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RESEARCH AND EDUCATION

Corrosion, ion release, and surface hardness of Ti-6Al-4V and cobalt-chromium alloys produced by CAD-CAM milling and laser sintering

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ABSTRACT

Statement of problem. How the corrosion properties of cobalt-chromium (Co-Cr) and Ti (Ti-6Al-4V) alloys, frequently used in dental prostheses, are affected by different production methods is unclear.

Purpose. The purpose of this in vitro study was to compare Co-Cr and Ti-6Al-4V alloys produced by computer-aided design and computer-aided manufacturing (CAD-CAM) milling or laser sintering in terms of corrosion, ion release, and surface hardness.

Material and methods. Co-Cr and Ti-6Al-4V specimens were produced by CAD-CAM milling and direct metal laser sintering/selective laser sintering techniques. Testing included Vickers hardness and then open circuit potential (OCP), Tafel extrapolation, and static immersion to determine the corrosion behavior. The study used an inductively coupled plasma mass spectrometer to measure ion release. The data were analyzed by using the Kruskal-Wallis and Mann-Whitney U tests, with Bonferroni correction (α=.05).

Results. The Ti-6Al-4V laser-sintered group showed the highest Vickers hardness value (P<.008), the lowest OCP value (P<.008), and the lowest corrosion potential (V_{corr}) value (P<.008). The corrosion current density (I_{corr}) level of the Co-Cr CAD-CAM milling group was statistically significantly lower than that of the Ti-6Al-4V CAD-CAM milling and the Ti-6Al-4V laser-sintered groups (P<.008). The highest weight change was observed in the Ti-6Al-4V laser-sintered group. The Co, Cr, and Ti ion emissions were higher in specimens produced by laser sintering (P<.05), and no statistically significant difference in terms of Al and V oscillations was found among the groups (P>.05).

Conclusions. Ti-6Al-4V alloys may be a good alternative for patients with Co-Cr allergies, but as per the results of this study, Co-Cr still seems more suitable for clinical use. (J Prosthet Dent 2022;128:529.e1–e10)

Dental alloys generally exist in the patient's mouth for many years, during which time they must be resistant to mechanical loads and environmental corrosion.[1] An understanding of the chemical and physical properties and biocompatibility of these materials that are constantly in contact with mucosa, saliva, and periodontal tissues in the mouth[2-4] is important for patient health. Metal ions released during corrosion can cause serious damage and may result in side effects, including local toxicity, systemic toxicity, and allergic reactions.[5] However, the oral cavity is an environment that is prone to corrosion because of saliva, microorganisms, dental plaque, and bacteria, as well as variations in oxygen pressure and pH changes.[6,7] In addition to environmental factors, the structure of the metal also plays a role in its corrosion properties.[8-11]

The development of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies, which are based on the principles of subtractive or

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Clinical Implications

The production methods of prosthetic materials affect corrosion properties, which are important for human health. Cobalt-chromium and Ti-6Al-4V alloys produced by CAD-CAM milling and laser sintering methods appear to be good options for clinical use.

additive manufacturing, has revolutionized the production of dental devices. CAD-CAM has eliminated the waxing, investing, and casting procedures and many of the problems seen in the casting method, making complex structures easier to fabricate.[12,13]

Titanium and its alloys have the advantages of having low density, low Young modulus, high mechanical properties, low thermal conduction, low electrochemical corrosion rate, and relatively lower costs than traditional noble metals such as gold.[14] Ti-6Al-4V alloy has been used extensively for biomedical implants.[15]

Cobalt-chromium (Co-Cr)−based alloys[16] have been widely used in dentistry for metal frameworks, removable partial dentures, and metal-ceramic crowns.[17] They have suitable engineering properties and are more cost-effective than the noble metal alloys. However, because of their high hardness, high melting temperature, and relatively low ductility, casting Co-Cr−based alloys can be relatively difficult,[18] but they are suitable for CAD-CAM fabrication.

The purpose of the present study was to evaluate the corrosion resistance, ion release, and surface hardness of Ti-6Al-4V and Co-Cr alloys in terms of the CAD-CAM milling and laser sintering production methods. The null hypotheses were that no significant difference would be found among the groups with regard to corrosion resistance, ion release, or surface hardness.

MATERIAL AND METHODS

Co-Cr and Ti-6Al-4V specimens were produced with 2 technologies, CAD-CAM milling and laser sintering. The compositions of the specimens are shown in Tables 1 and 2. For each group, 6 Ø12×5-mm specimens were prepared. The Co-Cr CAD-CAM milling specimens were prepared from CAD data (Mayka Expert 7.5; PicaSoft) that was sent to a communicating 5-axis milling machine (Yena D40; Yenadent) for the preparation of Co-Cr blanks (Yenadent) as per the manufacturer's recommendations. The Ti-6Al-4V CAD-CAM milling specimens were prepared similarly from Ti-6Al-4V alloy blanks (Kera Ti5-Disc; Eisenbacher Dentalwaren ED GmbH) milled as per the manufacturer's recommendations. The Co-Cr laser sintering specimens were prepared by entering data in the standard tessellation language format file as per the International Organization for Standardization 22674 standard into a laser additive manufacturing machine (EOSINT M 270; EOS GmbH). The specimens were heat treated after production. The Ti-6Al-4V laser-sintered specimens were produced with the EOSINT M 280 system (EOS GmbH) in accordance with the manufacturer's protocol. The specimens were heat treated after production.

All specimens were measured for Vickers hardness values with a hardness tester (Innovatest Nexus 4503 hardness testing machine; Innovest Europe). The hardness values of the specimens were identified by using the Vickers hardness test with a 49-N load and a contact time of 10 seconds[19] and making measurements from 4 different regions of each specimen and calculating the average of those values.

