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Evaluation of EDM inclusion into the conventional polishing of printed Co-Cr alloy by selective laser melting

Avaliação da inclusão de EDM no polimento convencional da liga de Co-Cr impressa por fusão seletiva a laser

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ABSTRACT

Objective: The selective laser melting (SLM) technique used in manufacturing results in a rougher surface that requires more satisfying processing than conventional hand-finishing operations. The electro discharge machine (EDM) has various possibilities in the adjustment of surfaces. The present study assesses whether the participation of the EDM technique with the conventional finishing and polishing methods enables surface improvement for the Cobalt-Chromium alloy fabricated by SLM. **Material and Methods:** Twenty discs of cobalt chromium alloy were fabricated by SLM, divided equally into two groups: (TF) control group for finishing and polishing in the conventional method in accordance with the manufacturer's recommendations; and (EF) group for conducting polishing incorporating the EDM method. **Results:** The EF group recorded the lowest mean value of surface roughness and the highest mean value of micro hardness compared to the TF group. Furthermore, statistically significant differences ($P < 0.05$) were found for surface roughness as well as micro hardness. **Conclusion:** Reliance of the electric discharge machine proactively within finishing and polishing procedures promotes competence in the conventional polishing method and improves the surface properties of cobalt chromium alloy printed by SLM technology.

KEYWORDS

Dental finishing; Cobalt-chromium alloy; Selective laser melting; Electric discharge machine; Additive manufacturing.

RESUMO

Objetivo: A técnica de fusão a laser seletiva (SLM) usada na fabricação resulta em uma superfície mais rugosa a qual requer um processamento mais satisfatório do que o acabamento manual. A máquina de eletro descarga (EDM) possui várias possibilidades no ajuste de superfícies. O presente estudo avalia se a participação da técnica EDM associada aos métodos convencionais de acabamento e polimento possibilita a melhora da superfície da liga Cobalto-Cromo fabricada através da SLM. **Material e Métodos:** Vinte discos de liga de cromo-cobalto foram confeccionados por SLM, e divididos igualmente em dois grupos: (TF) grupo controle, realizado acabamento e polimento pelo método convencional de acordo com as recomendações do fabricante; e (EF) grupo do polimento associado ao método EDM. **Resultados:** O grupo EF registrou o menor valor médio de rugosidade superficial e o maior valor médio de microdureza em relação ao grupo TF. Além disso, diferenças estatisticamente significativas ($P < 0,05$) foram encontradas para rugosidade superficial, assim como para a microdureza. **Conclusão:** A confiança na máquina de descarga elétrica proativamente nos procedimentos de acabamento e polimento promove a competência no método de polimento convencional e melhora as propriedades de superfície da liga de cromo-cobalto impressa pela tecnologia SLM.

PALAVRAS-CHAVE

Acabamento dental; Liga de cobalto-cromo; Fusão a laser seletiva; Máquina de descarga elétrica; Manufatura aditiva.

INTRODUCTION

Selective laser melting (SLM) has become an excellent approach for fabricating functional metal structures, which represents one of the essential additive manufacturing (AM) technologies in dentistry. The printing procedure for metallic alloys by the SLM technique is based on the emitted structure of metal powder being constructed in a layered pattern over the building plate using a laser beam to induce localised melting by focusing heat and prompt solidification of totally melted particles [1,2]. Cobalt-chromium (Co-Cr) alloy is regarded as an appropriate biomedical metallic alloy for dental prosthesis applications as well as a practical alloy in SLM printing with acceptable mechanical properties [3,4]. However , the SLM technique is conducive to high surface roughness for the produced metal structures compared to casting and block milling techniques [5,6]. Although factors such as build orientation and process parameters can alter the printed alloy properties towards acceptable performance , the roughness of the surface is a perennial problem in SLM manufacturing and may be difficult to overcome in the settings of the alloy printing phase [7,8]. There is still a need to refurbish how to tackle surfaces for various metal prostheses in dental applications, such as metal frames of removable partial dentures, which have a wide aspect of surface exposure [9]. particularly when produced using the SLM technique, which may require additional effort and efficiency [10-12]. Given that conventional finishing and polishing procedures may be difficult to predict their effectiveness, this may necessitate a more efficient alternative achieved on dental alloys printed by SLM technology that have high surface roughness. In this context, electric discharge machines (EDM), which are referred to in dentistry as “spark erosion,” may be used to alter the surface of conductive materials. This erosion function is caused by the electrical discharge’s high-frequency spark between two electrodes, which affects the substrate surface by removing excessive material through electric erosion [13-15].

