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Original Article

Effect of modified investment and casting system on the recasting properties of high-gold alloy

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KEYWORDS
High gold alloy(PFM);
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Abstract *Background/purpose:* High gold (Au) alloys have many advantages, such as good mechanical properties and stable chemical properties for dental restoration. The purpose of this investigation was to investigate the effect of zirconia (ZrO_2)-magnesia (MgO)-based investment combined with an argon arc vacuum pressure (Ar-arc VP) casting process on the recasting of high Au alloys.
Materials and methods: The recasting Au alloys were compared between the control group of conventional SiO_2-based investment/horizontal centrifugal (HC) casting and the experimental group of ZrO_2—MgO-based investment/Ar-arc VP die casting. The first-generation castings were defined as being made from purchased Au alloys and the second-generation castings were made from 50 wt% of the original Au alloys before casting, plus the balance of the remaining 50 wt% from the previous castings. The third-generation was made from all old surplus from the previous castings. The ingots were measured for the marginal gap, surface roughness, interface oxidation, hardness, and phase identification.
Results: The results showed that the recasting success rate reached 100%. The ZrO_2—MgO-based investment/Ar-arc VP group had better edge precision, smaller oxide layer thickness, and lower hardness than the SiO_2-based investment/HC group. However, surface roughness analysis indicated little difference between the two groups. Phase analysis showed that the

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recasting alloys of the second and third-generation groups contained higher Au contents than those of the first-generation.
Conclusion: Overall, the Au alloy can be better recasted and retain good mechanical properties under the clinically used 5 wt% ZrO2—MgO-based investment/Ar-arc VP casting method.

Introduction

High-gold (Au) alloy has been successfully utilized in dental restorations for decades. Au has many advantages, such as stable chemical properties, good castability, coefficient of expansion, and wear rate close to teeth.[1—4] Tjan et al.[5] examined the marginal accuracy of restoration using type III Au-alloy, Au—Pd alloy, high Pd alloy, Pd—Ag alloy, and Ni—Cr alloy. Their findings indicated that the best results are achieved using type III Au alloy.

Depending on how the metal is pushed into the mold, there are various types of casting machines, including sand casting, investment casting, centrifugal casting, and vacuum pressure casting. Shanley et al.[6] studied the influence of the casting method on marginal accuracy. They found the marginal accuracy was not influenced by the casting method. However, the casting machine and the type of dental alloy would affect the casting quality. Moreover, the casting method plays an important role in dental alloy casting in the study by Asgar and Arfaei.[7]

Pure titanium (Ti) casting was developed in the 1980s. Due to the titanium's tendency to oxidize in the air and when in contact with traditional phosphate-bonded investment, specially formulated investment and casting machines were developed. The mold materials were specially formulated and included alumina (Al_2O_3), magnesia (MgO), yttria (Y_2O_3), zirconia (ZrO_2), titania (TiO_2), and calcia (CaO).[8—17] Substituting an MgO-based investment for a silica (SiO_2)-based one has significantly reduced titanium interfacial reactivity.[11] Wang et al. developed ZrO_2 slurry coating on the wax pattern and found reduced surface reaction on Ti casting.[14] Hung et al. found that incorporating ZrO_2 into the MgO-based investment resulted in high-quality Ti casting with clinically acceptable marginal accuracy and a thin oxide layer.[15] Furthermore, the castability of Ti casting is often influenced by the choice of mold material, casting method and their combination.[18,19] Vacuum pressure and argon (Ar) gas filling, combined with a two-chamber casting machine, were found to improve castability and reduce surface reactions in Ti casting.[20—22]

In the 1970s, as the price of Au rose, several alternative alloys were developed, including Pd-, Co-, Ni-, and Ti-based alloys. Among these alloys, Au alloy still demonstrated better quality for dental casting regarding clinical performance and safety standards.[23—26] Accordingly, an alternative method for producing high-quality dental restorations involves recasting Au alloy. Recasting typically involves using the sprue and the bottom of the passage that connects the sprue through the molten casting. This process often allows for recycling and reusing, leading to cost savings and environmental benefits. Tuccillo et al.[27] studied the effect of different melting methods on the stability and hardness of alloy composition. The composition of precious metals and semi-precious metals was found to be relatively stable. However, trace elements such as Fe, In, Sn, and Zn may be lost during the casting process, with a greater likelihood of loss when using the gas-oxygen torch method. Due to the loss of these trace elements, recasting a low-Au alloy clearly affected the basic properties, such as yield strength, elemental distribution, hardness, and percentage elongation.[28] Using a traditional horizontal centrifugal casting machine to recast Pd—Ag alloy increased the content of Zn, Ag, and O, and resulted in a thicker oxide layer on the casting. This thick oxide layer significantly affected the bonding strength of alloys with the ceramic and increased corrosion susceptibility.[29,30] The presence of trace elements Sn and In would increase stability, resulting in a thinner oxide layer when recasting Pd—Ag using the argon arc vacuum pressure (Ar-arc VP) casting process.[31] Ti could be recast using a ZrO_2/MgO-based investment combined with Ar-arc VP casting method. The marginal accuracy, surface roughness, interfacial surface reaction, and elemental composition of the resulting recast Ti showed comparable with those of the first-generation casting group.[22] This study aimed to investigate the effect of repetitive casting of Au alloys under an Ar-arc VP casting process combined with ZrO_2/MgO-based investment compared to conventional horizontal centrifugal casting techniques and SiO_2-based investment.