The corrosion and metal ion release behavior of biomedical implants in Fusayama artificial saliva solution have been reported to be similar to those in human saliva.[20] In the present study, corrosion and metal ion release tests were measured in Fusayama artificial saliva solution.[21] The pH value, important for corrosion behavior, of Fusayama artificial saliva solution was approximately 5.50. The chemical composition of the artificial saliva solution, which was used in the experiments, was (in g/L) 0.40 NaCl, 0.40 KCl, 0.79 $CaCl_2$, 0.69 NaH_2PO_4, 0.005 Na_2S, and 1.00 urea.

Electrochemical corrosion experiments of the Ti-6Al-4V and Co-Cr specimens were carried out inside a glass corrosion cell (artificial saliva environment) by using a potentiate (Interface 1000; Gamry) and a software program (Echem and Framework; Gamry). Graphite and saturated calomel were used as a cathode and reference electrode, respectively. Electrochemical corrosion experiments were carried out at room temperature. Initially, open circuit potential (OCP) curves of the specimens were obtained. Tafel tests of the Ti-6Al-4V and Co-Cr specimens were carried out to obtain the corrosion current density and corrosion potential. Polarization resistance and electrochemical corrosion rates of the specimens were determined by the linear polarization resistance method.[11] The experiments for the electrochemical corrosion plots were duplicated to determine repeatability.

The Ti-6Al-4V and Co-Cr specimens were immersed for 14 days in the artificial saliva, removed from the solution, dried, and then weighed to determine the weight change. Metal ion release values from the Ti-6Al-4V and Co-Cr specimens were determined by using an inductively coupled plasma mass spectrometer device (Thermo Fisher Scientific). Weight change in the Ti-6Al-4V and Co-Cr specimens was calculated by weight measurements before and after the static immersion periods.

The microstructures of the polished and etched Ti-6Al-4V and Co-Cr specimens were investigated by

Table 1. Chemical composition of Co-Cr alloys tested

Group	Co	Cr	Mo	W	Si	Fe	Mn	Nb	Others (Si, Mo, Fe)
EOS Co-Cr SP (sintering)	63.80%	24.70%	0.10%	5.40%	1.00%	0.50%	0.10%	–	–
Co-Cr metal block (milling)	65%	29%	–	2%	–	–	–	2%	2%

Co-Cr, cobalt-chromium.

Table 2. Chemical composition of Ti-6Al-4V alloys tested

Group	Al (wt%)	V (wt%)	O	N	C	H	Fe	Ti
EOS Titanium Ti64 (sintering)	5.5-6.75	3.5-4.5	<2000ppm	<500ppm	<800ppm	<150ppm	<3000ppm	Balance
Kera Ti5-Disc (milling)	5.70	4.10	0.08%	0.01%	0.01%	0.00%	0.20%	–

using a scanning electron microscope (SEM) (FEG 450; FEI Quanta, SU 3500; Hitachi). For more detailed microstructure investigation, before the SEM analysis, etching was performed on a specimen produced by CAD-CAM and laser sintering techniques as specified. For Co-Cr specimens, hydrochloric acid and hydrogen peroxide (80:20, v/v) were used for 30 minutes at room temperature. For Ti-6A-l4V specimens, 10% hydrofluoric acid was used for 30 seconds at room temperature.

Statistical analysis of the results was performed with a statistical software package (IBM SPSS Statistics, v22; IBM Corp). The suitability of the parameters to the normal distribution was evaluated with the Kolmogorov-Smirnov and Shapiro-Wilk tests. Comparison of the groups was determined with the Kruskal-Wallis test. A Bonferroni-corrected Mann-Whitney U test was used to identify the group that created the difference (α=.008). The Mann-Whitney U test was used to compare parameters between the 2 groups (α=.05).

RESULTS

As seen in Table 3, the highest Vickers hardness value was observed in Ti-6Al-4V specimens produced by laser sintering (P<.008). The laser sintering technique gave higher results than the CAD-CAM milling technique for both the alloy groups (P<.05).

Table 3. Vickers hardness values

Group	Vickers Hardness Mean ±SD (Median)	Post Hoc
^{A} Co-Cr CAD-CAM milling	356.44 ±17.67 (349)	D>A-B-C
^{B} Co-Cr laser sintering	400.9 ±16.63 (394,9)	B>A-C
^{C} Ti-6Al-4V CAD-CAM milling	294.45 ±33.76 (289,6)	A>C
^{D} Ti-6Al-4V laser sintering	456 ±25.64 (459,8)	–
P	<.001	–

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium; SD, standard deviation.

In obtaining corrosion data, 3 repetitive tests were performed for each of the specimens. In general, the OCP values obtained at the beginning of the corrosion tests of the Ti-6Al-4V and Co-Cr specimens can be used to determine their corrosion behavior. Figure 1A shows the comparative OCP curves of the investigated alloys. The highest OCP value was found in the CAD-CAM Co-Cr alloy and the lowest in the laser sintering Ti-6Al-4V alloy (P<.05) (Fig. 1A, Table 4). Tafel plots were also used to determine the corrosion performance of the alloys. Figure 1B illustrates the effect of the alloy type on the Tafel curves. The lowest corrosion current density was found in the CAD-CAM Co-Cr alloy and the highest in the laser-sintered Ti-6Al-4V alloy. The I_{corr} level of the Co-Cr CAD-CAM milling group was found to be statistically significantly lower than that of the Ti-6Al-4V CAD-CAM milling and Ti-6Al-4V sintering groups (P<.008). No statistically significant difference was found among the other groups in terms of I_{corr} levels (P>.008) (Table 5). For V_{corr} measurements, a statistically significant difference was found among the groups (P<.05) (Table 6).

