Marginal Integrity of Direct and Indirect Castings for Implant Abutments

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Purpose: *Current implant systems with screw-retained abutments permit direct laboratory fabrication of castings. Computer aided drafting systems further enhance the fabrication of computer-milled abutments (CMAs) and castings. The purpose of this study was to compare marginal accuracy, as measured by gap size, of castings made directly on CMAs with those made indirectly on epoxy and stone dies.* ***Materials and Methods:*** *Castings were made directly for 10 CMAs. Marginal gap measurements were made with the castings seated on the abutments (group A). Castings were also made indirectly on stone and epoxy dies obtained from impressions of the abutments. Marginal gap measurements were made with these indirectly made castings seated on their CMAs (groups B and E). In addition, the directly made castings were transferred between CMAs and marginal gap measurements made (group D). Marginal gap measurements of the groups were compared with analysis of variance (ANOVA) and pair-wise comparisons (Scheffé test).* ***Results:*** *Groups A and D had marginal gaps of less than 100 μm. These marginal gaps were significantly smaller ($P < .05$) than the gaps of groups B and E, made on dies, which were approximately 200 to 500 μm.* ***Discussion and Conclusions:*** *With CMAs, it is possible to make an exact duplicate of the abutment. This permits the laboratory to make castings on duplicate abutments with greater precision than can be obtained using the indirect technique. Direct fabrication of castings resulted in smaller marginal gaps, which in turn allows a better marginal seal and improved retention of castings.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:593–599

Key words: *dental castings, implant abutments, implant prosthodontics, implants, retention*

The lost wax technique for fabrication of metal castings was first developed by the ancient Egyptians. It was introduced to dentistry by Taggart in 1907 for the fabrication of full-veneer crown restorations.[1] Wax patterns may be made directly to prepared teeth or on dies that replicate the form of the prepared tooth. Refinement of the casting process has evolved through enhancement of impression materials; use of die spacers; improvement in the properties of dental waxes, die materials, and investment materials; superior techniques that allow more precise control of mold expansion; changes in dental alloy formulations; and improved fitting techniques.[2–7] Precementation marginal gaps for crown castings in the range of 25 to 70 μm are generally considered acceptable.[8,9] Nevertheless, in spite of the precision that can be achieved, the process of fabricating the crown is technically demanding. There are 5 positive-negative transformations from the tooth to the crown.[10] These include the impression, the die, the wax pattern, the refractory investment mold, and the metal cast. The fabrication of cast metal restorations for natural teeth utilizing the lost wax process has inherent limitations that continue to challenge clinicians and technicians. For this reason, fitting and adjustment of castings is required at the lab bench, chairside, and intraorally.

Dental implants are now recognized as a predictable replacement for missing teeth. The restorative process requires a secondary component (an abutment) to be attached to the implant as a trans-

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mucosal element to support the definitive restoration. Abutment choices include stock abutments, custom cast abutments, and most recently, the computer-milled abutment (CMA).[11] Additionally, there has been increased use of cement-retained implant-supported prostheses.[12] Cement-retained dental implant restorations are usually fabricated using the lost wax technique previously described for natural teeth.[13] However, dental implant restorations offer a unique opportunity: Since the abutments are screw-retained and retrievable, the abutment can be accurately prepared in the laboratory with adequate resistance and retention and utilized as the die.[14] The waxup can thus be fabricated directly on the abutment, which will result in a more accurate fit of the cast coping. However, the process is labor intensive and lacks standardization. The results are largely dependent upon the skill of the laboratory technician, particularly if multiple abutments are required. In addition, if the abutment is used in the laboratory to make the casting, there is often a need for temporary abutments to be installed intraorally to manage the soft tissue during the time necessary for fabrication of the permanent restoration.[15]

