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RESEARCH ARTICLE - MEDICAL TECHNIQUES

Assessment of the Ultrasonic Machine for Surface Finishing of 3D-Printed Cobalt-Chromium Alloy by Selective Laser Melting Technology

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Abstract

The selective laser melting (SLM) system reaches the status of a contender with the traditional casting of dental alloys, with the essential drawback that it is conducive to roughness, making surfaces difficult to finish by the conventional method. Ultrasonic machines (USM) are instrumentally sensible for processes involving metal surface adjustments.
This study aims to assess the surface roughness for SLM by using USM instead of conventional finishing. The discs of cobalt chromium alloy were printed by SLM (n = 20) and evenly divided into two groups: one for finishing in compliance with the manufacturer's standard procedure, and the other for employing USM. The specimens were evaluated using the Surface Roughness Test, and the data was analyzed using the t-test.
Highly significant differences were found at $P < 0.01$. Furthermore, the mean value accounted for a low level of readings (Ra) in the USM group, which amounted to 1.707, and with regard to the control group, it was 4.539. Ultrasonic finishing processes promote the competence of the finishing procedure and improve the surface quality for dental cobalt chromium alloys that are printed by SLM technology.

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Keywords: Cobalt-chromium alloys; Ultrasonic vibration; Surface roughness; Finishing.

1. Introduction

Metal 3D printing systems have trended toward attracting attention in a variety of spheres that are affiliated with Additive Manufacturing (AM) processes for designing virtual patterns in advance. The selective laser melting (SLM) system is one of the distinctive systems regarded as a pioneering technique for medical and dental applications [1]. In principle, the model is emitted in stratified form across metal powder by the imposition of targeted melting by a laser beam. The building layer is formed by the instant solidification consequence of fully melted particles [2]. Among the appropriate alloy powders for this system is the cobalt chrome Co-Cr alloy, for which the feasibility of SLM production of metal prosthesis frames enhances precision that exceeds that of traditional casting production [3]. Whilst as discerned, the SLM tends to involve roughness as a result of the disparity of the layering process, which renders subdued opportunities for surface quality for products concomitantly confronted with a difficult post-process of finishing the surface [4 - 6]. The conventional approach to finishing may hinder the endeavor to achieve a smooth surface on metal prostheses [7 - 9]. Several studies have advanced the most prominent substitute for conventional fishing, including through laser power, which can be rather expensive with accompanying temperature [4, 10]. In contrast, ultrasonic technology can serve a wide range of applications, with the possibility of obtaining kinetic energy for mechanical finishing methods that may be applicable in this respect derived from ultrasonic vibration by wave transducer. The ultrasonic machines (USM) participate effectively in metal finishing, including a particularly stubby superficial material removal rate (MRR), whose abrasive tip side is equipped with symmetric vibration motion adopted on a wave scale. As well indicated, the studies show that the roughness is appreciably decreased when the vibration generated by USM technology is merged into surface burnishing machines tools , rendering them more efficient [11, 12]. As stated, the finishing USM was effective with a view to minimizing defects in the AM surface product [13]. Low surface roughness through finishing is promoted by a selection of the optimal power level of USM is consistent with held abrasive tools for surface material removal that is conducive to leaving substrate residue at low roughness [14]. The present study aimed to investigate the influence of ultrasonic finishing processes on the surface roughness of dental cobalt chromium alloys printed with SLM technology. The null hypothesis was that the ultrasonic machines did not influence the surface roughness property in the finishing procedures.

2. Materials and Methods

2.1. Materials

The cobalt-based Cr (WIRONIUM® RP, BEGO, Germany) powder is used for SLM printing with the following manufacturer specifications: It has a grain size of 10-45 µm, satisfies ISO 22674 [15].

Nomenclature			
AM	Additive Manufacturing	Rpm	Rotation per minute
SLM	Selective laser melting	SPSS	Statistical software
USM	Ultrasonic machines	ASTM	American Society for Testing and Materials
MRR	Material removal rate	KHz	Kilohertz
Co-Cr	Cobalt-based alloy	Ra	Average roughness
STL	Standard tessellation language file	mm	Millimeter
µm	Micrometer	Sig.	Significant
SEM	Scanning electron microscope		

2.2. Printing of specimens

The study design included twenty specimens designed virtually using application software (Rhino 7, produced by Robert McNeel & Associates, Robert McNeel & Associates, USA) in a disc shape 2 mm thick and 15 mm in diameter and saved as a standard tessellation language file (. STL) [5]. The specimens were printed in vertical orientation [6] using an SLM machine (NCL M2150X, China) according to manufacturing standards of alloy: powder layer thickness of 0.03 mm, laser output of 195 watts, a scan speed of 1200 mm/s, and track spacing of 0.09 mm, with the ensuing stress-relieving thermal treatment at 800 ºC for 45 minutes, Fig. 1 [15].