Materials and methods

Preparation of investment

In this study, two types of investments were used. One was gypsum-bonded investment (designed as SiO_2-based investment, Cristobalite New F-1, Tokuyama Co., Tokyo, Japan). The recommended liquid-to-powder ratio was 35 mL of water to 100 g of investment powder. The other investment was 5 wt% zirconia (ZrO_2, Hayashi Pure Chemical Ind. Ltd., Osaka, Japan) modified MgO-based investment (designed as 5wt% ZrO_2—MgO-baed investment; Selevest CB, Selec Co., Osaka, Japan). The recommended liquid-to-powder ratio was 20 mL of water to 100 g of casting investment powder. The powders for investments were blended in a mechanical vacuum mixer (Vacuum Mixer, Whip-Mix, Louisville, KY, USA) at a speed of 425 rpm for 60 s after mixing with water.

Preparation of casting

The method of die (MOD) cast molding was utilized to assess the accuracy of the casting inlay, as schematically shown in Fig. 1. A wax pattern measuring 8.0 mm in diameter, 7.0 mm in height, and 2.0 mm in thickness was placed on the metal die and annealed at room temperature. The distance between the metal die shoulder and the margin of the wax pattern was measured at eight fixed points for each specimen (dx) and then calculated. Three specimens were prepared and tested for each group. The specimens were placed in casting rings measuring 36 mm in diameter and 46 mm in height, with a layer of ring liner (35 mm in diameter and 2 mm in thickness, J. Morita Co., Tokyo, Japan) and a sprue (3 mm in diameter and 25 mm in length). The invested molds were burned out in a programmed electric furnace at a rate of 6 °C/min to 700 °C and were then kept at this temperature for 60 min in both groups of SiO_2-based investment and 5wt% ZrO_2/MgO-based investment.

The ADA Type III casting Au alloy (Au: 74.0 %, Ag: 13.5 %, Cu: 7.0 %, Pt: 2.4 %, Pd: 2.0 %, Zn: 1.0 %, Ir: 0.1 %, Degulor C, Degussa Co., Hanau, Germany) was used. This experiment also investigated the impact of various casting methods on the material properties after recasting. Therefore, the compared group used a traditional horizontal centrifugal casting machine (designated as HC, Centrific Casting Machine P-015, Kerr Co., Brea, CA, USA), which employed a gas-oxygen torch to melt the Au alloy and utilized 15 lb of centrifugal force to complete the casting procedure. The experimental group utilized a two-chamber automatic Ar-arc VP casting machine (Castmatic-S, Iwatani Co., Osaka, Japan). The Au alloy ingot was placed on the copper crucible, and the tungsten electrode was placed 5 mm above the ingot center. The argon pressure was 1.8 kgf/cm^2 with a current of 250 A. After casting, the molds were air-cooled to room temperature. The castings were removed from the molds and cleaned in water by an ultrasonic cleaner. The sprues and buttons, sectioned from each casting in every generation, were sandblasted with 50 μm Al_2O_3 and then soaked in 75% alcohol for 10 min. In the second-generation, 50 wt% new Au alloy was combined with 50 wt% surplus from first-generation as the ingot. In the third-generation, the ingots consisted entirely of surplus from the previous castings. The casting method was the same as previously described.[15] Each generation of the castings was divided into four groups according to two different investment materials and two different casting machines. There were twelve groups in total in this experiment, and each group had three samples for repeatability test characterization ($n = 3$).

Marginal accuracy measurement of casting

The irregularities and nodules of the castings were examined using Occlude (Pascal Co., Bellevue, WA, USA)) to eliminate defects before verifying the dimensions. A cutting machine (Model AG03, Ray Foster Co., Huntington beach, CA, USA) was used to separate the crown inlay and the sprue. The distance separating the margin of the castings and the metal die was set as dy and was measured at the same four points. The inlay was under a load of 5 kgf when the castings were seated. The marginal accuracy was calculated as dy - dx for each point, and the mean value was derived from the eight measurements for each crown.

Interface oxidation evaluation of castings

The sprues of the MOD castings were cut horizontally 3 mm from the attachment point. They were then sandblasted with 50 μm Al_2O_3 under a pressure of 4∼6 kgf/cm^2 using a

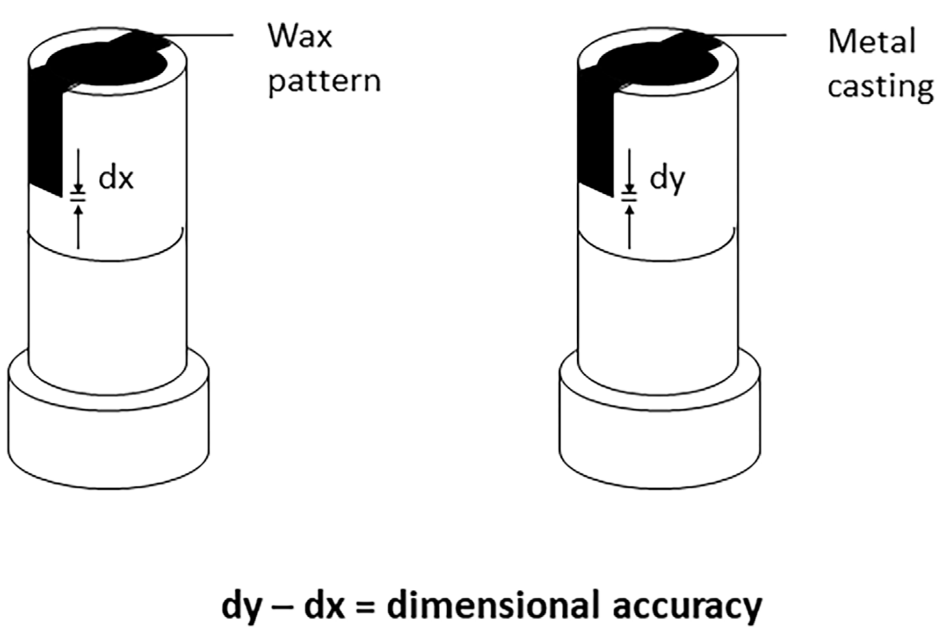

Figure 1 Dimensional accuracy of a casting crown is expressed by the discrepancy (dy-dx) measured on its wax pattern and the casting on the same die.