Recently, in an attempt to overcome limitations of stock and custom cast abutments, CAD/CAM technology has been introduced to produce CMAs (Atlantis Components, Cambridge, MA).[16] CMAs are milled to the desired morphological size and shape for each implant site from solid "blanks" of titanium. The digital dataset collected, analyzed, and sent to the computer numerical control implant milling machine can be used again to produce a second, identical abutment. The clinician can then place 1 abutment intraorally to support a transitional restoration, while the second CMA, the duplicate, can be used as a die for the creation of the definitive cast metal coping.[16] It is claimed that this technology, with precise coordinates for abutment size, shape, and orientation, permits direct fabrication of casting on the duplicate abutment without the need for additional impressions to capture margins or indirect die fabrication, thus minimizing the number of positive-to-negative transformations.[17,18]

The purpose of this study was to compare the marginal accuracy (gap) of cast metal copings fabricated by both direct and indirect techniques and fitted to a series of CMAs. The cast copings were evaluated for fit on dies, on the original CMAs, and then on the duplicate abutments to determine the clinical usefulness of the technology in reducing the complexity of the dental implant restorative process. The null hypothesis was that castings made using the 2 techniques and fit to implant replicas (analogs) would not differ with respect to marginal gap.

MATERIALS AND METHODS

For this experiment 10 prefabricated CMAs mounted to implant analogs were used. The implant analogs represented tapered Screw-Vent implants with a proprietary friction-fit internal-hexagonal connection (Zimmer Dental, Carlsbad, CA). The CMAs were milled from 12-mm-diameter blanks of commercially pure titanium (Zimmer Dental) into a standardized premolar shape with proximal walls at a total occlusal convergence of 10 degrees and a vertical height of 11 mm, with the apical 3 mm serving as the collar. The coronal 8 mm were prepared with a modified shoulder to simulate the preparation of an average natural tooth. The finished CMA had a mesiodistal width of 7 mm and a buccolingual width of 8 mm (Fig 1).

The implant analogs were mounted in a polymethyl methacrylate model (Zimmer Dental). The model included the central and lateral incisors for orientation. The analogs were positioned with the implant-abutment interface 1 mm below the acrylic resin gingival margin. Five samples were positioned on each side. Each CMA was inscribed sequentially with an identification number on 3 surfaces (Fig 2).

Custom light-cured urethane dimethacrylate trays (Triad; Dentsply, York, PA) were fabricated, and 2 full-arch impressions of the abutments were made with a vinyl polysiloxane material (Afffinis; Coltene/Whaledent, Mahwah, NJ). Two full-arch working casts with removable dies were fabricated (Pindex; Coltene/Whaledent), one from epoxy resin (American Dental Supply, Easton, PA) and the second from type IV die stone (Die Keen Green; Heraeus Kulzer, Armonk, NY), respectively. All dies were sectioned and trimmed to expose the marginal areas (Fig 3).

Three sets of castings were then made. For the first set, the direct technique was used. The titanium CMAs were used as dies for the waxups and fabrication of the cast metal copings. Using the indirect technique, waxups were done on the epoxy resin dies and stone dies for casting fabrication. The CMAs and the stone dies were each coated with 2 layers of die spacer (George Taub, Jersey City, NJ), and epoxy dies were coated with 3 layers of die spacer. The third layer of die spacer was used on the epoxy dies to compensate for epoxy shrinkage during polymerization.[3] A standardized premolar waxup, 10 mm in height, 8 mm in buccolingual diameter, and 7 mm in mesiodistal width, was created for each group. Using this waxup, a flexible split mold (Lab Putty; Coltene/Whaledent) was used to produce wax patterns of similar dimensions for all 10 of the abutments for each group. The margins were adapted, and the patterns were sprued, invested (Cristobalite; WhipMix, Lexington, KY) and cast in a type III alloy (Symphony; Jelenko, Armonk, NY).

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Fig 1 CMAs milled from 12-mm-wide titanium cylinders.