Fig 1. A printed specimen of Co-Cr made by selective laser melting (SLM) according to the adopted (. STL) file design

2.3. Finishing processes

The specimens were divided into two groups of ten specimens for each based on the finishing method.

2.3.1. Standard method (control group)

The finishing procedures of control group were carried out in accordance with the parameters of the machining process specified by the alloy powder manufacturer. In the first step, fine grit stones with a high cutting capacity (REF 43160, BEGO) and a 2.35 mm shank are used for efficient grinding of dental alloys. The specimens were mounted on a dental surveyor (RD, M-103) with a hand piece (Kavo Gmbh, Biberach, Germany) rotated at a rotational speed of 30.000 rpm at one-minute intervals for each specimen, Fig. 2. Then a fine sandblasting (Basic eco, Renfert) unit and particles (PerlaBlast glass bead blasting material, 50 microns, BEGO) were used to sandblast the specimens under a pressure of 4 bar, which were mounted in a special holder at 10 cm distance for 10 seconds [15].

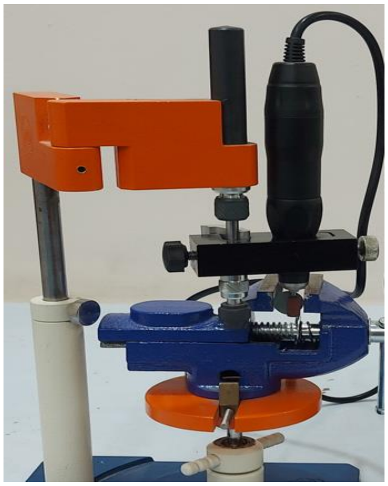


Fig 2. A specimen mounted on a dental surveyor of the finishing process in the standard method

2.3.2. Ultrasonic method

The finishing procedures of the study group UF were conducted through the machine (YJCS-5B, YIJING ELECTRIC Co., Ltd., China), which equips the function of ultrasonic finishing in outputs with a power of 60W, 19–28 KHz. The hand piece supplies vibration of the finishing tool tip by a transducer, which transforms electrical signals into a vibrating power function at a maximum of 28,000 times per second at the level of grade nine, which gradually declines by control to the level of grade one. In accordance with the manufacturer's instructions, the major removal tasks of coarse surfaces, which pose the finishing process, commence with an abrasive file tip that is electroplated with diamonds in a suitable vibrating grade depending on the roughness of the substrate surface. According to the pilot sample studied and previous instructions, to access the consistency of ultrasonic finishing with the corresponding conventional standard finishing process, the finishing proceedings initiate the use of a diamond file tip at a grade level of nine, then a grade level of five for a fine finishing surface at two minutes for each specimen, attached by a special holder, Fig. 3.