After 14 days, weight change was predominantly observed in the laser-sintered groups (P<.05). The Ti-6Al-4V group gave higher results than the Co-Cr group in comparison with other corrosion measurements (P<.008) (Table 7, Fig. 1C).

Co and Cr ion release showed statistically significantly higher values with the laser sintering technique than with the CAD-CAM milling technique (P<.05) (Table 8, Fig. 1D). Similarly, Ti ion emission was higher in the laser-sintered group (P<.05). For Al and V ion oscillations, no statistical difference was found between the production techniques (P>.05) (Table 9, Fig. 1D).

SEM images of the specimens showed that the specimens were generally sufficiently sintered. In the examination of SEM images, the titanium alpha phase created light-colored areas, while the titanium beta phase created dark areas. The milled specimens had fewer micropores and microcracks than the laser-sintered specimens, indicating that the CAD-CAM milling technique led to an improved microstructure (Figs. 2, 3). The microstructure of the etched CAD-CAM–milled Co-Cr alloy specimens consists of equiaxed Co-based grains and some fine intermetallic precipitates or carbides. The microstructure of the etched laser-sintered Co-Cr alloy

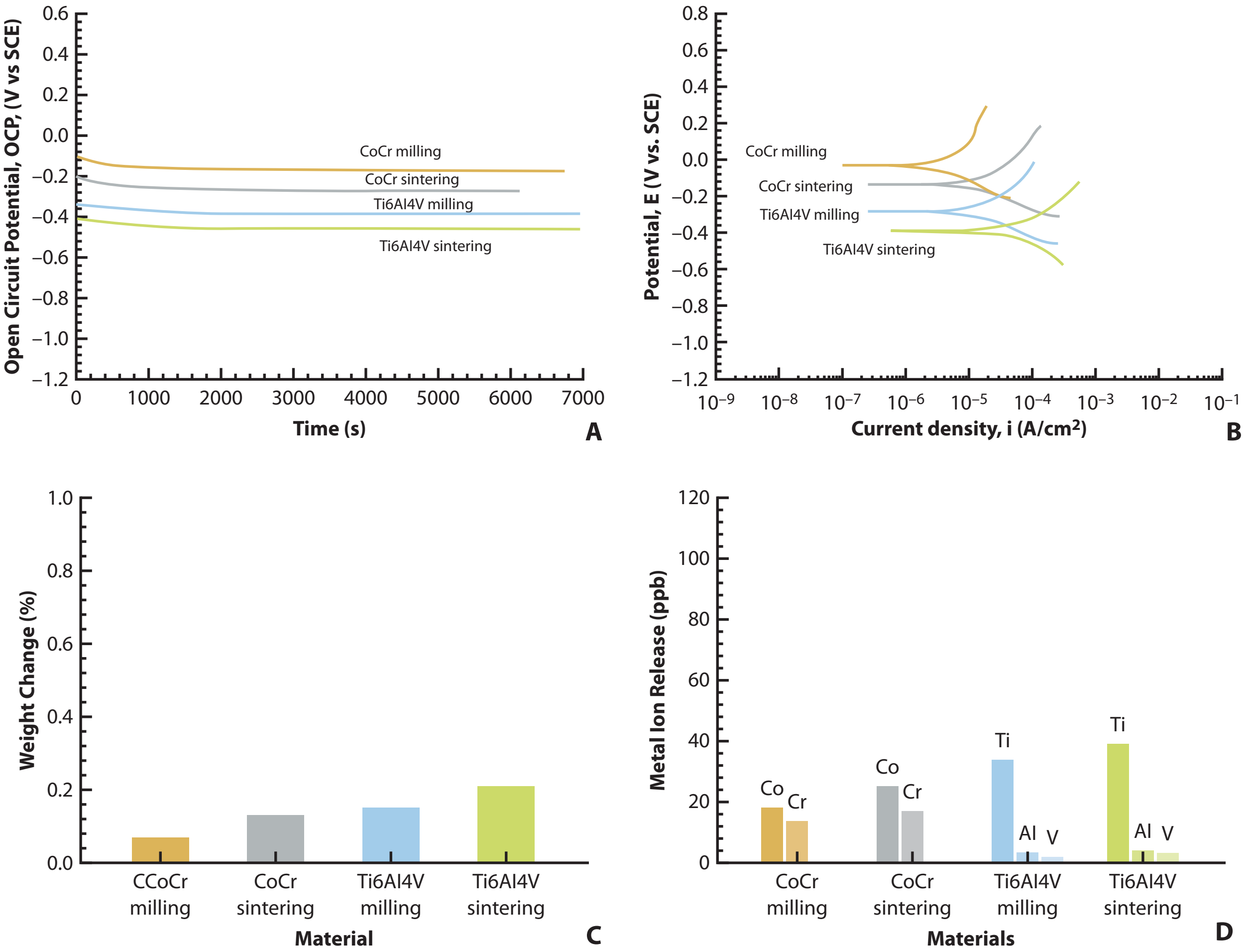

Figure 1. A, Corrosion potential versus time for different specimens studied. B, Tafel curves for specimens studied. C, Weight loss values of alloys. D, Metal ion release values of groups.

