THE EFFECTS OF SPURE AND INVENTS ON THE CASTING ACCURACY AND POROSITY OF TI-NI CASTINGS

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Statement of problem. Titanium-Nickel alloy might be used in various prosthetic restorations since it has a unique property such as super-elasticity and high fatigue resistance. However, little is known about the casting ability of this alloy.
Purpose. This in vitro study compared the casting accuracy and the porosity made with different investments and various sprue designs to ascertain what casting condition would be better for the fabrication of Ti-Ni cast restorations.
Material and methods. A total of 70 Ti-Ni alloy crowns were made and divided into 7 groups of 10 copings on a metal master die. For measuring the effect of the sprue numbers, two groups with one and two 8-gauge sprues were compared. Moreover, the results of the conventional sprue and the double thickness sprues were compared. Three investments were used; carbon free phosphate bonded investment, titanium investment and gypsum bonded investment. The cast restorations were evaluated at 48 points on the entire circumferential margin with a stereomicroscope measuring in micrometers. Each crown was radiographically examined for casting defects and porosity. Data on casting accuracy were analyzed using two-way and Post hoc Scheffe' s comparison to determine whether significant differences existed at the 95% confidence level. Student-Newman-Keuls test were performed to identify significant differences in the number of voids.
Results. The double sprueing group and double thickness group had significantly less marginal discrepancy than the single sprueing group ($P<.05$ and $P<.01$, respectively). The castings with phosphate bonded investment showed the least marginal discrepancy and the smoothest surface. The castings invested in the gypsum bonded investment had the greatest gaps in margin and the largest failure rate. The double sprueing group and phosphate bonded investment group had significantly smaller void numbers and smaller void size than the other groups.
Conclusion. Within the limitations of this in vitro study, the casting accuracy of the groups using thicker, double sprue design and the phosphate bonded investment was significantly superior. Moreover, void number and size were less than other groups.

Key Words
Casting, Accuracy, Porosity, Ti-Ni alloy

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Many low gold and base metal alloy systems are available for fixed partial denture construction. Other alternatives to gold or base metal alloys are titanium and titanium alloys. Titanium alloy is attractive for its low weight, fatigue resistance, and corrosion resistance. These characteristics are of interest to dentistry as well because it has excellent biocompatiblity and is relatively inexpensive.

Nevertheless, the high melting temperature and chemical reactivity of titanium necessitates casting machines and other casting conditions different from those used in conventional casting.[1] Cast titanium, as well as fabricated titanium has been produced for clinical applications in fixed or removable prosthodontics. In the last 20 years, titanium casting technology has continued to develop and be refined for dental use, although many practical problems remain to be solved.

Titanium is an inherently difficult metal to cast because of its high melting point, its strong affinity with gases such as oxygen, hydrogen, and nitrogen, and also its high reactivity with investment materials.[2] The high reactivity of titanium with investment materials results in the formation of hard, brittle reaction layers. These reaction layers reduce the elongation and fatigue limit of prosthesis.[3] Furthermore, these layers are undesirable in terms of surface roughness and the fit. Moreover, incomplete casting and undesirable porosity are well-known defects frequently observed in titanium casting.[4]

Several casting conditions such as type of casting machines, type of investment and sprue designs argon pressure might affect the quality of titanium castings. Hero et al.[5] found the argon pressure greater than 50 torr produced significantly more sound castings. Also, they concluded that highly permeable refractory material is needed for titanium castings.

The titanium-nickel alloy has almost the same nickel content since the various Ti-Ni alloys have a similar atomic ratio. A Ti-Ni alloy has a different component structure and has different ion release behavior from other nickel-containing alloys. Speck and Fraker[6] reported that this alloy had a higher degree of corrosion resistance than both stainless steel and cobalt (Co)-chromium (Cr) alloys. Biocompatibility studies of the Ti-Ni alloy in dogs showed no adverse reaction and no significant amount of metal release.[7] Recent studies on Ti-Ni alloy implantation reported that this alloy was cytocompatible and genocompatible.[8] Moreover, its effects on bone formation are similar to those of a commercial Ti-6Al-4V alloy.[9]

Therefore, the purpose of this in vitro study was to compare the casting accuracy and the porosity made with different investments and various sprue designs to ascertain what casting condition would be better for the fabrication of Ti-Ni cast restorations. To all possible variances that resulted from the use of materials and techniques, such as gypsum, used for the production of gypsum dies, die spacer, and impression materials, a metal die was used in which all waxing and measurements were made. The null hypothesis was that there will be no significant difference in the accuracy of fit and the porosity of the castings produced by different technique.