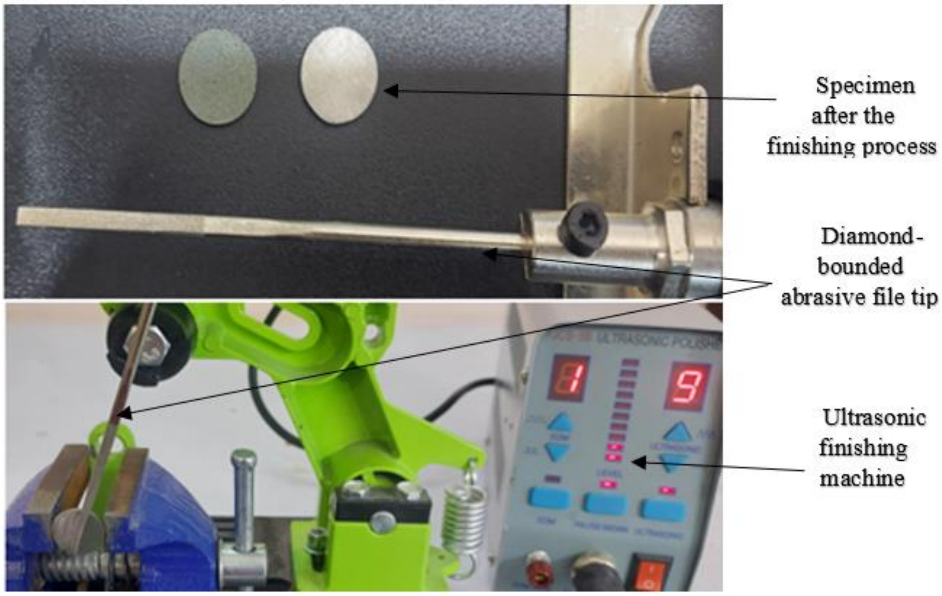


Fig 3. Finishing procedures through the ultrasonic method

2.4. Surface Roughness Test

Specimens were cleaned in an ultrasonic bath (CD-4860, CODYSON) with deionized water and 70 % propanol for 10 minutes, preparing for the surface roughness test. A profilometer (Taylor HOBSON, Leicester, UK) was used to measure the specimens in accordance with the standard test (ASTM-D7127-17) [17]. The test design consisted of consisted of two readings through two diagonal lines crossing perpendicularly, calibrated at a length of 8 mm "CUT-OFF," and applying Mean Value Ra (μm) to each specimen, Fig. 4.

Fig 4. A profilometer (Taylor) for surface roughness testing

2.5. Statistical Analysis

Statistical software (SPSS) version (22.0) was used to evaluate the study's findings and apply the independent-samples t-test analysis.

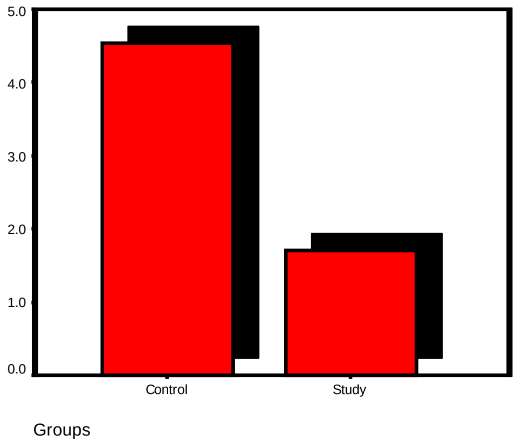
3. Result

In Table 1, the "surface roughness test," which was measured in the control group and study group UF. The results show that the mean value accounted for a low level of readings in the UF group.

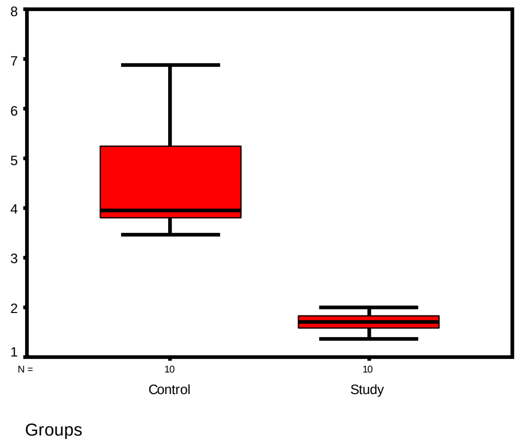
Table 1 Summary Statistics for Surface Roughness Tests distributed to the control and UF groups, gives a description of mean values, standard deviation, standard error, and 95% confidence interval (CI) at the lower bound (L.b.) and upper bound (U.b.)

Groups	No.	Mean	Std. D.	Std. E.	95% C.I. for Mean L.b.	95% C.I. for Mean U.b.	Min.	Max
Control	10	4.539	1.136	0.359	3.726	5.352	3.470	6.870
UF	10	1.707	0.196	0.062	1.567	1.847	1.366	1.989

In addition, the highest degree of homogeneity was recorded at the level of the data and at the level of the standard error of the arithmetic mean of the study group UF. Estimating the 95% confidence intervals for the mean values of the surface roughness test shows that highly gaps are accounted between the studied groups, since disjoint intervals are accounted by the studied groups. Fig. 5 represents the graphically plotting of bar chart regarding mean values concerning "surface roughness" test readings distributed into two groups, as well as the Stem-Leaf plot.



A



B

Fig 5. A) Mean values of the control group and study group UF, and B): Stem-Leaf Plot concerning "Surface Roughness Test" of the control group and study group UF

In order to clarify the levels of difference that were obtained as a result of the finishing processes for the control group and UF group, the graph of the aforementioned 95% confidence interval estimates clearly showed the behaviour of changes in relation to surface roughness for each group through the surface treatment, as shown in Fig. 6.

