Dimensional Accuracy Analysis of Implant Framework Castings from 2 Casting Systems

Ting-Ling Chang, DDS[1]/Chizuru Maruyama, CDT[2]/Shane N. White, BDSci, PhD[3]/
Seung Son, DDS,MS[4]/Angelo A. Caputo, PhD[5]

Purpose: *To compare the dimensional accuracy of implant framework castings from an argon vacuum casting machine with those from a centrifugal casting machine.* ***Materials and Methods:*** *Three 4 × 10-mm external hex-type implants (3i/Implant Innovations) were embedded in an acrylic resin block 7 mm apart, with a 2 mm offset of the middle implant. Eight reference points were marked on the implant collars. Twenty implant bar frameworks were waxed with UCLA abutments, invested with a ringless system, and subjected to the same thermal cycle. Ten wax patterns were cast in gold alloy using an oxygen-propane torch and centrifugal casting system; 10 were cast using an argon vacuum casting machine (KDF; Denken). The White 1-screw technique was applied after sequentially tightening the mesial and distal abutment screws to 10 Ncm. Fit of the implant framework castings was evaluated by measuring the marginal opening between the casting and implant at the reference points. These measurements were averaged and statistically compared for differences.* ***Results:*** *The mean marginal openings at the most distant measuring locations from the tightened retaining screw at location 1 was between 44 to 48 μm for the centrifugal system compared to between 28 to 32 mm for KDF (*$P < .01$*). For screws tightened at location 3, the mean marginal openings at the most distant measuring locations were between 40 to 51 mm for the centrifugal system compared to between 27 to 29 μm for KDF (*$P < .01$*).* ***Discussion:*** *In comparison with the centrifugal casting and oxygen-propane system, the argon vacuum system was more accurate and user friendly and less technique-sensitive.* ***Conclusion****: The argon vacuum casting machine tested produced more accurate, better fitting implant-supported prosthesis frameworks than a conventional centrifugal casting system. The "1-screw" method of evaluating casting fit was most effective when either of the prostheses' end screws were tightened.* INT J ORAL MAXILLOFAC IMPLANTS 2005;20:720–725

Key words: *argon vacuum casting machine, centrifugal casting machine, implant frameworks, implant-prosthesis fit*

The precision of fit between the bearing surfaces of implant abutments and the prosthesis framework has been considered fundamental to implant prosthodontic protocol.[1–4] However, the biologic impact of prosthesis misfit on osseointegration remains unclear. One 5-year clinical study on prostheses that were considered to have clinically acceptable fit, with measured mean center point misfits ranging from 91 to 111 mm, did not find a statistical correlation between degree of misfit and marginal bone loss.[5] However, an animal study showed that prosthesis misfit causes significant bone strain, and it has been suggested that bone strain may contribute to initial marginal bone loss.[6] Bone strain caused by misfit may be of greater importance for implant survival in soft bone and for early implant loading.[6] Another animal study on implants placed in baboon mandibles that supported prostheses with 2 degrees of fit did not find a difference in bone response.[7] It should be noted that the prostheses in the baboon study were not in occlusion, which normally superimposes substantial dynamic cyclic functional loads onto misfit loads.

[1]Clinical Assistant Professor, Division of Advanced Prosthodontics, Biomaterials, and Hospital Dentistry, School of Dentistry, University of California at Los Angeles.
[2]Staff Research Associate, Division of Advanced Prosthodontics, Biomaterials, and Hospital Dentistry, School of Dentistry, University of California at Los Angeles.
[3]Associate Professor and Chairman, Endodontics Section, School of Dentistry, University of California at Los Angeles.
[4]Lecturer, Division of Advanced Prosthodontics, Biomaterials, and Hospital Dentistry, School of Dentistry, University of California at Los Angeles.
[5]Professor and Chaiman, Biomaterials Science, Division of Advanced Prosthodontics, Biomaterials, and Hospital Dentistry, School of Dentistry, University of California at Los Angeles.