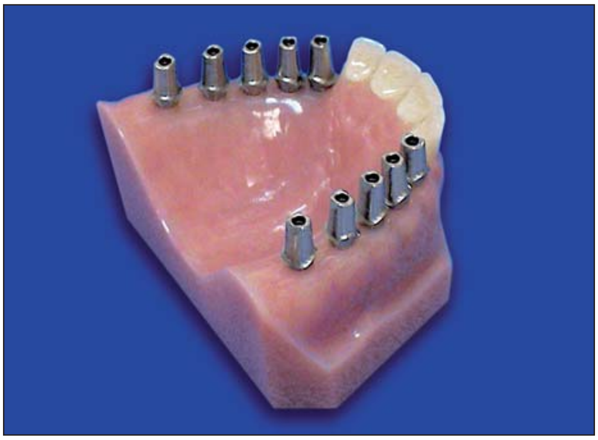

Fig 2 Acrylic resin model embedded with 10 implant analogs with CMAs attached. For identification each specimen (1 to 10) was inscribed on 3 surfaces.

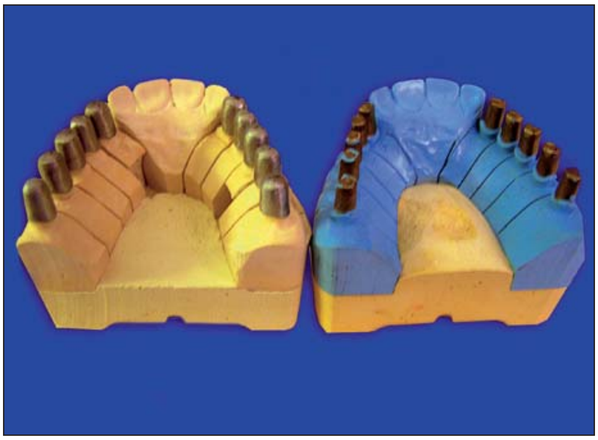

Fig 3 Epoxy (blue) and stone dies (yellow) used for the indirect fabrication of castings.

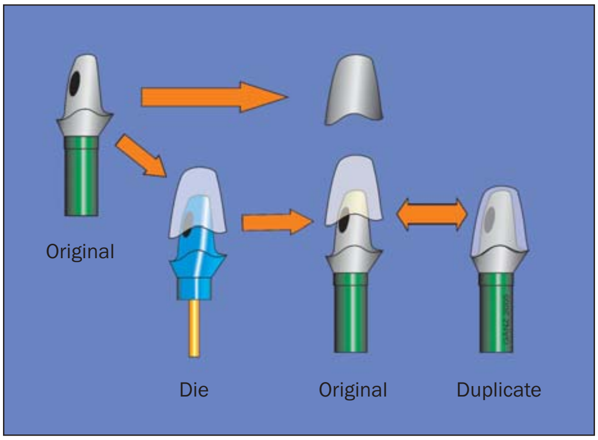

Fig 4 Schematic outline of the experimental measurement protocols. Castings were made on the original abutments and the dies. Measurements were made on the dies (groups C and F), the original abutments (groups A and B), and the duplicate abutments (group D).

Each casting was examined, cleaned, and fitted twice with a standardized protocol (FitChecker, GC America, Alsip, IL). The castings made on the epoxy or stone dies were fitted to their respective dies, while the castings made on the CMAs were fitted to their respective abutments. To ensure consistency, a single technician completed all waxups, castings, and fittings. The protocol is outlined in Fig 4.

For imaging, each computer-milled titanium abutment was removed from the model and attached to an analog mounted in a wood block for stability. The 3 castings (the one made on the abutment, the one made on an epoxy die, and the one made on a stone die) were individually seated on each abutment. The specimen assembly, consisting of the analog, CMA, and casting, was stabilized on the microscope stage with a custom-built holder, which was hand-tightened to exert positive finger pressure on the casting to ensure complete seating (Fig 5). The assembly

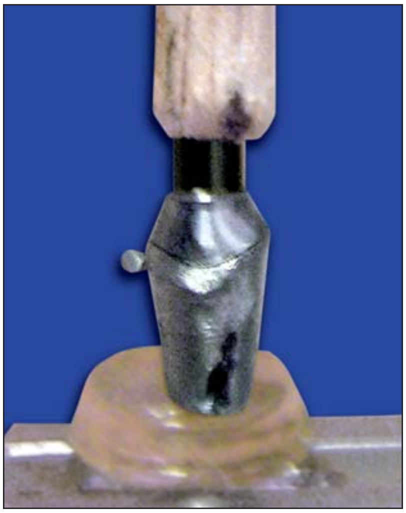

Fig 5 Specimen assembly used to stabilize the coping on the die during the measurement procedure on the microscope stage.

