AMERICAN COLLEGE OF PROSTHODONTISTS®

Volumetric Misfit in CAD/CAM and Cast Implant Frameworks: A University Laboratory Study

Riad Almasri, DDS,[1,2,3] Carl J. Drago, DDS, MS,[4,5] Sharon Crane Siegel, DDS, MS,[6] & Patrick C. Hardigan, PhD[7]

[1]Formerly, Chief Resident in Postgraduate Prosthodontics, Nova Southeastern University College of Dental Medicine, Fort Lauderdale, FL
[2]Clinical Assistant Professor, Department of Restorative Sciences, Texas A&M Health Science Center Baylor College of Dentistry, Dallas, TX
[3]Prosthodontist, Private Practice, Dallas, TX
[4]Formerly, Director, Dental Research, Biomet 3i, Palm Beach Gardens, FL
[5]Associate Professor, Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, OH
[6]Associate Professor and Chair, Nova Southeastern University College of Dental Medicine, Fort Lauderdale, FL
[7]Executive Director of Health Professions Division Research, Chair of the Statistical Consulting Center, Nova Southeastern University, Fort Lauderdale, FL

Keywords
CAD/CAM; conventional frameworks; precision of fit.

Correspondence
Riad Almasri, Department of Restorative Sciences, Baylor College of Dentistry, 3302 Gaston Avenue, Dallas, TX 75246.
E-mail: almasridds@gmail.com

Previously presented at the 39th Annual Session of the American College of Prosthodontists, San Diego, CA 2009.

Accepted July 29, 2010

doi: 10.1111/j.1532-849X.2011.00709.x

Abstract

Purpose: To compare the volumetric misfit between implant restorative platforms of implants and implant frameworks manufactured with two different technologies. One set of implant frameworks was made with a CAD/CAM protocol and a tactile probe; the second protocol consisted of frameworks made with the lost-wax technique and conventional casting technology.

Materials and Methods: In this laboratory study, an acrylic resin model with five "inter-foraminal" implants was used as the "patient" model. Implant level impressions were made, and 10 definitive master casts were fabricated. The casts were verified using an index made on the patient model. Five cast high palladium noble alloy and five CAD/CAM titanium alloy frameworks were fabricated. The patient's implants and the frameworks' implant restorative platforms were scanned with a tactile probe, and the data were digitized. The digitized implant restorative platforms of the frameworks were fit onto the patient's digitized implants via a software program, in a process called "lofting." This computerized procedure simulated a 1-screw test; the process was performed on both sides. The volumetric misfit between the implant restorative platforms of the frameworks and the patient's implants were measured. A Welch's *t*-test was used to determine significant differences ($p < 0.05$) between the misfit of the two technologies. Wilcoxon Signed-Rank tests were used to evaluate differences between the right and left sides.

Results: On average, the volumetric misfit of the CAD/CAM frameworks was 1.8 mm^3 less than the volumetric misfit of the cast alloy frameworks ($p < 0.05$). The Wilcoxon Signed-Rank tests showed no significant differences between the right and left sides within both systems ($p > 0.05$).

Conclusions: The scanning technology and computer software program used in this study demonstrated that the CAD/CAM implant frameworks had statistically significantly less volumetric misfit when compared with the cast implant frameworks. There were no significant differences between the right and left 1-screw tests within the same type of frameworks.

Implant bars fabricated using the conventional lost-wax casting technique may not routinely produce the desired fit between implants and implant bars.[1] This misfit is due to multiple factors, in particular the inconsistency of volumetric and linear expansion/contraction of the materials used. These include metal alloys used for casting, as well as gypsum, impression material, wax, and investment.[2] Different post-casting techniques, such as soldering and electronic discharge machining have been advocated to correct misfit resulting from the fabrication process.[1-5]

Various studies have assessed the precision of fit between frameworks and supporting implants.[6-9] May et al did a laboratory study using the Periotest instrument (Medizintechnik Gulden EK, Eschenweg, Germany) and compared three framework conditions and three implant locations.[6] Their results showed that the procedures used to fabricate a precise fit between frameworks and the supporting implants were influenced by the skill of the clinicians and technicians.

