PADRóS, R., GINER-TARRIDA, L., HERRERO-CLIMENT, M., PUNSET, M. & GIL, F. J. 2020. Corrosion resistance and ion release of dental prosthesis of CoCr obtained by CAD-CAM milling, casting and laser sintering. *Metals,* 10**,** 827.

QIU, J., YU, W. Q., ZHANG, F. Q., SMALES, R. J., ZHANG, Y. L. & LU, C. H. 2011. Corrosion behaviour and surface analysis of a Co–Cr and two Ni–Cr dental alloys before and after simulated porcelain firing. *European journal of oral sciences,* 119**,** 93-101.

SAJI, V. S. & CHOE, H. C. 2010. Preferential dissolution behaviour in Ni-Cr dental cast alloy. *Bulletin of Materials Science,* 33**,** 463-468.

SCHMALZ, G. & GARHAMMER, P. 2002. Biological interactions of dental cast alloys with oral tissues. *Dental Materials,* 18**,** 396-406.

SENGUPTA, J., GHOSH, S., DATTA, P., GOMES, A. & GOMES, A. 2014. Physiologically important metal nanoparticles and their toxicity. *Journal of Nanoscience and Nanotechnology,* 14**,** 990-1006.

THOPEGOWDA, N. B., SHENOY, K., SHANKARANARAYANA, R. K., JAYAPRAKASH, K., GINGIPALLI, K., VADDYA, S. B. & PRABHU, S. 2014. Evaluation of mechanical properties of recasted dental base metal alloys for considering their reusability in dentistry and engineering field. *Archives of Medicine and Health Sciences,* 2**,** 178.

VIENNOT, S., DALARD, F., LISSAC, M. & GROSGOGEAT, B. 2005. Corrosion resistance of cobalt-chromium and palladium-silver alloys used in fixed prosthetic restorations. *European journal of oral sciences,* 113**,** 90-95.

XIN, X., CHEN, J., XIANG, N., GONG, Y. & WEI, B. 2014. Surface characteristics and corrosion properties of selective laser melted Co–Cr dental alloy after porcelain firing. *Dental Materials,* 30**,** 263-270.

ZAHARIA, C., GABOR, A.-G., GAVRILOVICI, A., STAN, A. T., IDORASI, L., SINESCU, C. & NEGRUȚIU, M.-L. 2017. Digital dentistry-3D printing applications. *Journal of Interdisciplinary Medicine,* 2**,** 50-53.