The feasibility of using EDM to finish hard metals is considerable and can thus approach the micron level of finishing when the spark intensity and discharge electric current are precisely regulated in the suitable gap between the work piece and the terminal tool of the electrode, which should be smooth and regular in shape [16]. It is noteworthy that EDM applications in dentistry are given particular attention as an opportunity to benefit in limited inter-removal tasks of metal alloys to ensure precision fitting prostheses and superstructures interface over implants through surface refinement by thermal energy that is generated into electricity discharge [17-20]. From the same perspective, the dental literature may not give an accurate description of how to utilize EDM in surface finishing and knowledge about suitable parameters of this technique , although it may be practicable for EDM inclusion within conventional hand-finishing/polishing phases on dental alloys printed by SLM, which may be appropriate for the attainment of aspirations through the conciseness of the finishing process and participate treatment of SLM surface defects.

This study aims to determine whether inclusion of the electro discharge machine (EDM) in conventional finishing and polishing procedures for dental cobalt chromium alloys printed by SLM technology influences surface roughness and micro hardness.

The null hypothesis was that the inclusion of the electro discharge machine (EDM) in conventional finishing and polishing procedures not influences on tested properties.

MATERIAL AND METHODS

The commercial SLM processing dental alloy that is used is cobalt-based Co-Cr (WIRONIUM® RP, BEGO, Germany), 10-45 um grain size, ISO 22674 [21], with chemical compositions of (Co 66.2%, Cr 28.2%, Mo 5.5%, N < 1%) that are specified by the manufacturer.

Preparation of specimens

The study included twenty specimens that were designed from a computer-aided design (CAD) in a disc shape, 2 mm thick and 15 mm in diameter, utilizing application software (Rhino 7, Robert McNeel & Associates, USA) in a standard tessellation language (. STL) file [5], then printed by machine (NCL M2150X) operating with an ytterbium fiber laser beam of 200 watts of power (IPG Laser). The following settings were adopted: a 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. Then the stress-relieving thermal treatment was carried out for specimens that had been built in vertical orientation (6) and fastened to the platform surface by beds heated in a furnace to 800 degrees Celsius for 45 minutes as per the instructions of the alloy powder manufacturer.

Surface processing of specimens

Surface processing divided the specimens into two main groups (n = 10) based on the technique of finishing and polishing.

In the conventional finishing and polishing control group "TF", carried out in accordance with recommendations specified by the 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. Then a fine sandblasting (Basic Eco, Renfert) unit, nozzle 0.8 mm, and particles (Perla Blast glass bead blasting material, 50 microns, BEGO) were used to sandblast the specimens. mounted at a distance of 10 cm for 10 seconds under a pressure of 4 bar [22]. Thereafter, they electro "polished" for 5 minutes with 12 V of electric current, preparatory to the rubber-polishing phase too, which encompassed rubber wheels (AB201, AB202-Dentorium, USA) at a rotational speed of 10,000 rpm at two-minute intervals, respectively. Ultimately, the specimens were polished with paste (REF 52310, BEGO, Germany) by a buff brush (Wool Buff, Attenborough Dental, UK), and the ensuing leather deer mop (90 mm with Leather Strips, Vertex, Netherlands) by means of the polishing lathe (UNIVERSAL POLISHING BENCH, Balkan Motor San, Turkey). The specimens were postured on a special holder at successive speeds of 1500 and 3000 rpm.