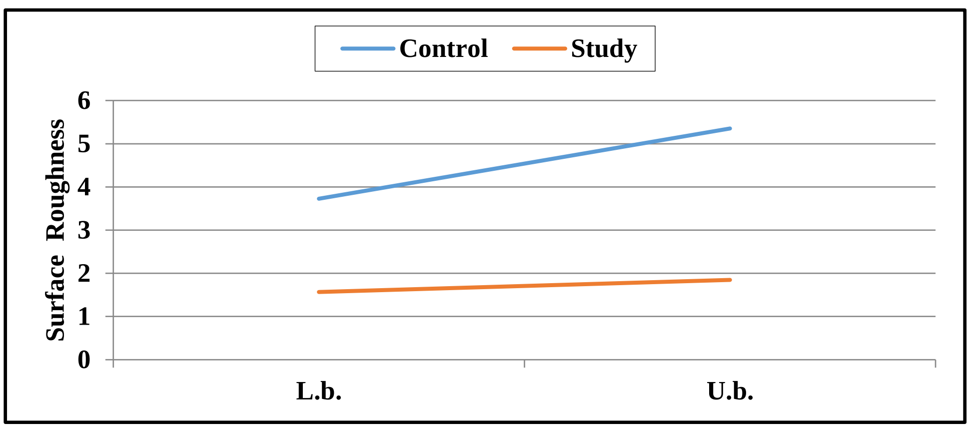


Fig 6. Line Charts of 95% confidence intervals at the lower bound (L.b.) and upper bound (U.b.) estimate the behaviour of improvements in each group at surface roughness

With respect to testing statistical hypotheses, and that should be proved according to the Testing Homogeneity of Variances "Levene test" that assumed equal variances and then applying the t-test that assumed equal mean values, the results showed that a highly significant difference was accounted at $P < 0.01$, and according to that, it could be concluded that a significant difference obtained between the two groups regarding the Surface Roughness test, as illustrated in the Table 2.

Table 2 Testing of equal variances and equal mean values are assumed for the Surface Roughness test concerning studied groups

Surface Roughness Test	Testing Homogeneity of Variances: Levene Statistic	Testing Homogeneity of Variances: Sig. (*)	t –test for Equality of Means: t- Statistic	t –test for Equality of Means: Sig. (*)
Control group x Study group UF	19.458	0.000 (HS)	7.767	0.000 (HS)

(*) HS: Highly Sig. at $P < 0.01$.

4. Discussion

The present study aimed to evaluate the surface roughness in post-ultrasonic surface treatment dental cobalt chromium alloys printed with SLM technology through the influence of finishing processes. In accordance with the result, the null hypothesis was rejected.
The existence of the lowest surface roughness in the study group UF might imply a better ability of USM to overcome the finishing difficulties, at least the alloy hardness [16] and, more fundamentally, roughness and micro-defects that breach the surface of SLM [17]. An important role in that regard is that, by the rubbing of the USM tool, partially melted particles may come crashing down and the substrate layer will later be reconditioned to be flawless [13] rather than merely slashed by grinding and stuck in the same stratum. At a later level, sandblasting and even optional electro-brightening as may be necessary as set out by the manufacturer might be sufficient only to minimise the sharpness of irregular ridged surfaces [18]. The material removal rate of the USM vibrating tool tends to skim the substrate surface in the reverse bilateral direction of the one-frequency wave static impact load, causing a profound hammering effect that alters surface morphology in stacked form so that it becomes more dense and would foster the surface quality that is observed through the photo of the scanning electron microscope (SEM) as mentioned in the studies of [19, 20].
From a practical perspective, the results obtained in the current study were consistent with those of the previous (Huuki, and Laakso, 2013) study, which found a reduction in surface roughness through ultrasonic finishing. as well as the (Malygin et al., 2018) study recognised low surface roughness combined with appropriate ultrasonic power for the finishing process [23, 24].
Adopting conventional finishing may not overcome the turbulent melting of alloy powder, even with optimal building orientation [6]. Accordingly, the appropriate initial finishing may give a prediction insofar as felicitous polishing in the rubber phase and subsequent lathe polishing machines, particularly for dental prostheses that predispose to soft tissue contact. This might draw attention to the feasibility of the assistance of ultrasonic technology in minor adjustments to recasting the exterior layer surface of the SLM metal product.

5. Conclusion

Within the limitations of this study *in vitro*, surface roughness was recorded at the low value of finishing processes in the ultrasonic group in comparison with the conventional finishing method. This demonstrates the potential of ultrasonic finishing processes to promote the competence of the finishing procedure and improve the surface quality for dental cobalt chromium alloys that are printed by SLM technology.

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