Table 4. Evaluation of groups in terms of OCP levels

	OCP (V vs SCE)	
Group	**Mean ±Standard Deviation (Median)**	**Post Hoc**
^{A} Co-Cr CAD-CAM milling	-0.14 ±0.02 (-0.1)	D<A-B-C
^{B} Co-Cr laser sintering	-0.24 ±0.03 (-0.2)	C<A-B
^{C} Ti-6Al-4V CAD-CAM milling	-0.36 ±0.01 (-0.4)	B<A
^{D} Ti-6Al-4V laser sintering	-0.47 ±0.04 (-0.5)	—
P	<.001	—

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium; OCP, open circuit potential.

Table 5. Evaluation of groups in terms of I_{corr} levels

	I_{corr} (A/cm2)	
Group	**Mean ± Standard Deviation (Median)**	**Post Hoc**
^{A} Co-Cr CAD-CAM milling	0.00006 ±0.00002 (0.00006)	A<B-C
^{B} Co-Cr laser sintering	0.00032 ±0.00045 (0.00004)	—
^{C} Ti-6Al-4V CAD-CAM milling	0.00057 ±0.00016 (0.00055)	—
^{D} Ti-6Al-4V laser sintering	0.00078 ±0.00015 (0.0008)	—
P	.018	—

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium; I_{corr}, corrosion current density.

Table 6. Evaluation of groups in terms of V_{corr} levels

	V_{corr} (V)	
Group	**Mean ± Standard Deviation (Median)**	**Post Hoc**
^{A} Co-Cr CAD-CAM milling	-0.13 ±0.03 (-0.1)	D<A-B-C
^{B} Co-Cr laser sintering	-0.23 ±0.03 (-0.2)	C<A-B
^{C} Ti-6Al-4V CAD-CAM milling	-0.37 ±0.02 (-0.4)	B<A
^{D} Ti-6Al-4V laser sintering	-0.46 ±0.03 (-0.5)	—
P	<.001	—

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium; V_{corr}, corrosion potential.

Table 7. Evaluation of weight change (%) levels of groups

	Weight Change (%)	
Group	**Mean ±standard Deviation (Median)**	**Post Hoc**
^{A} Co-Cr CAD-CAM milling	0.07 ±0.01 (0.1)	D>A-B-C
^{B} Co-Cr laser sintering	0.13 ±0.01 (0.1)	C>A-B
^{C} Ti-6Al-4V CAD-CAM milling	0.16 ±0.01 (0.2)	B>A
^{D} Ti-6Al-4V laser sintering	0.24 ±0.04 (0.2)	—
P	<.001	—

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium.

Table 8. Evaluation of ion release levels of Co-Cr CAD-CAM milling and Co-Cr laser-sintered groups

	Co (ppb)	Cr (ppb)
Group	Mean ± Standard Deviation (Median)	Mean ± Standard Deviation (Median)
Co-Cr CAD-CAM milling	17.5 ±1.05 (17.5)	14.67 ±1.21 (14.5)
Co-Cr laser sintering	23.17 ±0.98 (23.5)	16.83 ±1.47 (16.5)
P	.004	.027

CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium.

Table 9. Evaluation of ion release levels of Ti-6Al-4V CAD-CAM milling and Ti-6Al-4V laser-sintered groups

	Ti (ppb)	Al (ppb)	V (ppb)
Group	Mean ± Standard Deviation (Median)	Mean ± Standard Deviation (Median)	Mean ± Standard Deviation (Median)
Ti-6Al-4V CAD-CAM milling	31.67 ±2.16 (32.5)	2.5 ±0.55 (2.5)	1.83 ±0.75 (2)
Ti-6Al-4V laser sintering	40.17 ±3.6 (39)	3 ±1.55 (3)	2.83 ±1.17 (2.5)
P	.004	.615	.101

CAD-CAM, computer-aided design and computer-aided manufacturing.