The EDM group "EF" was conducted with a portable polishing machine (YJCS-5B, YIJING ELECTRIC Co., Ltd., China) that emits an electric spark at a direct current (DC) of 90 volts and a maximum discharge current of 1.83 amps. The machine discharges a high-frequency electric spark to remove excessive material during EDM erosion at an adjustable power level. In terms of control power, grade one has the lowest discharge at 0.25 amps, while grade nine has the highest discharge at 1.83 amps without change in voltage, which remains persistent at 90 volts. The presumption of reaching low surface roughness by the finishing process by EDM necessitates a low discharge current through a suitable spark of intensity [23]. Commensurate with dental alloy, the surface alteration process for fitting the superstructure on the implant through EDM is proceeded at 1.5A in the first stage of inter-surface removal task and final fitting at 0.5A to achieve optimal precision contact of clear surfaces [13]. In accordance with the manufacturer's instructions, grade "nine" is recommended for coarse surfaces and major removal tasks, then gradually proceed to the lowest grade until it reaches acceptable fine surfaces; that is, it is intended to be practicable to obtain a surface roughness of around Ra0.3 as a result of applying grade "one" power on reasonably smooth surfaces.

According to the pilot sample studied and previous instructions, the aspiration was to obtain a particular grade that corresponded to the phases of the standard finishing process, which resulted in the electric current selection (0.68 , 0.63, 0.46, 0.3, 0.25) of "five" to "one," operating grades, consecutively, one-minute duration per specimen that was attached to the power circuit with an electrode of anode and an electrode of brass rod H62 cathode, immersed in the water basin at a depth of 5 mm with a suitable effective spark gap for all held by a dental surveyor. After the EDM phase, all specimens in this group are polished by the rubber wheel polishing and eventually by the lathe polishing machine, as indicated in "TF.", in order to attain a lustrous surface.

Eventually, both groups (n = 20) were cleaned with deionized water and 70% propanol in an ultrasonic bath (CD-4860, CODYSON) for ten minutes [5] in readiness for the surface roughness and hardness tests.

Surface Roughness

Specimens were measured using a profilometer (Taylor HOBSON, Leicester, UK) according to the stander test method (ASTM-D7127-17) [24]. The test style was two diagonal lines crossed perpendicularly, calibrated at a length of 8 mm "CUT-OFF", and the adoption of Mean Value Ra (μm) on each specimen.

Hardness

The Micro Vickers Hardness HV tester (TH710, Beijing TIME High Technology Ltd.)

was used to measure specimens in accordance with the ASTM E 92 Standard [25] test method for Vickers Hardness of metallic materials at a setting dwell time of 15 seconds, an applied force of 4.904 (N), and the mean of three indentations for each specimen was recorded.

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

RESULT

Table I summarizes the surface roughness testing (Ra) and Table II summarizes the micro hardness measurements (HV) of two independent groups: the conventional finishing/polishing group "TF" and the (EDM) group "EF." With the inclusion of the electro discharge machine, the results show that the "Surface Roughness test" accounted for a low level of readings (Ra) and a high level of readings (HV) in the "EF" group of (EDM).

With respect to testing statistical hypotheses, and that should be proved according to the test of equal variances, as well as equal mean vales are assumed through Levene and t-test, respectively, the (Ra) results showed that no significant difference was accounted for at $P > 0.05$ regarding the test of homogeneity of variances, as well as a significant difference was accounted for at $P < 0.05$ with reference to testing of mean values, as illustrated in Table III.

Furthermore, the (HV) results showed that a significant difference was accounted for at $P<0.01$ regarding the test of homogeneity of variances, as well as a significant difference was accounted for at $P<0.05$ with reference to testing of mean values, as illustrated in Table IV.