Hi-blaster (Shofu Corp., Kyoto, Japan). After that, they were immersed in 75% alcohol for 5 min, washed ultrasonically for 30 min, and treated with high-pressure steam. The exposed surface was mounted in epoxy resin and polished with 600 mesh emery paper and 0.05-μm Al_2O_3 particles on a cloth-polishing wheel. The composition of the interface surface was detected by energy dispersive X-ray analysis (EDX) and backscattered electron image (BEI) of an electron probe microanalyzer (EPMA, JXA-8900R, JEOL Ltd. Tokyo, Japan).

Microhardness measurement of castings

The microhardness of the above-mentioned polished specimens was measured through the cross-section of the outer surface at 100-μm intervals with a Vickers microhardness indenter at a load of 200 gf (MTX-50, Matsuzawa Seiki Co., Akita, Japan). The samples were divided into as-cast conditions and oxide firing.

Surface roughness measurement of casting

The surface roughness of the sprue of MOD casting was measured. Four measurements were taken for each casting. The average surface roughness (Ra) was measured using a surface tester (Surface SJ-301, Mitutoyo Co., Kanagawa, Japan) with a sampling length (c) of 0.8 mm at a speed of 0.5 mm/s.

Statistical analysis

The results for different casting generations and machines were compared, using three-way analysis of variance (ANOVA) and Tukey HSD as indicated in the results, using a statistical software package (JMP® 10.0.0, JMP Statistical Discovery LLC, Cary, NC, USA).

Results

Marginal gap

Undesirable porosity, incomplete casting, and rounded short margins were considered unsuccessful casting. The study achieved a 100% success rate for complete casting. The mean marginal gap of the MOD inlays is shown in Fig. 2. The largest marginal gap in the second-generation/SiO_2-based/HC group was 77.46 ± 10.03 μm, the smallest gap shown in the first-generation/5 wt% ZrO_2—MgO-based/Ar-arc VP was 35.88 ± 1.15 μm. It was found that the type of investment material had a significant influence on the marginal accuracy (Three-way ANOVA, $P < 0.0001$). The casting machine and recasting did not influence the marginal gap of the Au-alloy casting (Three-way ANOVA, $P > 0.05$). Regardless of the casting machine used, the marginal gap of the 5wt% ZrO_2—MgO-based investment group was smaller than that of the SiO_2 investment group. Additionally, even after repeated casting, the marginal gap of the 5wt% ZrO_2—MgO-based investment group remained smaller than that of the SiO_2-based investment group (Turkey-Kramer HSD).

Surface roughness

The measurement of Ra was shown in Fig. 3. The smallest Ra of the casting was 1.24 ± 0.02 μm in the first-generation/SiO_2-based/Ar-Arc VP group. The largest Ra of the casting was 4.38 ± 0.27 μm in the third-generation/5wt% ZrO_2—MgO-based/HC group. The results showed recasting did not influence the Ra of the Au-alloy casting (Three-way ANOVA, $P > 0.05$). The type of investment, casting machine, and the interaction of the investment type and casting machine significantly influenced Ra of the Au-alloy casting (Three-way ANOVA, $P < 0.0001$ for all). The Ra of the Au-alloy casting was smaller when using SiO_2-based investment and Ar-arc/VP casting.

Since recasting had no obvious effect on the Ra, the Au-alloy castings were divided into four groups based on investment materials and casting machines for further evaluation. The four groups were 5wt% ZrO_2—MgO-based/Ar-Arc VP group, 5wt% ZrO_2—MgO-based/HC group, SiO_2-based/Ar-arc VP group, and SiO_2-based/HC group. There was a significant difference among the four groups (One-Way ANOVA, $P < 0.0001$) and the group of 5wt% ZrO_2—MgO-based/HC had larger Ra than the other groups (Turkey-Kramer HSD).

Interface oxidation

The elemental mapping of Au, Ag, Cu, Pt, Pd, and Zn in each group is presented in Table 1. The wt% of Au, Ag, Cu, and Pd was influenced by the casting generation, while the wt% of Pt was affected by investment (Three-Way ANOVA, $P < 0.05$). However, the wt% of all the elements was not affected by casting machines (Three-Way ANOVA, $P > 0.05$). The percentage of Au content in the second- and third-generation was higher than in the first generation (Three-Way ANOVA, $P < 0.05$, Turkey-Kramer HSD). Importantly, a higher wt% of Au in the casting was associated with a smaller marginal gap (Spearman's correlation, $r = -0.3306$, $P < 0.05$). The percentage of all elements did not affect the surface roughness of the casting.

The BEI cross-sectional images showed different gradation colors depending on the average atomic number. The blue, green and yellow colors meant the lighter the average atomic weight that was defined as oxidation zone. Generally, the oxidation zones were under 1 μm in each groups that was very thin because of the 74wt% Au was used. The 5wt% ZrO_2—MgO-based/Ar-arc VP group had usually slightly thinner oxide thickness. Recasting had no obvious effect on the thickness of the oxide layer (Figs. 4—6).