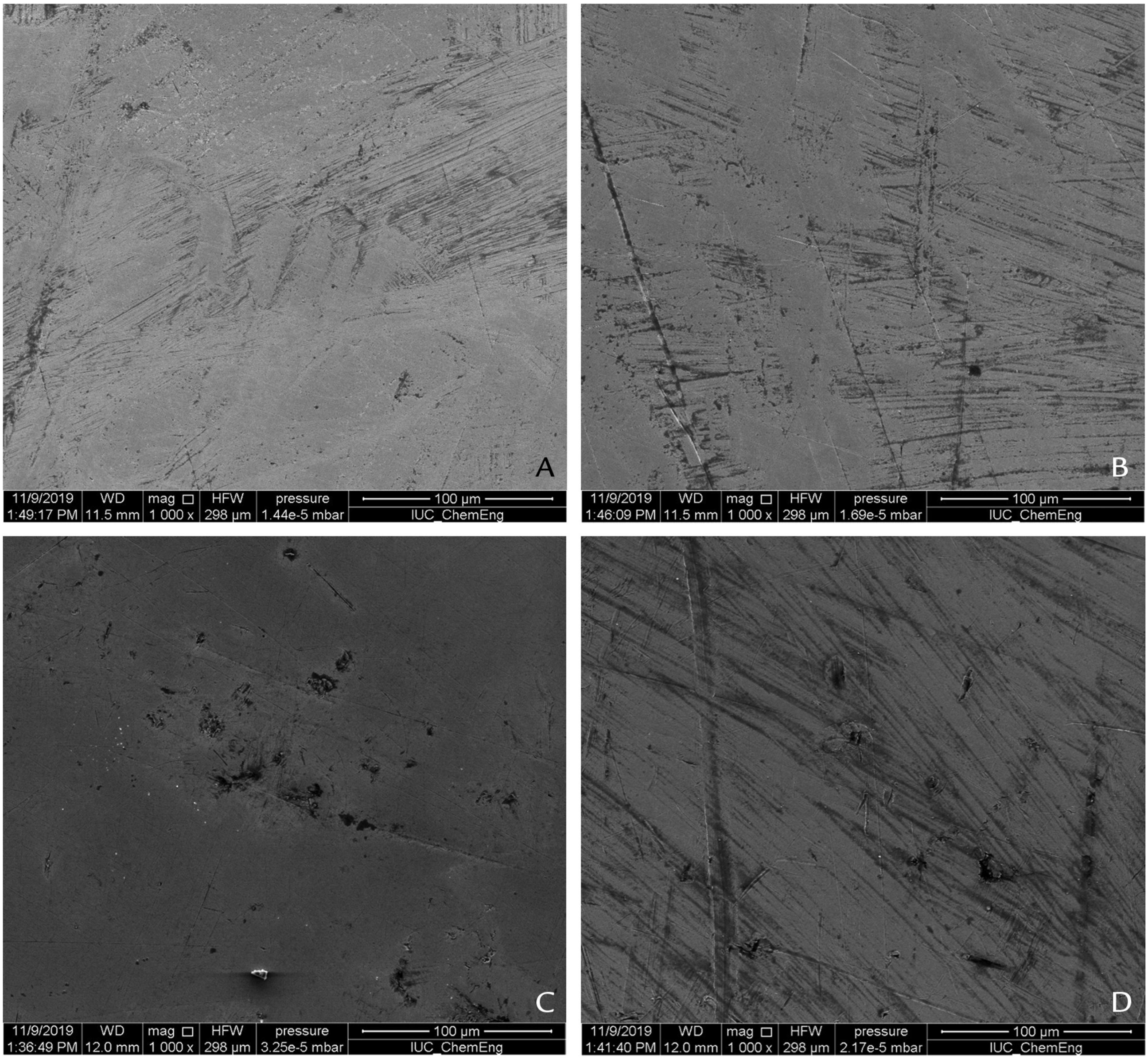

Figure 2. Scanning electron microscope images of polished Co-Cr and Ti-6Al-4V specimens produced by CAD-CAM milling and laser sintering techniques. A, Co-Cr CAD-CAM milling. B, Co-Cr laser sintering. C, Ti-6Al-4V CAD-CAM milling. D, Ti-6Al-4V laser sintering (original magnification ×1000). CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium.