In a clinical study, Calderini et al[7] used the OsseoCare device (Nobel Biocare, Zurich, Switzerland) and torque-angle signature analysis to assess the fit of titanium frameworks fabricated using three methods: (1) one-piece casting, (2) CNC (computer numerical controlled machining), and (3) CTiP (Cresco Ti Precision). The results demonstrated that the frameworks fabricated using the CNC and CTiP methods showed passive fit, while one-piece castings did not.

In a clinical study, Jemt[8] measured the misfit between implant frameworks on master cast abutment analogs and intraorally between implant frameworks and implants with a 3D photogrammetric technique. He demonstrated that prostheses connected to osseointegrated implants could demonstrate distortion between the frameworks and implants of up to several hundred microns.

Jemt and Book[9] presented the results of a clinical study where they reported prosthesis misfit and radiographic bone loss for 14 patients. They demonstrated that none of the frameworks exhibited a complete passive fit for any of the prostheses in vivo and suggested that implants may have a certain biologic tolerance to ill-fitting frameworks.

Other authors have studied the accuracy of fit between implants and implant frameworks made with different techniques, protocols, and materials. The results have tended towards CAD/CAM protocols resulting in better-fitting frameworks than the results obtained with traditional casting protocols. Multiple CAD/CAM protocols have been developed and tested (Table 1).

Summarizing the above studies, the misfit between implants and metal frameworks was generally measured in one or two linear dimensions. Several studies measured the misfit in three dimensions but not volumetrically. In clinical practice frameworks are inaccurate in mesial-distal, buccal-lingual, and occlusal-gingival directions. None of the cited papers provided volumetric measurements for the misfits. These studies did, however, generally report that CAD/CAM bars had better passive fits than conventional cast bars. Clinical misfit between implants and implant-supported frameworks should be reported volumetrically. This is a more accurate representation of clinical conditions, since misfits are non-linear. This could also provide an explanation for the failures that occur clinically. Therefore, this study will report on clinical misfits between implants and implant-supported frameworks with volumetric measurements (mm^3).

Table 1 Comparison of laboratory and clinical studies on the efficacy of castings and machined/welded implant frameworks

Author	Laboratory study findings	Clinical study findings
Torsello et al[10]	Excellent precision when compared with the traditional casting methods or with the use of prefabricated Ti copings	
Riedy et al[11]	Laser-welded frameworks exhibited a more precise fit with the mean *z*-axis gaps at the centroid points; then the 1-piece castings, with significant differences at 4 of 5 prosthodontic interfaces	
Jemt et al[12]	3D distortion of the cylinders in the completed prostheses ranged from 3 to 80 μm. Jemt et al suggested that CNC-milled prostheses could be a valid option for the routine fabrication of implant frameworks due to a precision of fit comparable to the conventional cast frameworks	
Ortorp et al[13]		Laser-welded Ti frameworks seem to be a possible alternative to conventional castings for implant prostheses in edentulous mandibles
Bergendal and Palmqvist[14]	Survival rates between laser-welded Ti frameworks and gold-alloy frameworks for implant-supported fixed prostheses. The authors considered the overall results for Ti frameworks after 5 years to be satisfactory	
Ortorp et al[15]		CNC frameworks had a better fit and precision of fabrication than conventional castings
Ortorp and Jemt[16,17]		CNC-milled Ti frameworks can be used to replace gold alloy castings in implant treatment in edentulous jaws
Al-Fadda et al[18]	CNC-milled frameworks yielded a more precise fit than conventional castings	