Microhardness

The microhardness result is shown in Fig. 7. The VHN of the casting was influenced by the generation and type of investment (Three-Way ANOVA, $P < 0.05$). As the cycle of repeat casting increased, the VHN of the casting decreased. The VHN in the 5 wt% ZrO_2—MgO-based investment group had a softer surface than in the SiO_2-based investment group. The casting machine did not have an effect on VHN (Three-Way ANOVA, $P > 0.05$).

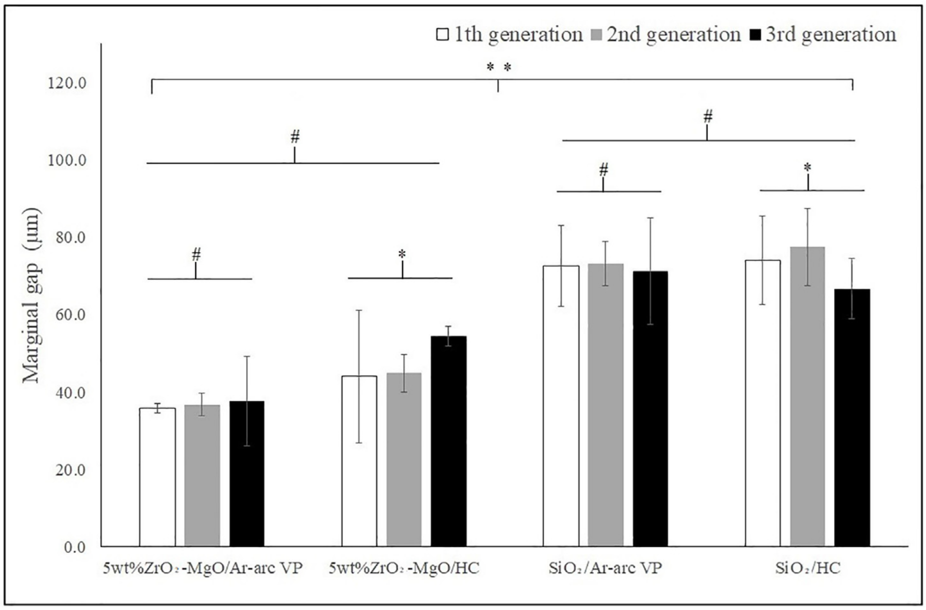

Figure 2 Dimensional accuracy of the castings made by different investments combined with casting machines in every generation. Each column represents the mean and standard deviation. 5wt% ZrO_2—MgO/Ar-arc VP:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, 5wt% ZrO_2—MgO/HC: 5wt% ZrO_2—MgO-based investment/HC casting machine, SiO_2/Ar-arc VP: SiO_2-based investment/Ar-arc VP casting machine, SiO_2/HC: SiO_2-based investment/HC casting machine. The symbol '#' means no significant difference among the groups ($P > 0.05$). The symbol '*' and '**' means the significant difference among the groups ($P < 0.05$ and $P < 0.01$).

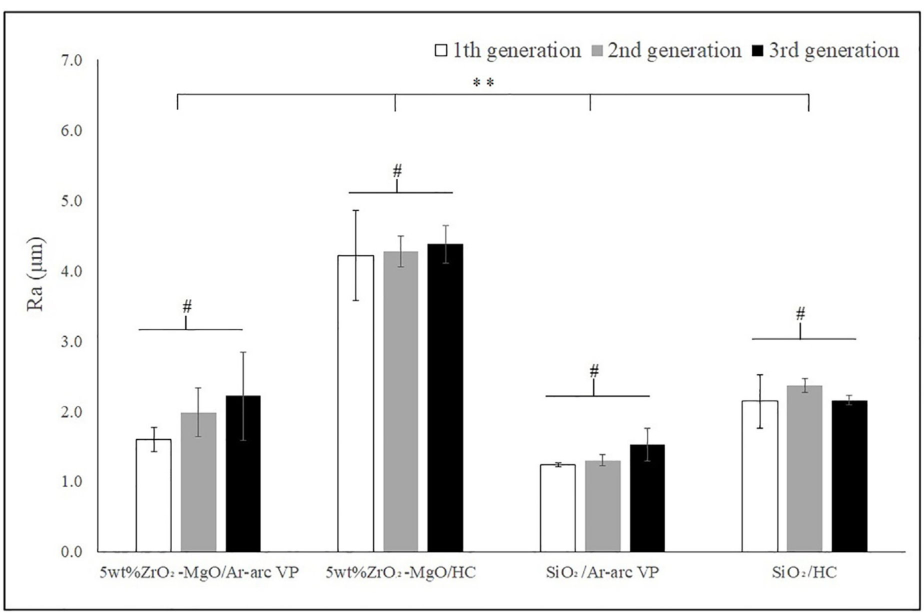

Figure 3 Surface roughness of the castings made by different investments combined with casting machines in every generation. Each column represents the mean and standard deviation. 5wt% ZrO_2—MgO/Ar-arc VP:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, 5wt% ZrO_2—MgO/HC: 5wt% ZrO_2—MgO-based investment/HC casting machine, SiO_2/Ar-arc VP: SiO_2-based investment/Ar-arc VP casting machine, SiO_2/HC: SiO_2-based investment/HC casting machine. The symbol '#' means no significant difference among the groups ($P > 0.05$). The symbol '*' and '**' means the significant difference among the groups ($P < 0.05$ and $P < 0.01$).