Correspondence to: Dr Ting-Ling Chang, B3-087 CHS, UCLA School of Dentistry, 10833 Le Conte Ave, Los Angeles, CA 90095-1668. Fax: + 310 825 6345. E-mail: tlchang@dent.ucla.edu

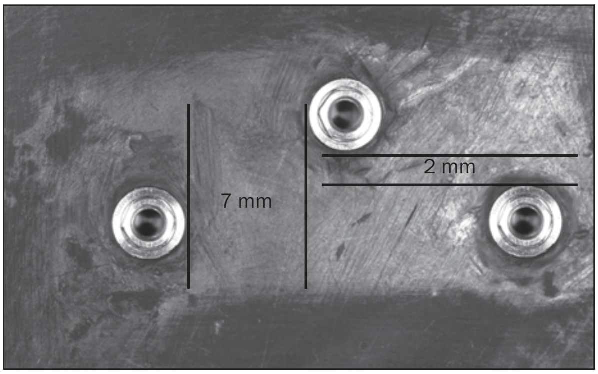


Fig 1a Occlusal view illustrating the arrangement of the implants.

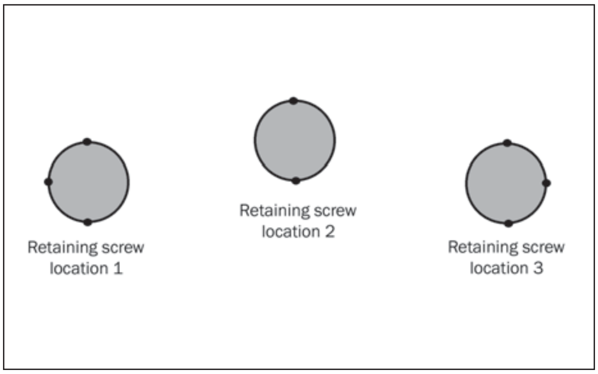


Fig 1b Diagram of the 3 single retaining screw locations and the reference points used for measurement. The dots around the retaining screw locations represent the reference points.

Although the biologic impact on osseointegration from prosthesis misfit has yet to be established, many reports have suggested that clinically passive fit is needed to avoid mechanical failures, including implant fracture, component breakage, and screw loosening.[1–4] In a 5-year prospective study, Kallus and Bessing related the occurrence of loose prosthesis-retaining screws and abutment screws in complete-arch fixed prostheses to framework misfit.[4] In a retrospective study by Adell and associates, an overall implant fracture rate of 3.5 % was reported.[8] The authors associated a reduction in implant fracture rate with improved framework fit. Interestingly, most implant fractures occurred after at least 5 years of function, indicating the important role of dynamic cyclic fatigue from masticatory function in implant mechanical failure.

Because of these mechanical complications, many studies have focused on various techniques to improve implant-prosthesis fit.[9–20] Currently, the conventional lost wax technique, used with centrifugal casting machines, is the most common method of implant prosthesis fabrication. However, the resultant misfitting castings often require corrective sectioning and soldering. Argon vacuum casting machines have been used to fabricate titanium castings, with the aims of reducing porosity, oxidation, and misfit.[21,22] Argon vacuum casting machines may have the potential to improve the fit of implant-supported prostheses cast from conventional precious alloys, but this has not yet been investigated.

Therefore, the purpose of this study was to compare the dimensional accuracy of precious metal implant frameworks made using an argon vacuum casting machine with those made using a conventional centrifugal casting machine.

MATERIALS AND METHODS

The design of this study was a factorial design consisting of 3 factors: casting method (2 types), single retaining screw location (3 locations), and measuring site (8 locations).

Three 4-mm-wide, 10-mm-long external hex implants (Osseotite; 3i/Implant Innovations, Palm Beach Gardens, FL) were embedded in an acrylic resin block (PL-1, Measurements Group, Raleigh, NC). The implants were arranged 7 mm apart, with the middle implant offset by 2 mm (Fig 1a). Eight measuring locations were marked on those 3 implants as indicated in Fig 1b.