MATERIAL AND METHODS

Master die

For standardized comparison, JIS No 3 master die was used (Fig. 1). On a master die 70 gypsum dies were made and divided into 7 groups of 10 copings. To consider all possible source of errors in the process of manufacturing, this study followed clinical procedure. The master metal die was duplicated with additional silicone impression material (Examix, GC, Japan) using a customized impression tray. The impressions were

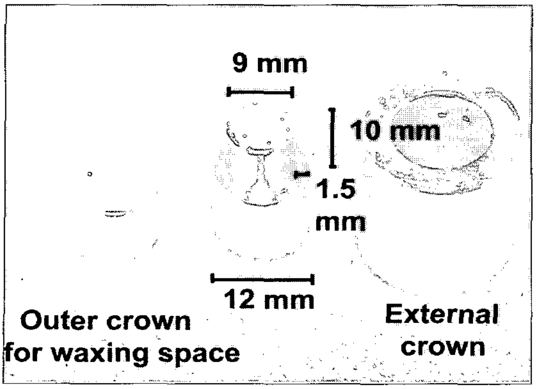

Fig. 1. Metal master die.

poured into type Ⅳ dental stone (Diekeen, Dentsply, USA). The dies were trimmed for evaluating the fit of the crown.

Wax patterns were prepared by pouring the molten casting inlay wax (Perfect fit system, GC, Japan) into the mold. Marginal sharpness was checked under a laboratory microscope at 10X magnification. The whole procedure was designed to resemble standard procedures commonly used at commercial dental laboratories. Total 70 wax patterns were divided into 7 groups of 10.

Spure design

For measuring the effect of the sprue numbers on the casting accuracy, 2 designs were included. The first group had one 8-gauge sprue centered occlusally on the pattern. The second group had two 8-gauge sprues placed occlusally on patterns at the occlusal-aixal line angles. For comparing the effect of the sprue thickness, 8-gauge and double 8-gauge sprues were attached to 2 groups of copings. The sprue lengths for every groups were 10mm. An 18-gauge vent was waxed to the pattern with a 2 mm margin at the top of the pattern and acted as an opened vent. In the single sprueing group, the vent was located along with the straight portion of the main sprue and the vent was located between the sprues on the wax patterns in the double sprueing group. The

Table Ⅰ. Casting mold preparation

Phase (℃)	Time (min)
20 → 300	30
300	60
300 → 900	60
900 → 430	gently cooling

sprue/wax pattern junction was carefully refined under 10X magnification.

Investing

The investment used in this study were divided into 3 groups. The first groups was invested using carbon-free phosphate-bonded investment (Rematitan plus, Dentarum, Germany) with a metal ring of 6.0 cm diameter. The other investment was titanium investment (Titan Crown master, Ohara, Japan) and gypsum bonded investment (Prestovalite, Whip-Mix, USA). The investments were hand mixed for 15 to 20 seconds and then mechanically mixed for 30 seconds using the vacuum mixer. The investment was allowed to bench set at room temperature for 1 hour before beginning burnout procedures.

Burnout and casting

Burnout procedures and temperature setting followed manufacturer' s recommendations, outlined in Table Ⅰ. The wax was eliminated and moulds were heat-soaked in a burnout furnace. Castings were made using an argon/electric arc vertical centrifugal casting machine(Titanumer, Obara, Japan) following manufacturer' s instructions. 13 X 25(2r) mm ingot of Ti-Ni alloy (TN10, Biosmart, Korea) was used to cast each specimen. The refractory mould was secured in the casting machine with the pattern mould orientated to the casting arm motion.

The castings were allowed to bench cool, divesting manually, blasted with 50 μm aluminum oxide at an air pressure of 0.4 Mpa for 30 seconds.

The castings were cut from their buttons and seated on the metal using only finger pressure applied by the same "blind" operator. No grinding, deburring, or polishing except gross bubble removing was attempted.

Casting accuracy

To measure marginal accuracy, the castings were placed on their respective stone master die in finger pressure. The gap between the external edge of the metal coping and the stone was defined as the standard for marginal accuracy. The marginal gap of each restoration was reproduced ×40 magnification using stereomicroscope(Olympus, USA) and the image captured with CCD camera. Then, a video image of the marginal gap was blindly examined using image analysis soft ware at 48 measuring point around each specimen.