Table 1 The weight percentages of Au, Ag, Cu, Pt, Pd and Zn in the Au alloy castings made by different investments and casting machines in every generation.

		Au	Ag	Cu	Pt	Pd	Zn
5wt%ZrO_2—MgO/Ar-arc VP	1st generation	74.28	12.41	7.13	2.23	1.89	1.11
	2nd generation	76.45	12.44	7.32	1.48	1.09	1.22
	3rd generation	75.76	11.73	8.84	1.14	0.76	1.69
5wt%ZrO_2—MgO/HC	1st generation	73.85	12.5	7.11	1.75	1.47	0.96
	2nd generation	75.88	12.25	7.28	2.66	1.41	1.25
	3rd generation	75.24	13.24	6.00	2.37	1.97	1.19
SiO_2/Ar-arc VP	1st generation	73.36	12.54	6.83	2.15	1.95	1.19
	2nd generation	74.95	12.19	7.43	2.29	1.70	1.43
	3rd generation	76.13	12.61	6.01	2.42	1.90	1.02
SiO_2/HC	1st generation	74.45	12.96	6.58	2.26	1.96	1.00
	2nd generation	75.19	11.64	8.79	1.32	0.86	2.16
	3rd generation	73.92	13.28	6.34	2.77	2.28	1.41

unit, wt%; Au, gold; Ag, silver; Cu, copper; Pt, platinium; Pd, palladium; Zn, zinc; 5wt%ZrO_2—MgO, 5wt%ZrO_2—MgO-based investment; SiO_2, SiO_2-based investment; Ar-arc VP, argon-arc vacuum pressure casting machine; HC, horizontal centrifugal casting machine.

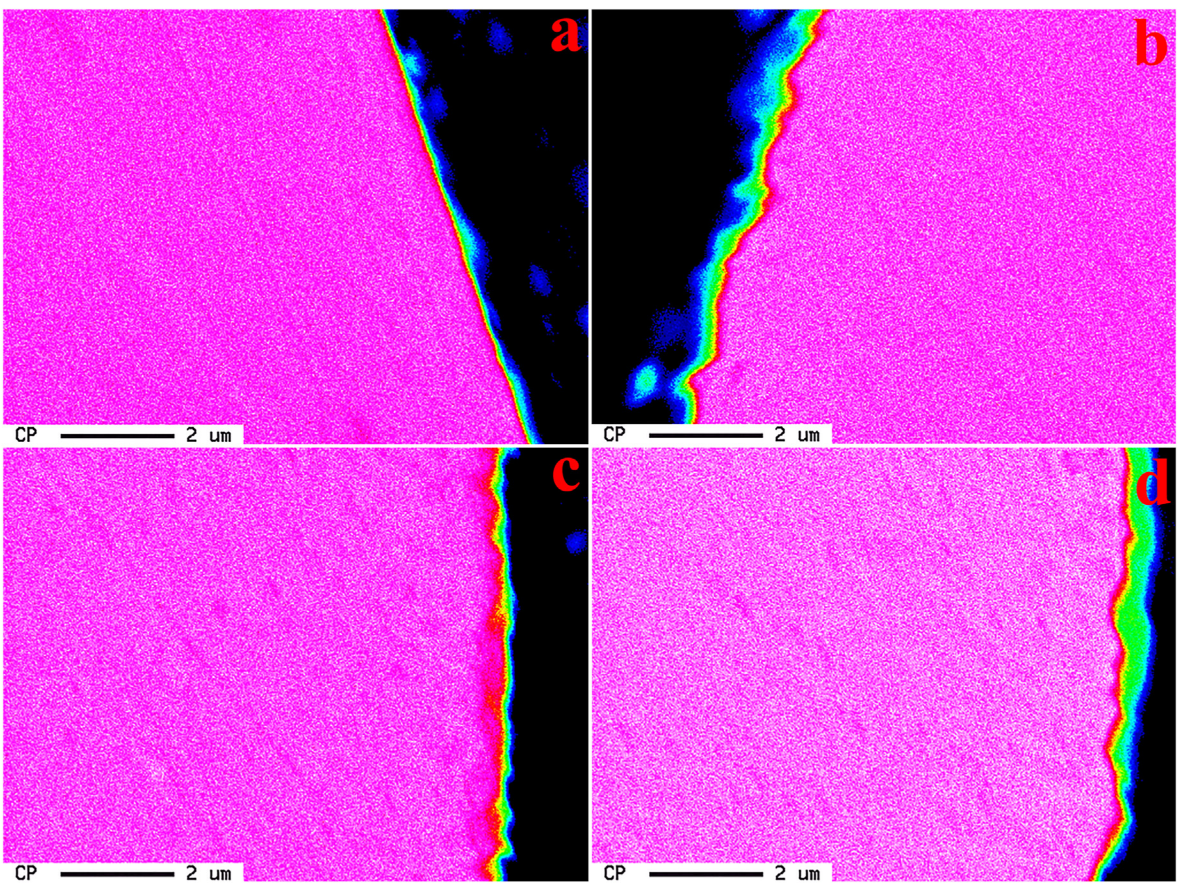

Figure 4 The interfacial oxidation zone in backscattered electron image (BEI) of the first-generation group (magnification: 10,000 ×). a:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, b: 5wt% ZrO_2—MgO-based investment/HC casting machine, c: SiO_2-based investment/Ar-arc VP casting machine, d: SiO_2-based investment/Ar-arc VP casting machine.