Table I - Mean values, standard deviation, standard error, and 95% confidence interval of mean parameters concerning mean values of the Surface Roughness Test for the studied group's readings and the two extreme values (min. and max.)

Test	Groups	No.	Mean	SD	SE	95% C.I. for Mean		Min.	Max.
						L.b.	U.b.		
Surface Roughness	TF	10	0.303	0.124	0.039	0.21	0.39	0.19	0.60
	EF	10	0.194	0.102	0.032	0.12	0.27	0.09	0.46

SD: Standard Deviation; SE: Standard Error; C.I.: Confidence Interval; L.b: Lower Bound; U.b: Upper Bound; 95% confidence interval (CI) at the lower bound (L.b.) and upper bound (U.b.).

Table II - Mean values, standard deviation, standard error, and 95% confidence interval of mean parameters concerning mean values of the HV Micro Hardness Test for the studied group's readings and the two extreme values (min. and max.)

Test	Groups	No.	Mean	SD	SE	95% C.I. for Mean		Min.	Max.
						L.b.	U.b.		
HV Micro Hardness	TF	10	328.48	95.405	30.17	260.23	396.73	172.3	452.2
	EF	10	416.52	17.383	5.497	404.09	428.96	381.4	432.8

SD: Standard Deviation; SE: Standard Error; C.I.: Confidence Interval; L.b: Lower Bound; U.b: Upper Bound; 95% confidence interval (CI) at the lower bound (L.b.) and upper bound (U.b.).

Table III - Testing equal variances and equal mean values for the Surface Roughness test concerning the studied groups TF and EF

Surface Roughness	Testing Homogeneity of Variances		T-Test- Testing Equality of Means	
	Levene Statistic	Sig. (*)	T-test	Sig. (*)
TF and EF	0.418	0.526 (NS)	2.144	0.046 (S)

(*) S: Sig. at P<0.05; NS: Non Sig. at P>0.05.

Table IV - Testing equal variances and equal mean values for the HV Micro Hardness test concerning the studied groups TF and EF

Micro Hardness	Testing Homogeneity of Variances		T-Test- Testing Equality of Means	
	Levene Statistic	Sig. (*)	T-test	Sig. (*)
TF and EF	22.110	0.000 (HS)	-2.871	0.017 (S)

(*) HS: Highly Sig. at P<0.01; S: Sig. at P<0.05.

DISCUSSION

This study aimed to determine the influence of surface roughness and micro hardness by the inclusion of the electro discharge machine (EDM) in traditional finishing and polishing procedures for dental cobalt chromium alloys printed by SLM technology. According to the results, the null hypothesis was rejected given the influence of incorporating the electro discharge machine (EDM) into conventional finishing and polishing procedures, which triggered decreased surface roughness and a rise in hardness value.

In practical terms, the presented findings are consistent with previous studies [26,27] that employed the EDM method as a finishing process conducive to surface improvement, accompanied by an obvious reduction in roughness value. Conversely, there is no agreement with studies by Wandra et al. [28] and Kushwaha et al. [29] as they reported dissatisfactory levels of roughness on the surface by EDM application.

The employment of EDM in the surface finishing demands consistent parameters with considering that current is the primarily affecting factor in electric discharge power for emitted spark [30,31]. This shows the operation of the EDM in group EF at an acceptable electric current of 0.68 A for surface finishing, followed by gradually diminishing the current to reach a minimum current of 0.25 A that ensures the surface roughness is obtained at a low value. This result is consistent with the study of Wang and Han [32], which reports that the progression of the decrease in the surface roughness for surface finishing purposes by the EDM operation is dependent on a gradually decreasing electric current parameter.