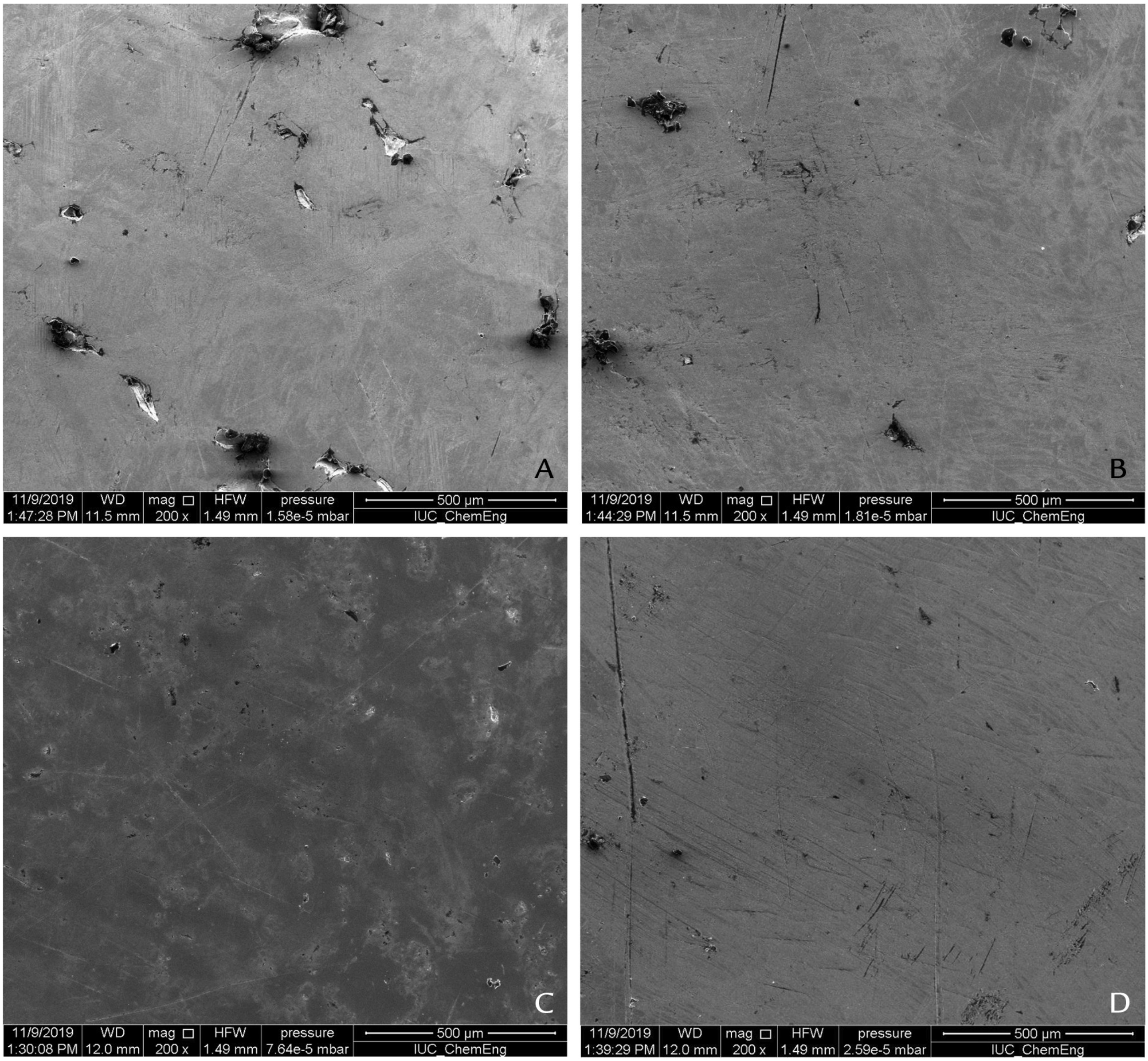

Figure 3. Scanning electron microscope images of polished Co-Cr and Ti-6Al-4V specimens produced by CAD-CAM milling and laser sintering techniques. A, Co-Cr CAD-CAM milling. B, Co-Cr laser sintering. C, Ti-6Al-4V CAD-CAM milling. D, Ti-6Al-4V laser sintering (original magnification ×200). CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium.

specimens consists of elongated columnar grains. Also, laser tracks and layered morphology in the laser-sintered Co-Cr alloy specimens could be observed (Fig. 4). The microstructure of the etched CAD-CAM–milled Ti-6Al-4V specimens consists of equiaxed alpha-Ti grains and some intergranular beta-Ti phases. The microstructure of the laser-sintered etched Ti-6Al-4V specimens consists of acicular plate-like alpha+beta titanium phases (Fig. 5).

DISCUSSION

This study assessed the electrochemical corrosion behavior, ion release, and surface hardness of Co-Cr and Ti-6Al-4V alloys produced by the CAD-CAM milling and laser sintering methods. The null hypothesis was rejected because the production method was found to affect corrosion, ion release, and surface hardness for both the groups.

The CAD-CAM milling technique showed better properties in terms of general corrosion behavior compared with the laser sintering technique. The OCP method monitors the potential of the specimen versus time. The OCP is the alloy's own potential that occurs in a given environment, and the testing is not destructive.[22] The E_{OCP} value is often used to provide a qualitative indication of a material's corrosion regime, and this can

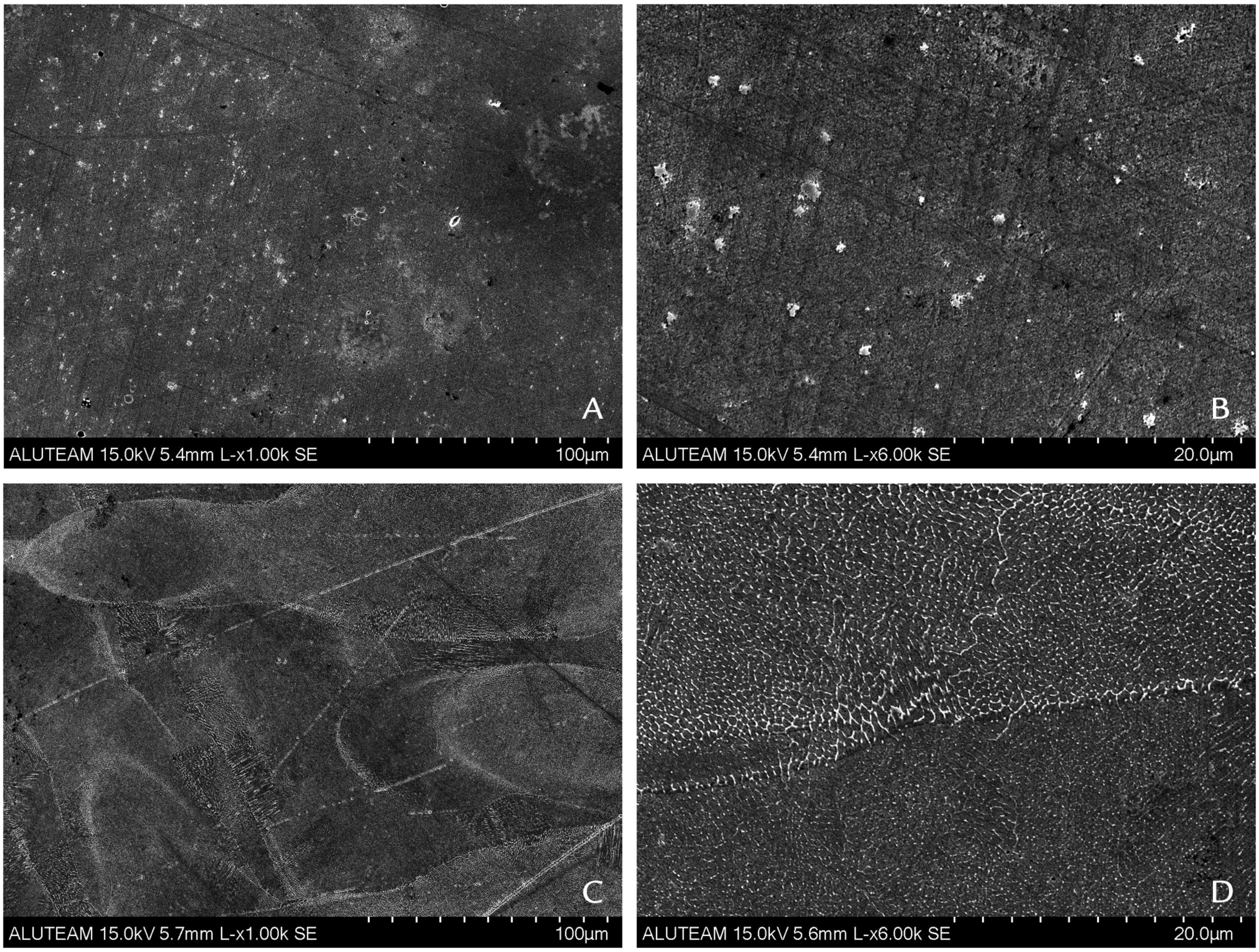

Figure 4. Scanning electron microscope images of etched Co-Cr specimens produced by CAD-CAM milling and laser sintering techniques. A, CAD-CAM milling (original magnification ×200). B, CAD-CAM milling (original magnification ×1000). C, Laser sintering (original magnification ×200). D, Laser sintering (original magnification ×1000). CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium.