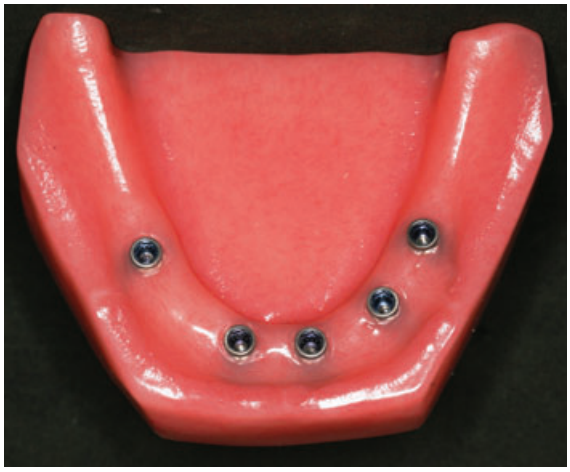

Figure 1 Occlusal view of the patient model used in this study.

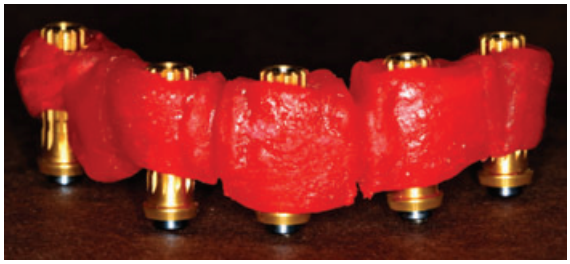

Figure 2 Buccal view of verification index after the clinical procedure.

Figure 3 Scanning unit with a master cast in the cast holder.

The purpose of this research project was to compare the volumetric fit between implant restorative platforms and implant frameworks fabricated with two different technologies. One set of implant frameworks was made with a CAD/CAM protocol; the second protocol consisted of frameworks made with the lost-wax technique and conventional casting technology. The research hypothesis for this study is that implant restorative platforms of frameworks made with CAD/CAM technology will have a better volumetric fit than those frameworks made with conventional casting technology.

Materials and methods

Five OSSEOTITE Certain® (4.1 mm diameter) implants (IOSS410, Biomet 3i™, Palm Beach Gardens, FL) were placed into a patient model simulating an edentulous mandibular jaw (Fig 1). Implants were placed in a manner simulating a prototypical edentulous patient with five inter-foraminal implants. This prototypical patient was scheduled to be restored with an implant-retained primary bar for supporting/retaining a mandibular overdenture. The patient model was made with heat-processed acrylic resin.

Custom tray fabrication

An alginate impression (Schein Alginate Fast Set, Henry Schein, Inc, Melville, NY) of the patient model was made using a stock tray. This impression was poured using Type III dental stone per the manufacturer's instructions (Microstone, Whip Mix Corporation, Louisville, KY). Light-cured resin (Triad Tru-Tray, Dentsply International, York, PA) was used to fabricate ten open-face custom impression trays on the diagnostic casts. Access openings were placed into the impression trays consistent with the implant positions on the casts for open tray impressions.

Implant level impression/definitive master casts

Ten definitive impressions of the patient model were made. For each impression, new pick-up impression copings were used (IIIC41, Biomet 3i). Definitive implant level impressions were

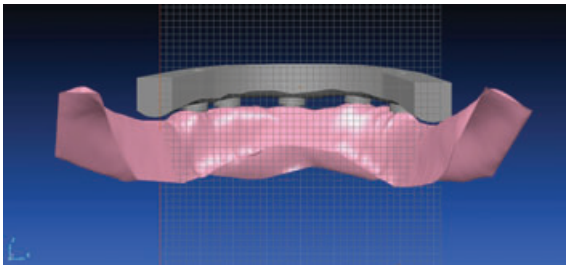

Figure 4 Lingual image of CAD design for the CAD/CAM bar used in this study.

Figure 5 Occlusal and intaglio views of one of the 5 CAD/CAM bars milled in this study.

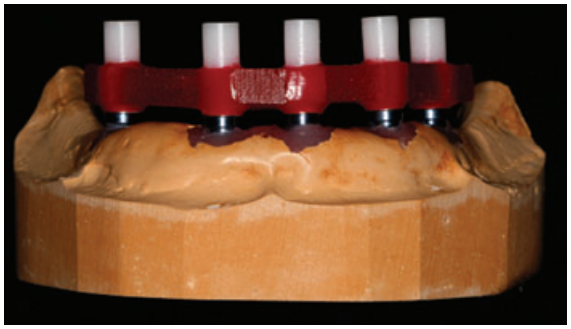

Figure 6 Buccal view of one of the waxed bars on a working cast.