Microporosity

The internal porosity of all specimens was examined radiographically by means of a digital x-ray unit(D-60-S; Dong-Seo Med., Korea). The x-ray source(90kV/25mA) was positioned perpendicularly to the digital film at a camera distance of 10 cm. Exposures of 30x1/60 seconds impulses were used. Preliminary tests revealed that theses conditions yielded the best definition of the small pores in the castings. Quantitative image analysis of the internal porosity was performed by a image analysis software(ImagePro 4.0; Mediacybernetics, Silver Spring, Md.). If it was assumed that the pores were spherical, the minimum pore diameter detectable by this technique was less than 0.05 mm. The porosity levels were than compared. Porosity was ranked by ordinal scales from 0 to 2 and was defined as follows: 0, free of porosity; 1, mild porosity (0 to 1 mm pore diameter); 2, severe porosity (pore diameter > 1 mm).

Statistical analysis

Data on casting accuracy were analyzed using two-way and one-way ANOVA to determine whether significant differences existed at the 95% confidence level. When differences were significant, multiple comparison test was done by Scheffe' s method (< 0.05). The Kruskal Wallis test used to evaluate the proper sprue design and investment from the porosity rank. Student-Newman-Keuls test were performed to identify significant differences in the number of voids according to size ranking from 0 to 2 for the different test groups.

RESULTS

Results of the Casting Accuracy

From the entire measurements, the marginal gap ranged from 0 to 99 μm. Comparing with the 12.7±3.8 μm, marginal accuracy of the wax pattern, it was concluded that the marginal discrepancies of casting were increased with investing and casting procedures. Marginal discrepancy values varied around the circumference of all castings. The means and standard deviations of marginal discrepancies for test groups of different sprue designs are listed in Table II and Fig. 2. There were statistically significant differences in data between the mean value within the groups ($P < .05$). The overall mean and standard deviation of marginal discrepancies for the single sprueing group and the double sprueing group were 65.4 ±5.8 μm and 54.3±4.3 μm, respectively. The double sprueing group had significantly less marginal discrepancy than the single sprueing group ($P < .05$). The sprue thickness also affected the marginal discrepancy. The 8 gauge, the thinner sprue design group showed greater marginal discrepancy than thicker group (double 8 gauge) ($P < 0.01$). However, the effect size of sprue number was smaller than that of the sprue

Table Ⅱ. Mean and S. D. of marginal discrepancy of Ti-Ni crowns measured of various sprue designs (μm)

	Single	Double	8 gauge	double 8 gauge
Mean	65.4	54.3	72.8	60.5
S.D	5.8	4.3	12.2	4.7

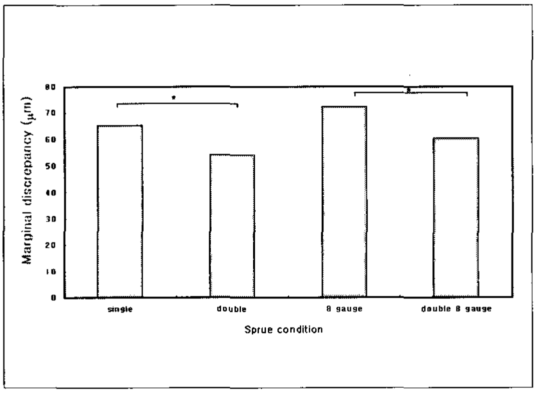

Fig. 2. Effects of sprue on the marginal discrepancy of Ti-Ni crowns measured (μm) (Groups connected by horizontal lines are significantly different.)

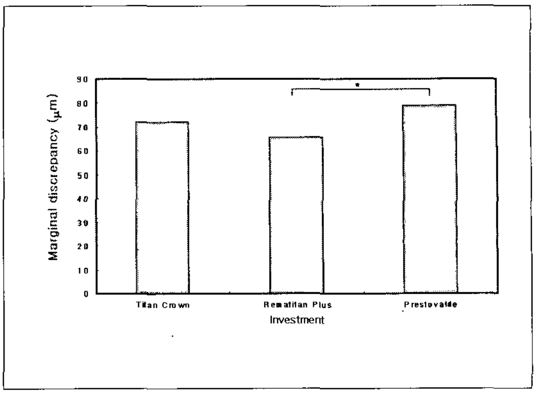

Fig. 3. Effects of investments on the marginal discrepancy of Ti-Ni crowns (μm) (Groups connected by horizontal lines are significantly different.)

Table Ⅲ. Mean and S. D. of marginal discrepancy of Ti-Ni crowns measured of various investments(μm)

	Titan Crown	Rematitan plus	Prestovalite
Mean	72.3	65.8	79.0
S.D	6.1	5.8	9.2

thickness. The marginal discrepancy of 8 gauge group was the greatest within the all groups.