Discussion

The Au alloy casting made by the traditional casting method (SiO_2-based investment with HC) was researched 100% in all generations. Using the new '5 wt% ZrO_2—MgO-based investment' materials and the 'Ar-arc VP casting machine' did not affect the casting success rate. Recasting also did not decrease the success rate of the Au alloy casting. The Au alloys used in this experiment were ADA Type III casting Au alloy, which contained up to 74 wt% Au. The high

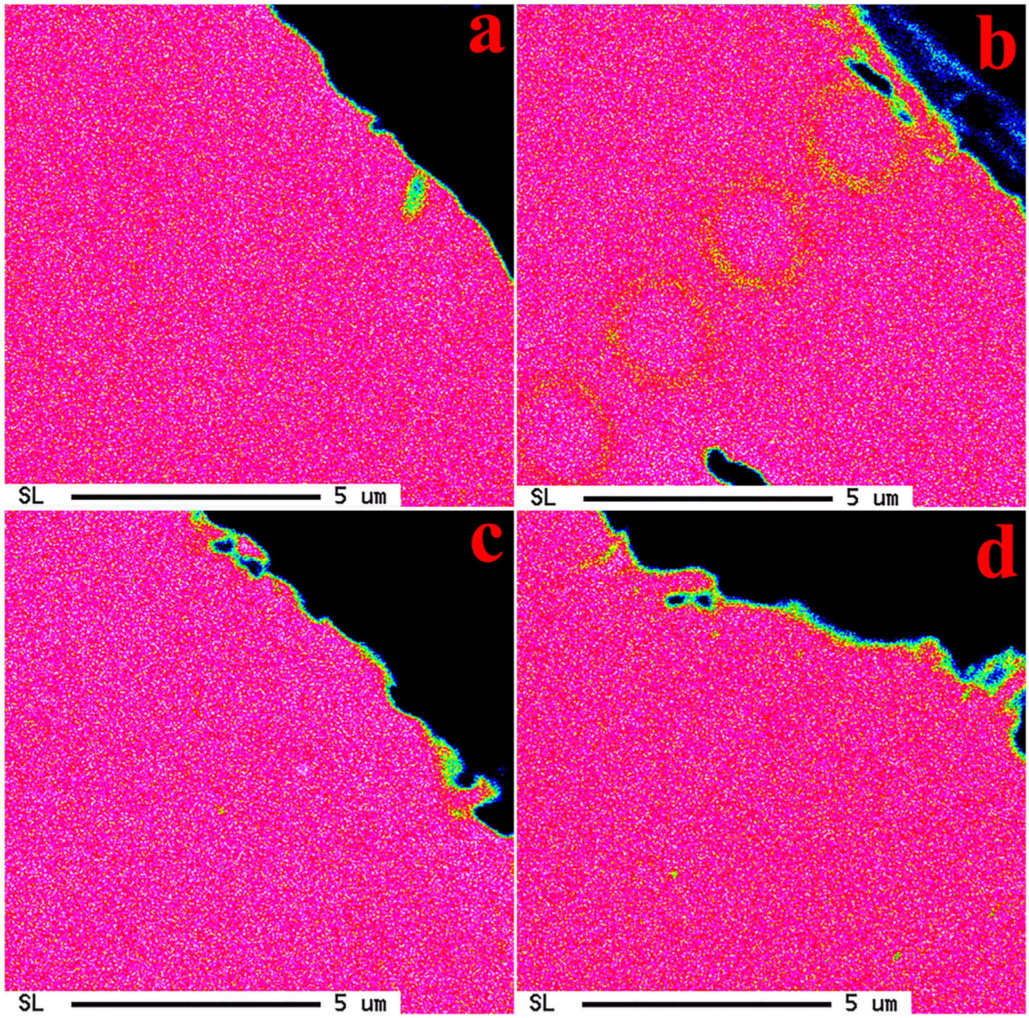

Figure 5 The interfacial oxidation zone in backscattered electron image (BEI) of the second-generation group (magnification: 10,000 $\times$). a:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, b: 5wt% ZrO_2—MgO-based investment/HC casting machine, c: SiO_2-based investment/Ar-arc VP casting machine, d: SiO_2-based investment/Ar-arc VP casting machine.

content of Au made the castability not affected by generation, investment materials, and casting machines, thus maintain a consistent casting success rate.

Regardless of the type of casting machine used and the casting generation, the marginal gap of gold alloy castings made with SiO_2-based investment was measured to be 66.71 $\pm$ 7.87 to 77.46 $\pm$ 10.03 μm. This range exceeds the clinical requirement of 50 μm for MOD castings of gold alloy.[32] The marginal gap of the castings in the 5wt% ZrO_2—MgO-based groups, except for the third-generation/HC, was less than 50 μm. This indicated only the investment materials significantly influenced the MOD castings of the Au alloy. Generally, the marginal gap has high correlation with the expansion rate of the investment. The higher the expansion rate of the investment, the smaller the value of the marginal gap. According the data provided by the manufacture, the expansion rate of the SiO_2-based investment was about 1.23% which was less than 1.62% that expansion rate of the 5wt% ZrO_2—MgO-based investment.[15] Therefore, the marginal gap of the castings in the 5wt% ZrO_2—MgO-based groups had smaller values than the SiO_2-based investment indeed.

The marginal gap of Pd—Ag alloy castings can be influenced by the casting machine and generation, as noted in the literature.[31] However, in the present study, it was found that the marginal gap of Au alloy MOD castings was not affected by the casting machine and recasting. This suggests that the castability of Au alloy may be better than that of Pd—Ag alloy, resulting in the marginal gap of the castings being unaffected by recasting.