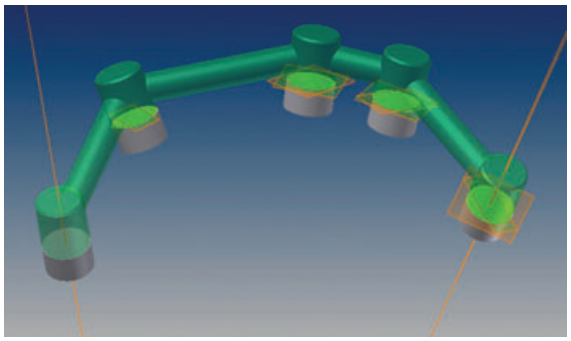

Figure 8 Occlusal view of one virtual one-screw test for the CAD/CAM bar and implants. The degree of misfit is identified by the red planes. The virtual abutment screw was applied to the left distal implant.

made in the custom trays with light/heavy polyether impression material per the manufacturers' instructions (Impregum, 3M ESPE Dental Products, St. Paul, MN). After the impression material set, new implant analogs (IILA20) were screwed into the impression copings; soft tissue replication material (Gi-Mask, Colténe/Whaledent Inc, Cuyahoga Falls, OH) was injected around the implant analog/implant impression copings and onto the intaglio surfaces of the impressions. Working casts were poured with vacuum spatulation using Type IV dental stone (Resin Rock, Whip Mix Corporation) per the manufacturers' instructions. Five impressions were poured to fabricate the master casts for the cast alloy frameworks, and five impressions were poured to fabricate the master casts for the CAD/CAM frameworks. The latter set of casts was sent to Biomet 3i for scanning, bar design, and milling.

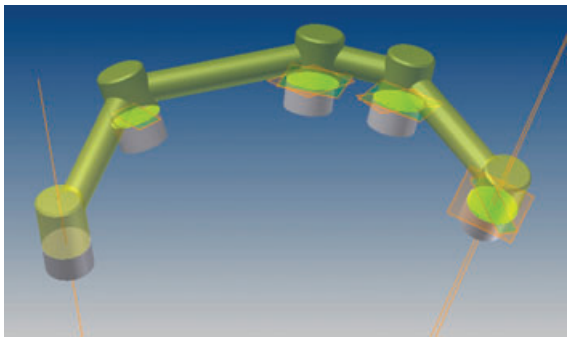

Figure 9 Occlusal view of one virtual one-screw test for the cast bar and implants. The degree of misfit is identified by the red planes. The virtual abutment screw was applied to the left distal implant.

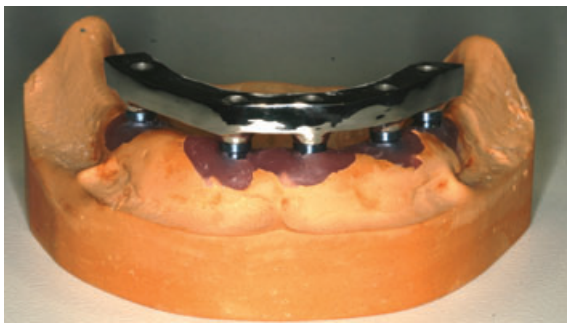

Figure 7 Buccal view of an alloy cast bar on a master cast after finishing and polishing.