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Fig 6 *Photomicrographs taken at 60× of specimens from each of the 4 groups. The photomicrographs are representative of the casting-abutment interfaces of either the buccal, lingual, mesial, or distal surfaces.*

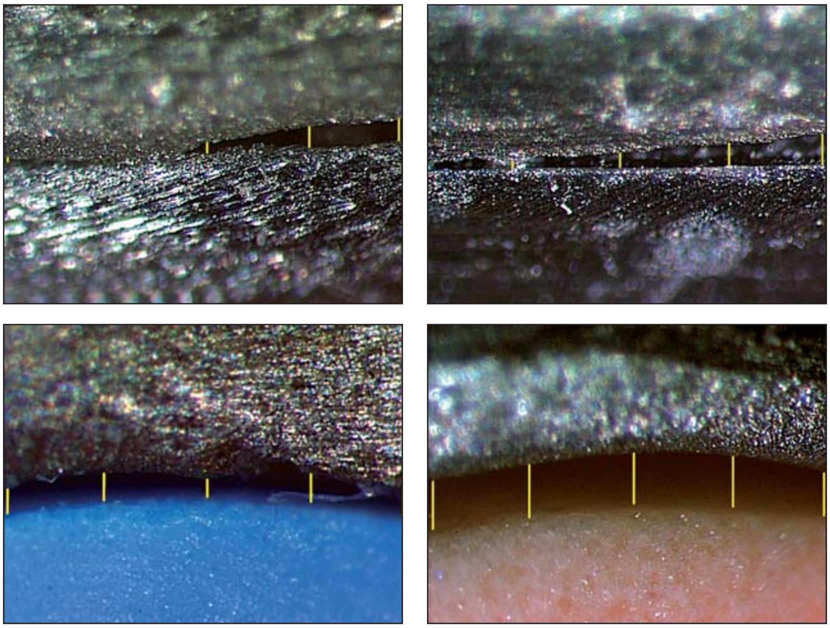

Fig 6a Group A specimen of the casting-abutment interface of a mesial surface. In group A the castings were made directly on the CMAs. Note the relatively small marginal gap size.

Fig 6b Group D specimen of the casting-abutment interface of a facial surface. In group D the castings were made directly on the CMAs. Note the relatively small marginal gap size.

Fig 6c Group B specimen of the casting-abutment interface of a mesial surface. In Group B the castings were made indirectly on an epoxy die. Note the large marginal gap size.

Fig 6d Group E specimen of the casting-abutment interface of a distal surface. In Group E the castings were made indirectly on a stone die. Note the large marginal gap size.

could be rotated along its long axis, perpendicular to the central beam of the microscope. In addition, castings made with the indirect technique were also photographed and measured on their respective epoxy dies and stone dies as controls. After calibration, photographic images were obtained of the facial, mesial, lingual, and distal surfaces of the margin interface at 60× using an Olympus SZX12 microscope with a USB camera head and an Optronics microprocessor unit (Olympus, Melville, NY). Each image was saved in a digitized JPEG format on the computer for future measurement and analysis. Specialized imaging and measurement software was used to measure the marginal gap (Bioquant 2000; Biometrics, Nashville, TN). Five measurements were made along the length of the marginal interface at uniform intervals along the interface on each surface.

The measurements of the marginal gap were averaged to obtain a mean marginal gap (MMG) for that specimen's surface.