Table Ⅲ and Fig. 3 shows the means and standard deviations of marginal discrepancies of the three different investments. Analysis of variance showed that the mean values of marginal discrepancies were significantly different among investments ($P < .05$). The castings with phosphate bonded investment showed the least marginal discrepancy. The castings invested in the gypsum bonded investment had the greatest gaps in margin. Moreover, the failure of castings such as fins and large porosities were frequently happened. The success rate of the castings using this investment was almost 50%. The casting surface of each specimen presented different characteristics. The crowns invested in the Rematitan plus investment showed the most smooth surface of all.

Results of the Microporosity

From the radiographic examination, the internal porosities of the castings were mainly at the opposite side to the vent. Most of the microporosities were spherical type, however oval or rod shaped porosities were rarely showed in the axial surface (Fig. 4). No significant porosity was revealed at the sprue junction with the crown portion. Individual numbers of porosities were compared (Table Ⅳ). There were some statistically significant differences in the means ($P < .05$). The double sprueing group had significantly smaller void numbers and smaller void size than the single sprueing group ($P < .05$). The sprue thickness also affected the marginal discrepancy. The 8 gauge, the thinner sprue design group showed more microposorities than thicker group (double 8 gauge) ($P < 0.01$). Moreover, the castings using

Table Ⅳ. Mean numbers of porosity rank per crown by various sprue designs and investments.

Rank	Single	Double	8 gauge	double 8 gauge	Titan Crown	Rematitan plus	Presto-valite
0	3.2	6.1	2.7	6.8	6.5	8.1	2.4
1	5.8	3.3	5.2	3.1	3.1	1.8	6.2
2	1.0	0	2.1	0	0	0	1.4

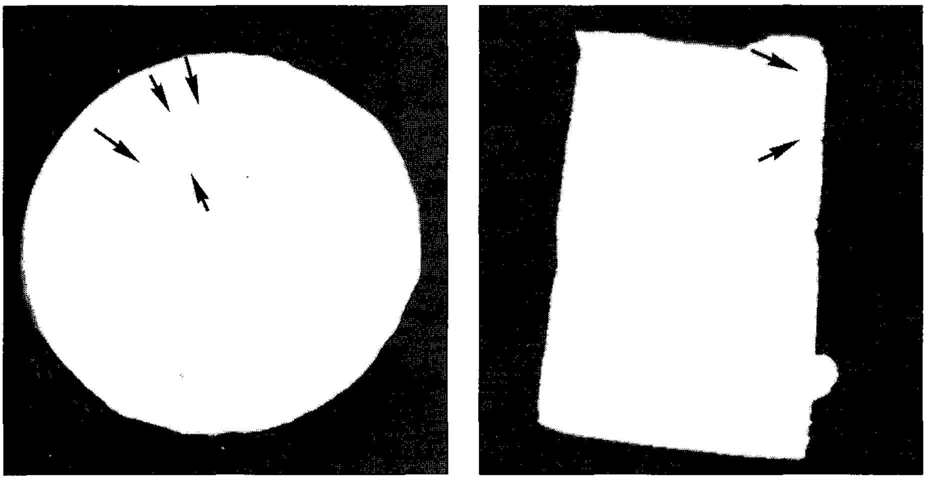

Fig. 4. Radiographs of void and internal defect (Left: occlusal view, Right ; Axial view).

phosphate bonded investment showed the least porosity number and size. The rank 2 porosities were only found in the castings using gypsum bonded investment.

DISCUSSION

The use of titanium and titanium alloys in preference to conventional dental alloys among prosthodontists is somewhat controversial. This controversy stems in part from the necessity of using specialized equipment and techniques in applying titanium materials. Although recent studies[10-15] have shed light on some of the problems regarding the castability, accuracy of fit, and the welding or soldering techniques, titanium prostheses and their clinical applications are still in the developmental stages. Therefore the efficacy of titanium prostheses must be assessed in future clinical studies.

Inadequate mold filling and internal porosity are commonly observed defects in titanium castings.[3] Available technology for casting Ti-Ni like titanium alloys is clearly not free of problems. Typically molten titanium alloy, with a temperature of 1720℃, is forced into a preheated mold with a temperature of less than 800℃. The extreme difference between mold and melting temperatures created rapid cooling of the metal and thereby shortened the time for the gases to escape.[5] It is likely that other factors such as argon pressure affected the quality of titanium alloy castings. However, no consensus exists on the proper argon pressure. Sunnerkrantz et al.[16] reported that an argon pressure of 50 torr in the melting chamber would be sufficient to fill the mold for a crown. However, Her et al.[3] reported that the soundness of castings made under an argon pressure of 50 torr was significantly greater than that of casting made under a pressure of 400 torr. In spite of present controversy, continuous argon filling is thought to be the most important factor on the casting soundness. In this experiment, the failure of castings might be related to insufficient argon pressure, also. However, this failure was not included in the analysis of marginal discrepancy. In recent study, Krypton seemed to be a promising inert gas alternative to Argon, as the elimination of porosity and having lower hardness of titanium for easy grinding and polishing.[17]