Verification index

Before initiating bar fabrication, a verification index was fabricated to ensure the accuracy of the impressions and definitive casts. New, non-hexed metal temporary cylinders (ITCS42, Biomet 3i) were placed onto the implants in the patient model, and a one-piece verification index was fabricated with a low-expansion autopolymerizing acrylic resin (GC Pattern Resin, GC America, Alsip, IL). The index was sectioned into individual segments using separating discs less than 1 mm thick and allowed to set for at least 24 hours.[19] The segments were placed back onto the patient model and luted together with new resin (Fig 2). The index set undisturbed for 15 minutes. The index was transferred to each master cast, and evaluations were made as to the accuracy of fit onto the implant analogs in the casts. One cast was considered to be inaccurate and was

remade. A new impression was made for a new master cast. This second cast was reevaluated with the index and was found to be accurate.

Scanning and CAD design

For the CAD/CAM bars, a tactile probe (Vertex Automatic Measuring System, Model 220, Florida Metrology, Inc., Ft. Lauderdale, FL), (Fig 3) was used to scan the implant restorative platforms of the implant analogs in the five master casts. This protocol was the same used by the manufacturer to fabricate CAD/CAM bars on a commercial basis. The digitized data were sent to the workstation of a PSR designer (Patient Specific Restorations, ARCHITECH, Biomet 3i). Implant primary bars were designed with the following prosthodontic parameters: 2 mm cantilevers measured from the distal surfaces of the distal implants, 6 mm B/L width, 4 mm vertical height, parallel walls, and no attachments (Fig 4).

Milling

The CAD/CAM bars were machined from blanks of titanium alloy TiAl6V4, finished, and polished per the manufacturer's protocol (Biomet 3i) as if for a clinical patient try-in appointment (Fig 5). After the finishing and polishing procedures were completed, the implant restorative platforms of the milled bars were scanned using the same tactile scanner noted above.

Cast bars

The first author fabricated all five cast alloy bars. Non-hexed UCLA gold cylinders (IGUCA2C, Biomet 3i) were placed into the implant lab analogs in the definitive master casts. The implant primary bars were designed with the same prosthodontic parameters used for the CAD/CAM bars. Resin patterns were made using the low expansion autopolymerizing acrylic resin. The resin patterns were sectioned into five individual pieces, each containing one of the UCLA cylinders on the master casts. Casting wax (Dipping wax, Kerr Corporation, Orange, CA) was used to connect the pieces (Fig 6). The resin patterns were sent to a commercial dental laboratory (DSG Americus Southeast Dental Laboratory, Clearwater, FL) and were invested (1700, Talladium Inc, Valencia, CA) by one laboratory technician, per the manufacturers' instructions. The patterns were cast using the noble dental alloy routinely used by the preselected dental laboratory for casting implant bars (Argelite 70+, The Argen Corporation, San Diego, CA) (Table 2). The sprues were removed in the commercial dental laboratory; the castings were returned to the first author for finishing and polishing. The cast bars were finished and polished following the protocol as if for a patient try-in appointment (Fig 7). Polishing protectors were in place on all the restorative platforms of the bars during all polishing procedures. None of the bars were sectioned, soldered, or laser welded because doing so would introduce a set of variables regarding the bars' strength and the veracity of the rigid connectors.[20] In clinical practice the authors acknowledge that these types of frameworks would likely be sectioned and soldered to improve the fit between implants and ill-fitting bars. After the cast bars were finished and polished, they were sent with their master casts and the patient model to Biomet 3i for scanning using the same tactile scanner mentioned above.

Evaluation

The scans for the ten frameworks occurred within the same verification cycle. The patient model was used to evaluate the fit of all bars. The tactile probe scanned the restorative platforms of the implants on the patient model as well as the frameworks. The digital data were stored and transferred to a computer-generated model using a computer software program (Autodesk Inventor 11, Autodesk, Inc., San Rafael, CA); framework fit was evaluated with the computer software program.