Two casting systems were evaluated in this study. One was a conventional centrifugal casting machine (Kerr, Romulus, MI). The other was an argon vacuum casting machine (KDF Super Cascom; Denken, Kyoto, Japan). Twenty implant bar frameworks with identical configurations incorporating UCLA abutments (4.1 mm Gold Non-Hexed Abutment Cylinder; Implant Innovations) were waxed and invested with a phosphate-bonded investment (Cera-Fina; Whip-Mix, Louisville, KY) into a casting ring by the same operator. All 20 casting rings underwent the same thermal cycle (430°C for 30 minutes, with the temperature rising at a rate of 7°C per minute to a maximum temperature of 870°C) in the oven. Ten rings were cast using an oxygen-propane torch and the centrifugal casting machine and the other 10 were cast using the argon vacuum casting machine. In the argon vacuum machine, the alloy was melted inside a muffle chamber in a deoxygenized argon-pressurized environment. Once the molten alloy was ready for casting, a preheated invested casting ring was placed in the muffle chamber, the muffle door was closed, the chamber was inverted, and a vacuum

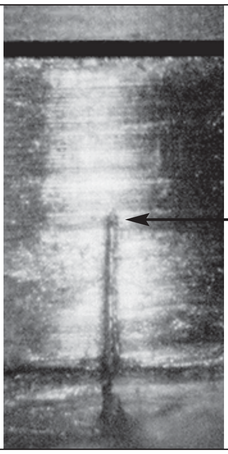


Fig 2 Representative marginal opening measurement relative to a marked measuring point.

Table 1 Three-way ANOVA for the Effects of Casting Machine Type, Retaining Screw Location, and Measuring Location on Implant Framework Casting Fit

Main effects	Sum of squares	Degree of freedom	F ratio	*P*
CM	6,106	1	22.6	< .001
RSL	7,425	2	13.8	< .001
ML	2,737	7	1.4	.18
CM × RSL	1,017	2	1.9	.15
CM × ML	647	7	0.3	0.93
RSL × ML	34,662	14	9.2	< .001
CM × RSL × ML	3,169	14	0.8	.63
Residual	103,677	384		
Total	159,443	431		

CM = casting machine; RSL = retaining screw location; ML = measuring location.

pump was turned on to draw the argon-pressurized molten metal into the casting ring. A high gold ceramic metal (550 SL, Silhouette Line; Argen Alloys, San Diego, CA) was used for all castings. All castings were devested with the usual manner using minimal aluminum oxide air abrasion and avoiding critical interfaces. Internal casting imperfections were removed with a bur using a 10× microscope before marginal opening measurements were made.

The "1-screw" technique was applied to evaluate casting fit.[23] Each casting was placed back on the master model with only 1 gold retaining screw at a time on one of the 3 implants (Fig 1b). The screw was tightened to 10 Ncm, based on White's protocol,[23] using a calibrated torque driver (Straumann torque control device; Institut Straumann, Waldenburg, Switzerland). The torque driver was calibrated with the Instron machine (Canton, MA), and a 0.5-mm gradation scale and stopper were included[24] to facilitate delivery of the desired 10 Ncm. The marginal opening between the casting and the implant was measured at 8 locations (Fig 1b) under a toolmaker's microscope with 80× magnification (Unitron, Newton Highlands, MA) and digital positioners (Boeckeler Instruments, Tuscon, AZ) calibrated to 0.1 mm. This measuring procedure was repeated on the same casting with the single screw placed sequentially at 3 different retaining positions (Fig 1b). A typical marginal gap measurement between the implant framework casting and implant at a marked measuring location is illustrated in Fig 2. The measurement at each location was repeated 3 times, and the mean of these values was used to describe the point. Three-way analysis of variance (ANOVA) was used to determine the influence of the main effects of, and interactions among, casting machine type, single retaining screw location, and location of measurement of casting fit. If ANOVA indicated significant differences, Tukey HSD multiple comparisons testing was used to identify where the differences lay. Results were considered significant if the value of *P* was < .05.

RESULTS

The type of casting machine used had a highly statistically significant effect on prosthesis fit (Table 1). The argon vacuum casting machine produced more accurate castings than the conventional centrifugal casting machine. Averaging the marginal openings for all retaining screw locations and measuring locations, the argon vacuum casting produced significantly smaller marginal openings than the conventional centrifugal casting machine.