be categorized as active or passive as a function of its markers.[23] The decrease in OCP of a metal in contact with a certain environment indicates an increase in chemical reactivity and susceptibility to corrosion.[24] Figure 1A shows E_{OCP} measurements, that is, how the manufacturing technique affected the passivity of metal alloys over time. The OCP curves recorded in this study confirm a noticeable increase in the chemical reactivity of Ti-6Al-4V and Co-Cr made by using different production techniques. CAD-CAM–milled specimens of Co-Cr showed a natural potential at approximately -0.14 V, followed by laser-sintered specimens at -0.24 V, while the natural potential was approximately -0.36 V for the CAD-CAM–milled specimens of Ti-6Al-4V, and -0.47 V for the laser-sintered specimens of Ti-6Al-4V. This difference between the groups was found to be statistically significant ($P<.05$). However, OCP solutions alone are insufficient to determine the corrosion resistance of an alloy.[1]

The electrochemical corrosion potential values and electrochemical corrosion current values of the Co-Cr and Ti-6Al-4V specimens were determined from the Tafel curves.[25] In general, metals with high electrochemical corrosion current values show low electrochemical corrosion resistance, and those with low electrochemical corrosion current values show high corrosion resistance.[5] In the present study, a statistically significant difference was found between the groups in terms of I_{corr} and V_{corr} values ($P<.05$) (Tables 5 and 6). In the examination of the weight changes (%) of the groups, the least change was in the Co-Cr CAD-CAM milling group (0.07%), and the highest change was in the Ti-6Al-4V laser-sintered group (0.24%). The difference among all the groups was found to be statistically significant ($P<.05$) (Fig. 1C). These results, suggesting that milling and sintering production methods have an effect on corrosion behavior, conflicted with those of Tuna et al[26] but were consistent with those of Padros et al.[23]