The virtual frameworks and patient implants were aligned on the computer screen to simulate the one-screw test for each pair. This process, called "lofting" in CAD, included placing the virtual image of the distal restorative interface of a framework onto the implant restorative platform of the corresponding distal implant. The second one-screw test was repeated with the other distal implant. This process has been validated with an accuracy of 10 μm as established by the manufacturer

Table 2 Argelite 70+ (composition, ingredient information)

Metal	%	Symbol	Cas No.	ACGIH 8 HR TLV	OSHA 8 HR PEL
Gold	3	Au	7440-57-5	Not established	Not established
Palladium	70	Pd	7440-05-3	No data	No data
Silver	9.5	Ag	7440-22-4	0.01 mg/m^3	0.1 mg/m^3
Ruthenium	x	Ru	7440-18-8	No data	No data
Indium	2	In	7440-74-6	0.1 mg/m^3	0.1 mg/m^3 TWA
Gallium	x	Ga	7440-55-3	No data	No data
Zinc	5	Zn	7440-66-6	5 mg/m^3	No data
Tin	9.8	Sn	7440-31-5	2 mg/m^3	2 mg/m^3

Note: % values are in weight percent and reflect nominal composition.

Note: 'x' denotes a content of less than one percent.

Modified from MSDS (The Argen Corporation, San Diego, CA).

ACGIH 8 HR TLV: American Conference of Governmental Industrial Hygienists 8 Hours Threshold Limit Value.

OSHA 8 HR PEL: OSHA 8 Hours Permissible Exposure Limit.

TWA: total weight average.

(Biomet 3i).[21] To further elaborate on this procedure, this process measured the volumetric spaces between the other four implant/abutment interfaces. This is a computerized mathematical equation whereby each point in space is identified in the x, y, and z axes for both the implants and the restorative implant platforms. Once each of these sets of data representing the implants and the restorative platforms is equalized (the one-screw test), the computer is then able to measure the misfits between the other four sets of interfaces (implant restorative platform–framework restorative platform). Thus, the two sets of data were recorded. The first virtual one-screw test was performed on the right distal implant. For each one-screw test, the total volumetric differences were added and averaged.

Once the frameworks and patient models were scanned, the coordinates were exported as a text file. This text file was converted into an Excel spreadsheet formatted for import into the CAD software. The imported Excel spreadsheet contained XYZ points from the Vertex tactile scanner as follows: 4 points per restorative platform (3 points for a plane, 1 point for the center of the platform). Three independent points from the calibration implant were used for orientation. Within the software program, the frameworks were perfectly seated onto the patient implants, center point to center point.

The misfits between the framework implant restorative platforms and implants on the patient model were measured in mm^3. Volumetric measurements were recorded for the four implant/abutment interfaces for each one-screw test and averaged for both the right and left sides. All measurements were done at Biomet 3i (Figs 8 and 9). The volumetric measurements were recorded with absolute values, as positive and negative values would cancel each other out and would not be descriptive of the data sets.

Statistical analysis

To compare the differences in misfit between the CAD/CAM implant bars and the conventional cast bars, a Welch's *t*-test was performed first because the variances were unequal. In addition, right versus left one-screw tests were included as factors in the analysis. Two Wilcoxon Sign-Rank tests were conducted to evaluate if differences existed between sides (right vs left) within systems.

Results

The volumetric measurements for the misfits between implants and implant restorative platforms for the CAD/CAM and cast bars are listed in Table 3. The cast frameworks exhibited greater misfits than the CAD/CAM frameworks: significant differences were found between groups ($p < 0.05$). On average, the volumetric fit between the implant restorative platforms of the CAD/CAM frameworks was 1.8 mm^3 less (better) than the corresponding volumetric fits between the implant restorative platforms of the cast frameworks (Fig 10). No significant differences were found between right and left screw tests within the same system.

Table 3 Means and SDs for the volumetric misfit measurements (mm^3) between the implant restorative platforms of frameworks and implants on the patient model