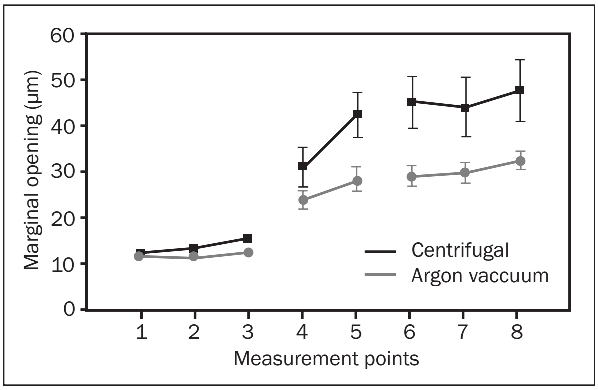
The location of the screw tightened for the "1- screw" test technique also had a highly significant effect on prosthesis fit (Table 1). Multiple comparisons testing showed that tightening the middle retaining screw (location 2) produced a significantly smaller marginal opening than that produced when either of the end screws (locations 1 and 3) was tightened. Tightening either end retaining screw produced similar effects.

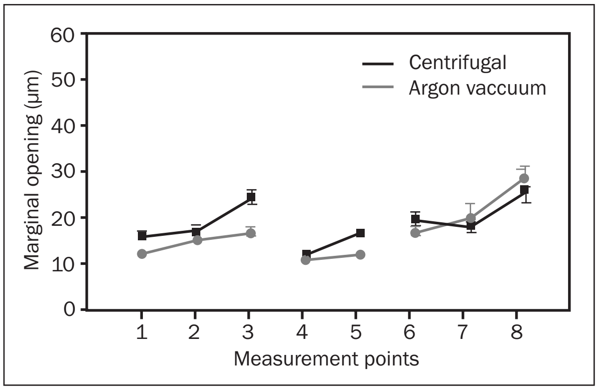
Larger differences between castings from the 2 machines were observed when the end screws were tightened. For example, as shown in Table 2, with the retaining screw tightened at location 1, the mean marginal openings at the most distant measuring locations were in the range of 44 to 48 mm for centrifugal castings versus 28 to 33 mm for the argon vacuum castings. Similarly, with the retaining screw tightened at location 3, the mean marginal openings at the most distant measuring locations were in the range of 40 to 51 mm for centrifugal castings versus

Table 2 Mean Marginal Opening (μm) Between Implant Framework Casting and Implants at 8 Measuring Locations with 1-Screw Technique

Measuring location	Centrifugal		Argon	
	Mean	SE	Mean	SE
With single screw tightened at location 1				
1	12.17	0.56	11.82	0.71
2	13.19	0.39	11.63	0.40
3	15.61	0.66	12.95	0.53
4	30.90	4.20	23.81	1.96
5	41.99	4.82	28.10	2.63
6	44.66	5.54	28.97	2.10
7	43.74	6.39	29.66	2.15
8	47.40	6.57	32.43	1.97
With single screw tightened at location 2				
1	16.07	0.91	12.33	0.63
2	17.07	1.16	15.24	0.82
3	24.29	1.59	16.98	0.89
4	12.16	0.63	11.19	0.68
5	16.55	0.46	12.37	0.64
6	19.61	1.46	17.28	1.43
7	18.21	1.57	20.41	2.43
8	25.46	2.44	28.44	2.27
With single screw tightened at location 3				
1	40.50	6.97	27.04	3.38
2	45.43	7.83	28.32	3.24
3	50.26	7.26	27.93	2.94
4	25.49	3.78	18.97	2.36
5	33.94	4.36	18.96	2.08
6	13.10	0.58	11.85	0.61
7	11.83	0.70	12.31	0.74
8	15.26	0.66	13.23	0.68

SE = standard error of the mean.