The surface roughness of castings could affect the time required for finishing and polishing. Generally, the type of alloy, investment material, casting temperature and casting method, and recasting had the ability to influence the surface roughness of casting.[22,33—37] In our study, the recasting did not significantly influence Ra of Au alloy casting, but the type of investment and casting machine did. The first-, second-, and third-generations used all new, 50 wt% new and 50 wt% casted, and full recast Au alloy. This means the recasting using 74 wt% Au alloy could be done

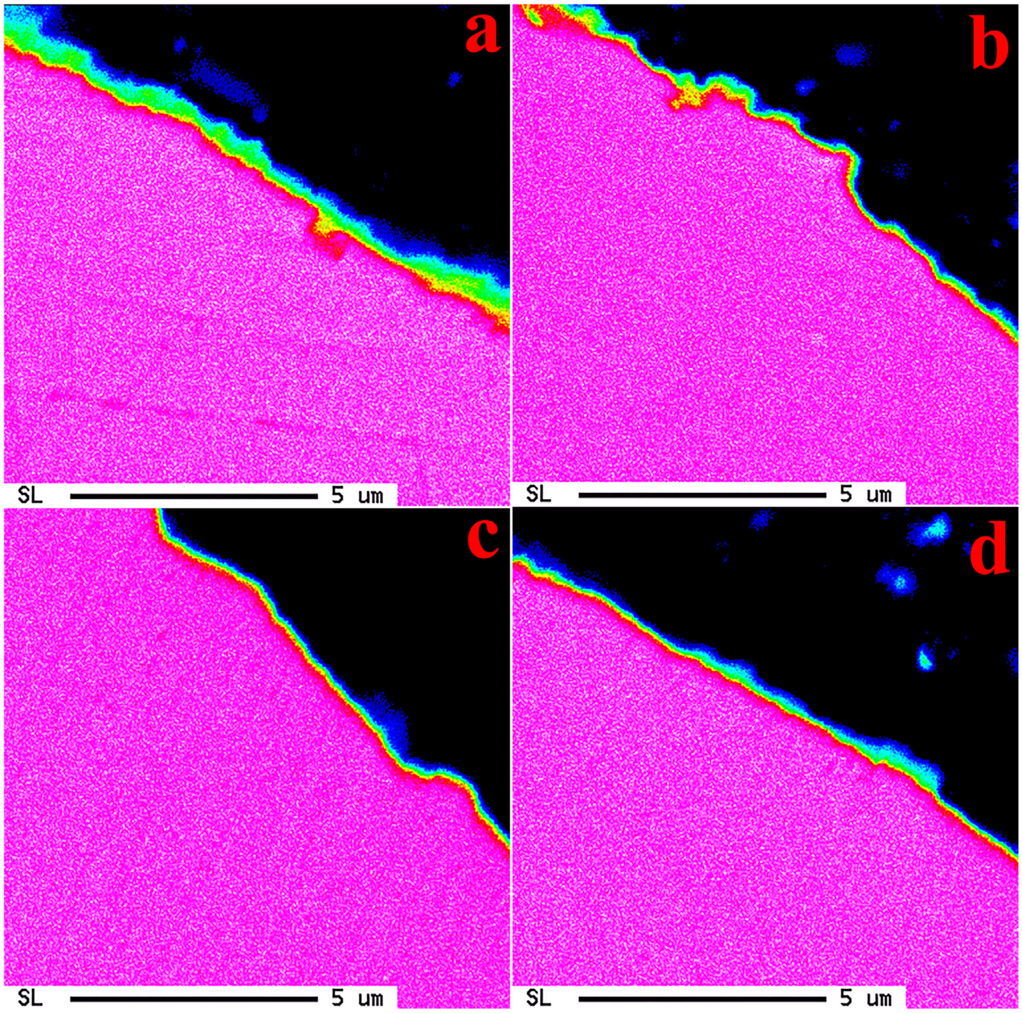

Figure 6 The interfacial oxidation zone in backscattered electron image (BEI) of the third-generation group (magnification: 10,000 ×). a:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, b: 5wt% ZrO_2—MgO-based investment/HC casting machine, c: SiO_2-based investment/Ar-arc VP casting machine, d: SiO_2-based investment/Ar-arc VP casting machine.

with fully recast Au alloy without influencing the surface roughness of the castings. Traditionally, Au alloy casting was commonly made by the SiO_2-based investment/HC casting method. The smoothest surface roughness of the Au alloy castings was achieved with the SiO_2-based/Ar-arc VP group. Generally, the powder particles of the gypsum-bonded investment were smaller than those of the 5wt% ZrO_2—MgO-based investment. Smaller particles in the investment often resulted in a smoother surface for the casting, especially when combined with the Ar-arc VP casting machine. This meant that the permeability of the SiO_2-based investment was good for gas escaping. According to a study by Thompson et al.,[38] an Au alloy containing 51.5% Au and a Pd—Cu alloy would result in a greater surface when using the induction/VP casting method. However, when the Au content reached about 87.4%, there was no significant difference in roughness performance compared with the HC method. In our study, we used an Au alloy with a gold content of 74wt%. The Ra of the gold alloy casting, made using the traditional SiO_2-based investment/HC method, was approximately 2.22 μm. The average surface roughness of the castings could be further improved by using the Ar-arc VP casting method. It was suggested that the roughness of the casting could be further improved when it is made in an argon environment.