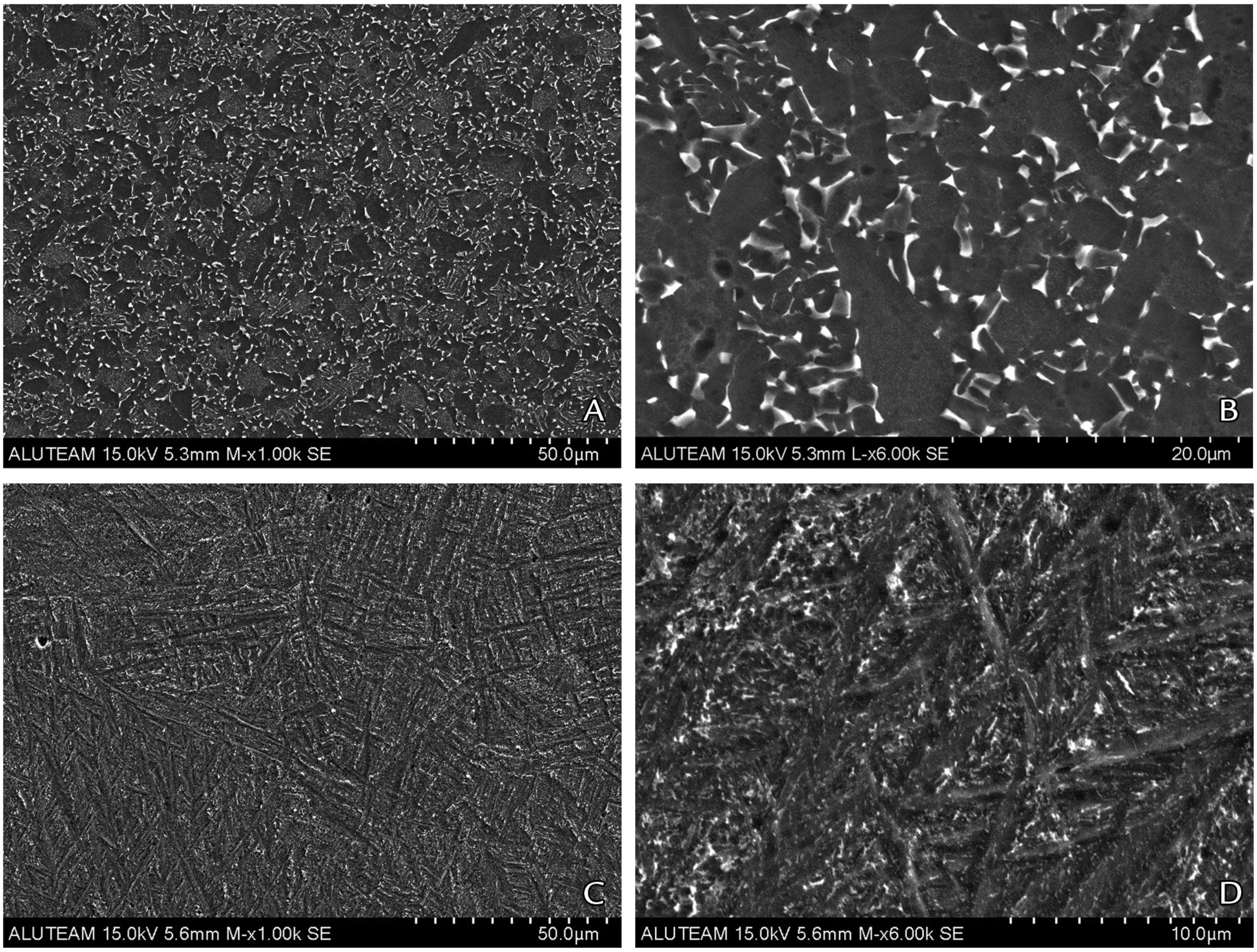

Figure 5. Scanning electron microscope images of etched Ti-6Al-4V specimens produced by CAD-CAM milling and laser sintering techniques. A, CAD-CAM milling (original magnification ×200). B, CAD-CAM milling (original magnification ×1000). C, Laser sintering (original magnification ×200). D, Laser sintering (original magnification ×1000). CAD-CAM, computer-aided design and computer-aided manufacturing.

However, the environment and conditions were not the same in these studies, making comparisons difficult.

Metal ion release is important for dental materials, with minimal release being required.[26] In general, metal ion release values were determined by the chemical compositions of the metals, the thickness of the metal oxide film, the properties of the chemical bond types of the surface metal oxide, and the microstructure of the metals.[8] The content of the alloy component can also have an effect on ion release.[26] In the present study, differences in the chemical compositions of the CAD-CAM specimens and laser sintering specimens were attributed to the producers and suppliers. However, differences in the chemical compositions of the specimens were not high. The contents of the alloys used for CAD-CAM and laser sintering have been reported to be different in similar studies.[13,26] Depending on the production method used, the content, microstructure, and surface properties of the alloy will have an effect on metal ion release, so care should be taken when choosing the production method.[7,9] The materials produced by the CAD-CAM milling method release fewer ions (Fig. 1D) (for Co-Cr alloy, Co: 17.5 ppb, Cr: 14.67 ppb and for Ti-6Al-4V, Ti: 31.6 ppb, Al: 2.5 ppb, V: 1.83 ppb). Ion release of the sintering group was found to be higher (for Co-Cr alloy, Co: 23.17 ppb, Cr: 16.83 ppb and for Ti-6Al-4V, Ti: 40.17 ppb, Al: 3 ppb, V: 2.83 ppb). When the ion emissions were analyzed statistically as per the production methods, in the sintering group for Co-Cr alloy, Co and Cr ion oscillations were found to be significantly higher ($P<.05$) for Ti-6Al-4V alloy. The amount of Ti release was significantly higher in the sintering group ($P<.05$), but no statistically significant difference was found between Al and V release amounts ($P>.05$). In a previous study,[26] no difference was reported between CAD-CAM milling and laser sintering methods in terms of ion release, but differences were found among groups. However, it was reported that Co and Cr ion releases were affected by different production methods, and these results were similar to those of the present study, with CAD-CAM milling showing less ion release in both studies. The ion release measurements confirmed the results of the corrosion studies and the chemical heterogeneity of specimens produced by sintering, with fewer defects such as pores, volume contractions, or coring in specimens produced by the CAD-CAM milling method.[23]

A dental restoration should be strong, rigid, and sufficiently hard for masticatory forces. Elastic modulus and hardness values of the biomedical metals must be close to values of the bone tissue to prevent the stress shielding effect.[3] Hardness is a good indicator of an alloy's ability to resist local permanent deformation under occlusal load[4] and is affected by a homogeneous and regular surface of the material.[19] However, the Vickers hardness results of specimens obtained by different production methods have been reported to differ.[13,19,27] In the present study, higher values were measured for both materials in the group produced by sintering, and differences among groups were statistically significant ($P<.05$).

Ti alloys are used for biomedical implants because of their relatively lower elastic modulus and high specific strength, biocompatibility, and corrosion resistance. Elastic modulus values of the Ti alloys are lower than the other alternative dental materials such as stainless steels, Co-Cr alloys, and also zirconia ceramic. The production of the beta-Ti phase by adding alloying elements such as Nb, Ta, and Zr can decrease the elastic modulus. Nevertheless, the elastic modulus of beta-Ti alloys is still higher than that of bone.[15]

The SEM images revealed that the CAD-CAM–milled specimens had smoother surfaces and contained fewer micropores and microcracks than the laser-sintered specimens. Pits were seen in the Ti-6Al-4V specimens, defined as pitting corrosion (Fig. 2 C,D). Electrochemical corrosion test results showed that the CAD-CAM milled specimen corroded less than the specimens produced by laser sintering, consistent with the SEM findings. In addition, Co-Cr alloy showed better results in terms of electrochemical corrosion when compared with Ti-6Al-4V alloy for both the production methods. The SEM images were similar at low magnification (Fig. 3), but more cavitation areas were seen in the CAD-CAM–milled specimens at high magnification (Fig. 2). When small in size, these areas indicate pitting corrosion, while larger ones suggest the material has pores, errors, or impurities that may occur during production.

Limitations of this study included the in vitro design and that it was carried out in Fusayama artificial saliva solution. Future studies should evaluate the corrosion behavior of dental alloys produced by using different parameters for different environments and solutions.

CONCLUSIONS

Based on the finding of this in vitro study, the following conclusions were drawn:

1. The different production methods affected electrochemical corrosion, metal ion release, and surface hardness.
2. Higher surface hardness was found for the specimens produced by laser sintering.
3. Less electrochemical corrosion and metal ion release was seen in specimens produced by CAD-CAM milling.
4. Corrosion and ion release was less for Co-Cr alloy than for Ti-6Al-4V alloy.

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