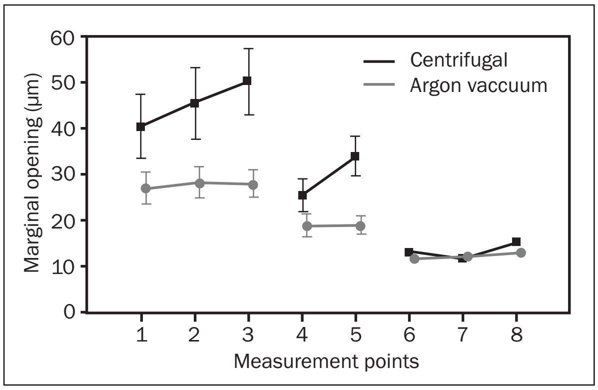


Fig 3a *(Top right)* Marginal opening measurements with retaining screw tightened at location 1. Vertical lines represent ± 1 standard error (SE).

Fig 3b *(Center right)* Marginal opening measurements with retaining screw tightened at location 2. Vertical lines represent ± 1 SE.

Fig 3c *(Bottom right)* Marginal opening measurements with retaining screw tightened at location 3. Vertical lines represent ± 1 SE.

27 to 29 mm for the argon vacuum castings. These differences were statistically significant ($P < .01$). Figure 3 illustrates that differences among measuring locations were small close to the tightened retaining screw. However, the differences among measuring locations distant from the tightened retaining screw location were much larger.

Although the statistical effect of measuring location was not significant (Table 1), a consistent trend was noted. The measuring locations on the outside of the curve produced by offsetting the middle implant (measuring locations 1, 4, and 6) tended to have larger marginal openings than those measuring locations on the inside on the of the curve (measuring locations 3, 5, and 8) (ie, the lines connecting measurement points on each implant are not horizontal but tend to tilt upwards to the right on the graphs in Fig 3). This trend suggests that a small amount of distortion manifested in a twisting of the prosthesis for both types of casting machine.

DISCUSSION

The results of this study suggested that an argon vacuum casting machine improved the fit of a simple prosthesis supported by 3 implants. It is possible that more marked improvements in fit could be found in larger and more complex prostheses. Improved fit of implant-supported prostheses is believed to reduce mechanical complications such as screw loosening and fracture.[1–4,8] It is likely the forces caused by misfit itself interact with the substantial, repetitive, and dynamic forces of masticatory function that may lead to mechanical fatigue of prostheses, screws, and implants. While the effect of prosthesis misfit on osseointegration is largely unknown, it appears that misfit causes bone strain, which may affect osseointegration.[6] Such effects may be more important when bone quantity or quality is compromised or in early loading situations.

Numerous techniques using optical and tactile methods have been reported to evaluate the fit of implant castings in clinical and laboratory settings, including a stylus contact technique, laser videography, and photogrammetric analysis.[6,8,25] The "1-screw" method described by White[23] was used to evaluate the fit in this investigation. This method has been shown to be a sensitive technique capable of detecting small amounts of casting misfit.[26] Using this technique, it was shown that the implant framework castings fabricated with the argon vacuum unit exhibited significantly less misfit compared with those from the centrifugal casting unit. This increased dimensional accuracy may be of importance for implant-supported prostheses, because there is no periodontal ligament at the bone-implant interface and minimal physiologic movement compared to that seen with natural dentition.[27] This study demonstrated that the "1-screw" test was equally effective in evaluating misfit when the retaining screw was tightened at either end locations (1 and 3). However, this test was less effective when the retaining screw was at the middle location (2).

In addition to increased dimensional accuracy, the argon vacuum has other potential advantages. In comparison with the centrifugal casting and oxygen-propane system, the argon vacuum system is very user friendly and less technique sensitive. Because the metal is melted and cast in an inert environment, flux is not needed to prevent oxidation, and the importance of including new metal is reduced. Less porosity is produced, thus making the castings stronger and easier to polish.

CONCLUSION

The argon vacuum casting machine tested produced more accurate, better-fitting implant-supported prosthesis frameworks than a conventional centrifugal casting system in this testing model. The "1-screw" method of evaluating casting fit was most effective when either of the prostheses' end screws were tightened.