In a study by Tuccillo et al.,[27] it was shown that the levels of noble metals such as Au, Pt, and Pd remained stable, while trace base metals could be lost through volatilization and oxidation. The loss of these trace base metals meant that the Au content would increase, which could be the reason for the increase in Au content during recasting. Maintaining a high Au content could reduce the risk of corrosion of the casting in the oral environment.[39] In comparison to the type III Au alloy used in the study, which contained 74wt% Au, the oxide layer thickness was very thin as expected. However, it could be found that the oxide layer of the Au alloy casting was slightly thinner in the 5 wt % ZrO_2—MgO-based investment group and Ar-arc VP machine group. This meant that the interaction between the melting ingot and the 5 wt% ZrO_2—MgO-based investment group would be decreased more than that of the SiO_2-based investment group. The ingots were also more protected by

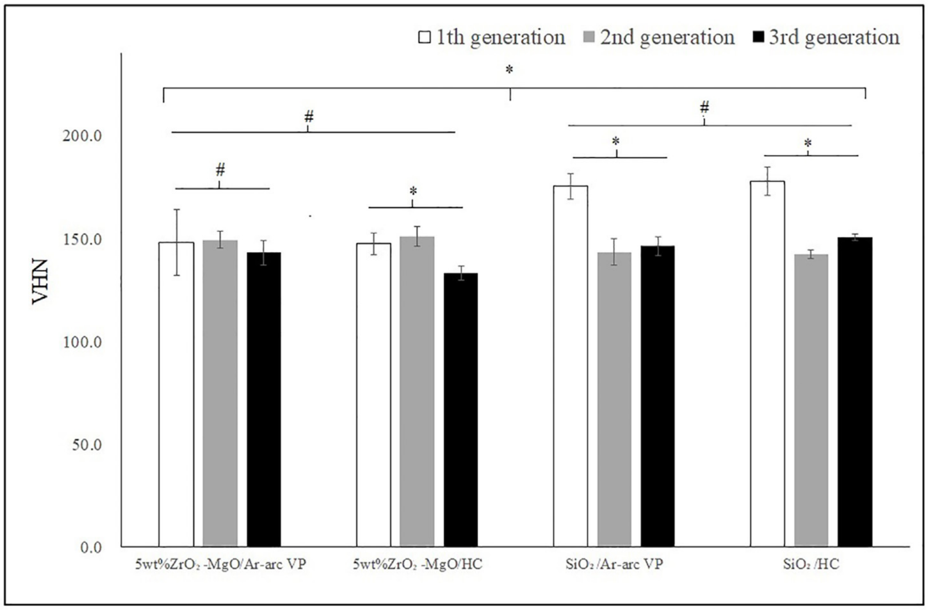

Figure 7 The VHN of the castings made by different investments combined with casting machines in every generation. Each column represents the mean and standard deviation. 5wt% ZrO_2—MgO/Ar-arc VP:5wt% ZrO_2—MgO-based investment/Ar-arc VP casting machine, 5wt% ZrO_2—MgO/HC: 5wt% ZrO_2—MgO-based investment/HC casting machine, SiO_2/Ar-arc VP: SiO_2-based investment/Ar-arc VP casting machine, SiO_2/HC: SiO_2-based investment/HC casting machine. The symbol '#' means no significant difference among the groups ($P > 0.05$). The symbol '*' means the significant difference among the groups ($P < 0.05$).

the Ar-arc VP casting environment to absorb less impurity. In this way, the composition and properties of the Au casting would not change significantly. The mechanical property could be remained good.

In the present study, the investment type and generation could influence on the microhardness of the Au alloy casting. Oxide layer thickness, lattice size, morphology, reactive layer inclusions, and metal cooling rate are all factors that affect casting VHN values.[40—43] The compositions of investment materials would affect the ingredient of oxides and the thickness of oxide layer on the surface of the castings. This oxide layer influenced the VHN value. It was suspected that the elements and the thickness of oxide layers of the Au alloy casting in the 5wt% ZrO_2—MgO-based group were different from the SiO_2-based investment because ZrO_2 and MgO were more stable oxide than SiO_2.

Horasawa and Marek[44] pointed out that recasting comprised remelting and re-solidification and the new grain size may be different from the original one. The lattice size and morphology further influenced the microhardness. Remelting at high temperature treatment tends to homogenize the lattice and reduce the VHN value of the Pd—Ag alloy.[31] The Au alloy castings had the same phenomenon in this study.

In our study, we found that the microhardness of recast Au alloy was influenced by the generation of casting. The first-generation had a higher VHN value compared to the second- and third-generations. Additionally, the composition of Au differed between the generations ($P < 0.05$). The second- and third-generations contained significantly more Au content than the first-generation. This suggests that recasting slightly increased the gold content, which might have caused a decrease in the microhardness of the casting. However, in future studies, the decrease in microhardness should be investigated to evaluate the stability and durability of Au alloys for long-term use, especially in the high-wear environment of dental restorations.

The results of this study indicate that recasting the type III Au alloy using a 5wt% ZrO_2—MgO-based investment with Ar-arc vacuum pressure resulted in better marginal accuracy, VHN, and oxide layer compared to the traditional SiO_2-based investment with HC method. This new method also showed potential for clinical application. The Ra analysis revealed similar outcomes between the 5wt% ZrO_2—MgO-based investment with Ar-arc VP recasting and the traditional SiO_2-based investment with HC method. Overall, recasting the Au alloy under the 5wt% ZrO_2—MgO-based investment with Ar-arc VP casting method improved its mechanical properties. The next step should be to evaluate the cost-effectiveness of this new casting process for large-scale clinical application to ensure widespread adoption in the dental industry.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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