The decreasing level of roughness caused by reliance on the EDM technique may give priority to how to achieve dispensing with a series of initial finishing-phases: grinding, sandblasting, and electro-polishing, which are likewise preparatory in fostering subsequent polishing [33,34]. It is conceivable that the material removal rate (MRR) produced by EDM on the surface was stable and coordinated at an appropriate discharge energy level, resulting in a decrease in surface roughness on the remaining substrate [30].

In this study, the specimens were printed in the optimal vertical orientation in the SLM recommended methods, which obtain low roughness results by stability in layering formative. However, they are not asserted to be released from disparity in melting entirely at the consolidation of powder particles as a result of turbulence in maintaining the necessary heat in wetting the previous layer and applying the heat necessary to melt the subsequent layer, which causes surface defects [8].

There might be an assignment for EDM to upgrade finishing/polishing in EF group to overcome the defects of turbulent melting on the substrate layer of the SLM process through recasting the surface, which has not been obtained by the initial phases of the TF group [26]. The thermal energy generated through electrical discharge power by EDM serves as a heat treatment by recasting the surface into a more consolidated layer by means of addressing the defects such as porosity and cracking in the substrate [35,36]. This result essentially correlates with the low electric current extent possible to the completion of the finishing process through the thermal propagation of spark discharge, which permits the partially melted particles to evaporate and collapse the peak of sharpness irregular ridges by means of melting and subsequent solidification, which performs as a surface modulation [23].

Consequently, recasting assists in eliminating surface meanders and surface protrusions, which might facilitate the finishing process of SLM surface by providing an accessible posture of refinement by altering the surface to accommodate the polishing phase. This shows that the results of the EF group had a significant difference in comparison with the TF because of the effectiveness of the polishing phases by the rubber wheel polishing and the lathe polishing machine, as illustrated in Table III.

This reveals mastery of the EDM finishing process on surface refinement was not implemented by sandblasting with glass bead blasting material, 50 microns preceded by stone bur finishing according to the manufacturer's recommendations. That might be construed as the existence of extra edges of the SLM surface arising from the partial melting of particles along the melting path, obstructing the striking of sanding glass beads, leaving the beads in a stacked state at surface scratches [37,38].

Concerning micro hardness, the EDM technique offered a rise in hardness value recorded in the EF group that was not attained with the exception of including EDM as in the TF group. This finding was in agreement with Mahajan et al. [14] and Adarsh et al. [29] as they reported an increase in hardness value correlating with the surface treatment by the EDM. This technique fundamentally improves the hardness of the surfaces when the energy of the spark tends to generate heat that causes, in return, melting of the external layer surface followed by re-solidification by quenching in the same electric water basin, which modifies the substrate surface by recasting the superficial layer into a more dense layer [35]. The aforementioned demonstrate the qualifications of the EDM method in compensating for conventional finishing in the initial phases in this sense, the reliability of EDM inclusion within conventional hand-finishing/polishing operations on dental alloys printed by SLM may be appropriate for the attainment of aspirations through the conciseness of the finishing process. It implies seizing the opportunity of recasting the surface by EDM for a surface adjustment that may be deficient in resorting to conventional finishing techniques and, furthermore, revealing the efficaciousness of final polishing phases for the same technique.

CONCLUSION

Within the limitations of this study, it demonstrates the potential of including EDM proactively within conventional finishing and polishing procedures for dental cobalt chromium alloys that are printed by SLM technology. resulting in a reduction in roughness with an increase in micro hardness for the surface.

Author's Contributions

MAAAN: Methodology, Writing – Original Draft Preparation. IMH:Supervision.

Conflict of Interest

We have no conflicts of interest to disclose regarding this article. The opinions expressed are solely those of the authors and have not been influenced by any financial or personal relationships.

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Regulatory Statement

This article did not involve the use of any hazardous materials, living organisms, or any procedures that could harm the environment. There was no need to comply with any specific regulatory laws or regulations regarding occupational health and safety or the environment. All necessary measures were taken to ensure compliance with ethical research practices and laboratory safety.

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