REFERENCES

1. Kohavi D. Complications in the tissue integrated prostheses components: Clinical and mechanical evaluation. J Oral Rehabil 1993;20:413–422.
2. Jemt T, Linden B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Brånemark implants: From prosthetic treatment to first annual checkup. Int J Oral Maxillofac Implants 1992;7:40–44.
3. Tolman DE, Laney WR. Tissue-integrated prosthesis complications. Int J Oral Maxillofac Implants 1992;7:477–484.
4. Kallus T, Bessing C. Loose gold screws frequently occur in full-arch fixed prostheses supported by osseointegrated implants after 5 years. Int J Oral Maxillofac Implants 1994;9:169–178.
5. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11:620–625.
6. Jemt T, Lekholm U. Measurements of bone and framework deformations induced by misfit of implant superstructures. A pilot study in rabbits. Clin Oral Implants Res 1998;9:272–280.
7. Carr AB, Gerard DA, Larsen PE. The response of bone in primates around unloaded dental implants supporting prostheses with different levels of fit. J Prosthet Dent 1996;76:500–509.
8. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implant in the treatment of the edentulous jaws. Int J Oral Surg 1981;10:387–416.
9. Riedy SJ, Lang BR, Lang BE. Fit of implant frameworks fabricated by different techniques. J Prosthet Dent 1997;78:596–604.
10. Rubenstein JE, Ma T. Comparison of interface relationships between implant components for laser-welded titanium frameworks and standard cast frameworks. Int J Oral Maxillofac Implants 1999;14:491–495.
11. Burns J, Palmer R, Howe L, Wilson R. Accuracy of open tray implant impressions: An in vitro comparison of stock versus custom trays. J Prosthet Dent 2003;89:250–255.
12. Gordon GE, Johnson GH, Drennon DG. The effect of tray selection on the accuracy of elastomeric impression materials. J Prosthet Dent 1990;63:12–15.
13. Boulton JL, Gage JP, Vincent PF, Basford KE. A laboratory study of dimensional changes for three elastomeric impression materials using custom and stock trays. Aust Dent J 1996; 41:398–404.
14. Millstein P, Maya A, Segura C. Determining the accuracy of stock and custom tray impression/casts. J Oral Rehabil 1998; 25:645–648.
15. Saunders WP, Sharkey SW, Smith GM, Taylor WG. Effect of impression tray design and impression technique upon the accuracy of stone casts produced from a putty-wash polyvinyl siloxane impression material. J Dent 1991;19:283–289.

16. Boulton JL, Gage JP, Vincent PF, Basford KE. A laboratory study of dimensional changes for three elastomeric impression materials using custom and stock trays. Aust Dent J 1996;41: 398–404.
17. Carr AB. Comparison of impression techniques for a five-implant mandibular model. Int J Oral Maxillofac Implants 1991;6:448–455.
18. Liou AD, Nicholls JI, Yuodelis RA, Brudvik JS. Accuracy of replacing three tapered transfer impression copings in two elastomeric impression materials. Int J Prosthodont 1993;6: 377–383.
19. Phillips K, Nicholls JI, Tsun M, Rubenstein JE. The accuracy of three implant impression techniques: A three-dimensional analysis. Int J Oral Maxillofac Implants 1994;9:533–540.
20. Assif D, Marshak B, Schmidt A. Accuracy of implant impression techniques. Int J Oral Maxillofac Implants 1996;11:216–222.
21. Chai TI, Stein RS. Porosity and accuracy of multiple-unit titanium castings. J Prosthet Dent 1995;73:534–541.
22. Atsu S, Berksun S. Bond strength of three porcelains to two forms of titanium using two firing atmospheres. J Prosthet Dent 2000;84:567–574.
23. White GE. Osseointegrated Dental Technology. Chicago: Quintessence, 1995:123, 124.
24. Simon H, Caputo AA. Removal torque of immediately loaded transitional endosseous implants in human subjects. Int J Oral Maxillofac Implants 2002;17:839–845.
25. Tan KB, Rubenstein JE, Nicholls JI, Yuodelis RA. Three-dimensional analysis of the casting accuracy of one-piece, osseointegrated implant-retained prostheses. Int J Prosthodont 1993;6:346–363.
26. Randi AP, Hsu AT, Verga A, Kim JJ. Dimensional accuracy and retentive strength of a retrievable cement-retained implant-supported prosthesis. Int J Oral Maxillofac Implants 2001;16:547–556.
27. Brånemark P-I, Zarb GA, Albrektsson T. Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:11–76.