There were 6 MMG measurement groups:

- Group A: Directly made castings measured on the abutments
- Group B: Indirect castings made on epoxy dies and measured on the abutments
- Group C: Indirectly made castings measured on epoxy dies
- Group D: Directly made castings measured on duplicate abutments
- Group E: Indirect castings made on stone dies measured on the abutments
- Group F: Indirectly made castings measured on stone dies

The rationale for groups C and F was to demonstrate that the castings fit their respective dies and thus that the marginal gap discrepancies, when the indirect castings were measured on their respective abutments, resulted from discrepancies between the die and abutment dimensions, not from poorly made castings. Similar measurements were completed for the specimens of all 6 groups. A total of 240 images and 1,200 measurements were obtained (Fig 6). One examiner performed all the measurements. The MMG for the indirect and direct casting groups for each surface were compared using 1-way analysis of variance followed by pair-wise comparison using the Scheffé test. The significance level was set at $P \leq .05$. These results allowed comparison of the marginal gaps of crowns made indirectly on the dies versus those made directly on the duplicate abutments. Secondly, the marginal gaps of castings seated on the abutments from which they were waxed and cast directly were compared with the marginal gaps of the same castings after transfer to a duplicate copy-milled abutment.

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Table 1 MMG Measurements in μm by Group

	Surface							
	Facial		Mesial		Distal		Lingual	
Group	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
A	39.62	7.98	61.94	8.93	61.99	8.96	85.96	10.04
B	520.44	77.92	509.30	61.12	487.30	68.89	515.30	69.99
C	102.02	13.39	60.20	15.06	74.11	14.70	96.11	18.30
D	67.14	23.30	44.87	15.05	58.75	18.58	95.92	29.92
E	210.17	46.48	93.62	30.04	163.99	38.84	202.50	65.49
F	95.95	18.76	66.16	23.19	61.18	17.46	45.76	18.10

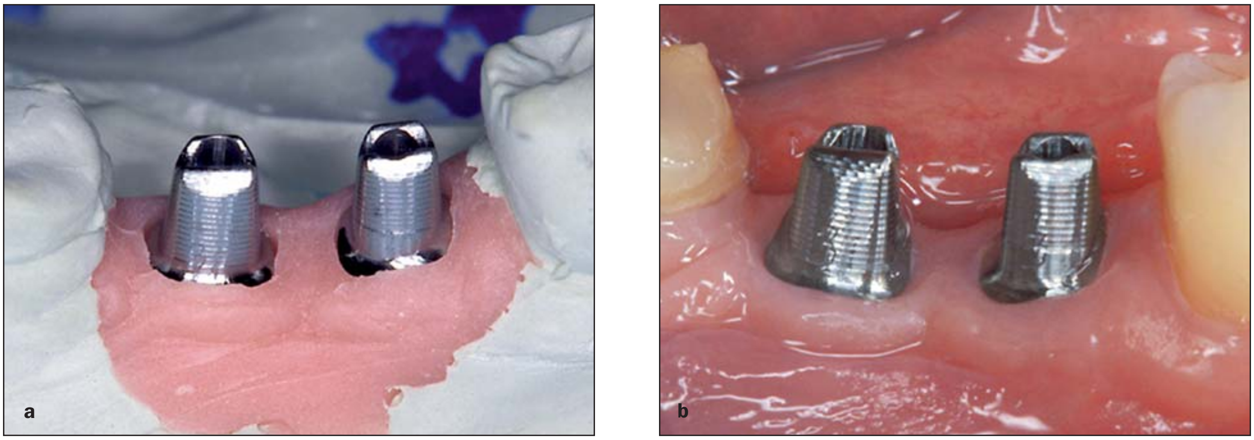

Fig 7 A clinical case in which duplicate abutments were used for direct casting. Duplicate abutments *(a)* in the working cast and *(b)* intraorally.

RESULTS

The MMGs for each group are given in Table 1. Castings made directly on the abutments (group A) had the smallest MMGs ($P \leq .001$). These gaps were clinically acceptable with minimal fitting procedures. This was not true for the indirectly made castings, groups B and E. While the indirectly made castings had an acceptable fit on their dies (groups C and F), when placed on the abutments, the MMGs for group B (castings made from epoxy dies) and group E (castings made from stone dies) were significantly larger ($P \leq .001$). Finally, transfer of directly made castings from 1 CMA to a duplicate (group D) did not result in any significant change in MMG compared with group A.