Sprue design is a mechanism that controls the velocity and adequate supply of metal to the mold. Strickland et al.18 demonstrated the importance of the size, type, shape and location of the sprue. Sprue diameter may be the most significant variable that influences the quality of the casting. In crown fabrication, there is a controversy of the effect of the sprue on the casting success. Preston and Berger[19] revealed that commonly used sprue designs were inadequate when casting titanium. Sprue geometry was also identified as an important factor producing porosity effects with low density titanium alloys.[20] Ryge et al.[21] characterized the porosities in gold castings into two groups: (1) porosities caused by cooling and solidification, (2) porosities caused by gas. They recommended the use of a sprue diameter larger than the thickest cross section of the casting to eliminate shrinkage porosity. This recommendation might be applied to the titanium castings. In our study, the effect of the thickness of the sprue diameter was larger than that of the sprue number. These results suggest that the thicker sprue should be used in Ti-Ni alloy castings.

Chan et al.[22] insisted that specific sprue design such as large angulated sprues might resolve the mold filling problem. However, the effect of the sprue locations seemed to be negligible. Al-Mesamar et al.[10] reported the ball-sprue design produced better castings than the tree and circular sprues, with respect to the completeness to titanium removable partial denture frameworks. The sprue design was not included in this study because this effect was less significant than that of the sprue thickness.

The reactions between titanium and investment materials may contribute to inadequate mold filling and porosity, too. Titanium castings produce a hard surface layer (the α case) because of the reaction of molten metal with the elements of investment. The extent of case varies from 80 to 150 μm, whereas its thickness is varied with the type of the investments. Especially SiO_2 investment was known to have the high reactivity with titanium. However, commercial phosphate bonded SiO_2 investment showed good titanium casting products. Moreover, the gas permeability of the investment material in the mold is likely to affect the back pressure from trapped Argon gas in the mold cavity. In comparing the mold filling of titanium castings using various investments with different gas permeability, Syverud and Hero[3] presented Rematitan plus had similar mold filling with Titan Crown in casting 3 unit prosthesis. However, Rematitan plus showed better marginal fidelity of three investments in this study. It seemed to be different experimental condition such as more simple shape of master crown used in this study. Moreover, the casting products from Rematitan plus presented the smoothest surface.

The marginal discrepancy of the restoration is believed to be closely associated with the development of secondary disease such as caries and periodontitis. The marginal gap inevitably is produced during dental restoration setting due to cement film thickness and dimensional change. Many methods to examine the marginal accuracy were introduced. Groten et al.[23] reported that small numbers site of measurement in current in vitro studies are not appropriate for precision. Moreover, they insisted approximately 50 measurement per crown regardless of whether the measurement sites are required for clinically relevant information about gap size. The measurement method used in this study was direct visualization by stereomicroscope (× 40) and reading 48 points per crown.

Radiographic analysis of castings revealed an inconsistency of internal porosity according to the manufacturer' s recommended evaluation of casting porosity. By use of x-ray inspection of titanium castings, Wang and Boyle[24] found porosity to be a common occurrence. Results of this study indicated that large(double 8 gauge) and two sprues result in the superior accuracy and smaller porosity. The porosity was rarely found in gold or Chromium(Cr) -Cobalt(Co) alloy. However, the structural failure of these alloys also happened. Therefore, the reason for the little or no porosity in the gold alloy and Cr-Co alloy might due to the fact that the attenuation coefficient of these alloys are higher than that of Ti-Ni alloy.[25] A higher kVp would be needed to detect any real porosity in these alloys.

Despite some limitations of this study, the results emphasize the investing and sprueing method would affect the casting accuracy and the porosity of the restoration. Further investigations to determine the mostly appropriate casting method for Ti-Ni alloy should follow.

CONCLUSIONS

Within the limits of this study, the following conclusions were drawn:

1. The double sprue and double thickness group had significantly less marginal discrepancy than the single sprue group.
2. The castings with phosphate bonded investment showed the least marginal discrepancy the smoothest surface.
3. The castings invested in the gypsum bonded investment had the greatest gaps in margin and the largest failure rate.
4. The double sprueing group and phosphate bonded investment group had significantly smaller void numbers and smaller void size than the other groups.

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