DISCUSSION

The results of these experiments demonstrate that CAD/CAM abutments or CMAs can be duplicated with sufficient accuracy so as to permit accurate exchange of castings between the original abutment and the duplicate abutment. The need for impressions and provisional abutments can thus be eliminated, since a duplicate abutment can be utilized in the laboratory for casting fabrication. These findings could have important implications, since fabrication of castings indirectly, ie, using stone or epoxy dies, was associated with a significantly larger marginal gap when the castings were replaced on the original titanium abutment ($P < .001$). It has been long recognized that stone and epoxy dies undergo dimensional changes. The epoxy die material undergoes shrinkage as it sets. Stone dies exhibit expansion but are extremely sensitive to water-powder ratios.[3,19] These dimensional changes can affect the size of the castings. Materials that shrink will result in an undersized casting. This shrinkage is most prominent along the length of the die.[3] Hence, when a casting made on an epoxy resin die is returned to the original tooth or abutment, it will have a tendency toward incomplete seating unless alterations have been made in the casting. Although die stone demonstrates expansion, frequently this expansion is not

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uniform, so incomplete seating is also a problem with this material. A number of strategies, including use of die spacer, use of a ring liner for the investment mold, and use of fitting materials such as FitChecker (GC America), have been employed to compensate for these discrepancies.[20] Nevertheless, the magnitude of these discrepancies has been accepted because of the limitations of the indirect die-casting process.[21] However, fabrication of castings without the use of dies, using a direct technique on duplicate CMAs, resulted in a significant reduction of marginal gap width and represents a technological advance.

Indirectly made castings did not have as precise a marginal adaptation between the casting and the abutment as directly made castings. Clinically, discrepancies in fit of castings on abutments can have significant consequences. In the case of natural teeth, the cement seal between the tooth and crown may be lost, with sequelae of recurrent decay and marginal gingivitis.[22] Marginal gingivitis resulting from plaque accumulation in the marginal gap area may extend itself into the periodontium and result in chronic periodontitis.[23] A smaller marginal gap between the crown and abutment even in the case of implant-supported crowns reduces the likelihood of plaque retention at the crown-abutment interface and may have a positive effect on soft tissue response.[23]

In addition, a poor fit can reduce retentive forces and make an implant-supported crown more vulnerable to displacing forces.[24] Cement stabilizes the crown on the abutment. When a crown is seated on an implant with a thick layer of cement, the cement is more vulnerable to shear forces. The shear strength of both zinc phosphate and glass ionomer cements is significantly less than their compressive strengths.[25] Thus, the crown can be more readily displaced.

Fabrication of castings directly on the abutments will result in a more uniform adaptation of the inner wall of the casting to the abutment. This may reduce the effects of torquing forces by distributing the contact forces more uniformly around the abutment.[26] In addition, it is less likely that there will be an occlusal prematurity from incomplete seating of the casting.[27] In the case of implant-supported restorations, where a periodontal ligament is lacking, the consequences of an occlusal prematurity may be more significant, although the effects of clinical occlusal trauma on the osseointegrated interface between the implant and the bone are not well understood. The clinical implications for the use of direct fabrication techniques are a reduction in treatment time, increased accuracy, fewer laboratory remakes, and an improved fit of the coping to the abutment (Fig 7). The stability of the casting on the abutment lessens the possibility of torquing forces that may cause flexure of the abutment-implant joint, loosening of the abutment screw, and a loss of preload.[28]

CONCLUSIONS

In this study, the marginal gaps of direct castings seated on abutments were significantly smaller than the marginal gaps of abutments made indirectly on stone and epoxy dies ($P < .001$). The marginal gaps of indirect castings made from epoxy dies when seated on abutments were significantly greater ($P \geq .01$) than those made from stone dies. The marginal gaps of direct castings seated on duplicate CMAs were not significantly different from the marginal gaps measured with the original abutments.

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