System	Mean	Std. Dev.	Min	Max
CAD/CAM	2.4	1.1	1.5	4.5
Cast	4.2	2.3	1.1	7.5

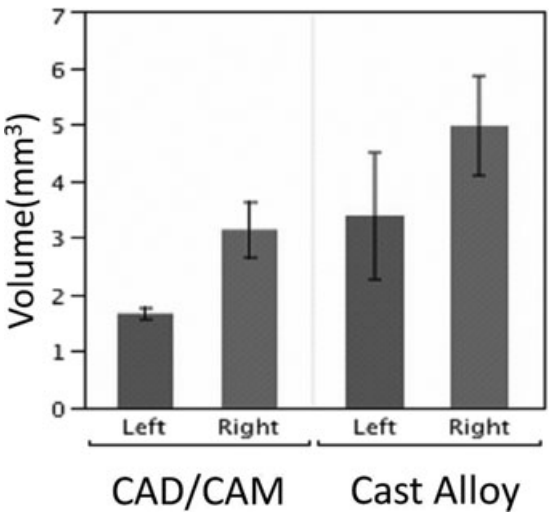

Figure 10 Results of volumetric misfit between two side (right vs left) per system, when one-screw test was performed (means and standard deviations).

Discussion

This study was conducted to assess the volumetric misfit between implants and Cast/CAD/CAM primary implant bars. The results of this laboratory study demonstrated that the CAD/CAM bars fabricated in this study had a statistically significant better fit with less distortion than did the cast frameworks fabricated with the same design parameters.

Generally, previous papers described accuracy within one-dimensional protocols to assess misfit between implants and implant-supported bars. Results were generally described as linear measurement in microns. However, clinical dentistry is practiced in three dimensions, with 3D objects including implants, components, bars, and patients; clinical misfits between implants and components do not occur in one dimension. Misfits occur in x, y, and z planes independently. Volumetric measurements appear to be a better method to assess clinical misfits than one-dimensional linear measurements.

Many previous studies demonstrated that CAD/CAM-fabricated titanium implant-supported frameworks were more accurate than cast frameworks.[12–17] CAD/CAM framework fabrication techniques, including virtual design, as well as copy milling techniques, are dramatically different than virtual techniques in that technicians must spend time fabricating patterns prior to scanning. In the case of complex frameworks, the time associated with these patterns may be significant. Copy milling requires dental laboratory technicians to construct custom wax or resin patterns on master casts. One advantage of copy milling is that technicians can fabricate the patterns with their particular

design parameters. For some technicians, this may be easier and more predictable than evaluating framework designs on a computer monitor. The copy mill patterns are then scanned, and the bars are milled with a CAD/CAM protocol. The virtual design and fabrication techniques used in this study eliminated the issues noted earlier.

The CAD/CAM bars milled in this study required imaging the implant analogs in the master casts and designing the frameworks by one dental laboratory technician using a computer software program. The protocol used in this study also allows dental laboratory technicians the opportunity to evaluate framework designs prior to milling, via JPEG files sent over the Internet. At this point in time, changes to designs cannot be made in real time. The technician would simply call one of the PSR technicians at Biomet 3i and discuss the changes; the designer would make the changes, submit them to the dental laboratory technician, and then view another set of JPEG files prior to having the bar milled.

Evaluations of the misfits involved a CAD principle called "lofting." Lofting technique is widely used in commercial industries using CAD, such as the automotive, architectural, and aeronautical/aircraft industries. Lofting has proven to be a valuable adjunct in improving efficiencies in work flow and design.[22,23]

This particular software program aligned the implant and restorative interface for one of the distal implants. The software then evaluated the "sections" between the restorative interfaces for the remaining four implant/restorative interfaces. The volumetric spaces between the implants and abutment interfaces were then measured, and the data statistically analyzed. This research was the first time that the "lofting" technique has been used in a dental application for research purposes.

The authors cited CNC protocols in this paper because of their prevalence in the dental literature. The CAD/CAM implant-supported frameworks milled in this study were designed virtually; they were not copy milled. All of the frameworks in this study were designed by one dental laboratory technician, using a computer software program on his personal workstation computer. The CAD/CAM and cast frameworks were made as similar as possible to each other. The authors designed the clinical protocol based on clinical techniques generally accepted by the prosthodontic community.

There were several limitations to this study. The cast frameworks were fabricated by one prosthodontic graduate resident, who possessed certain skills regarding waxing, casting, and finishing frameworks. The protocol and materials were controlled as much as possible to standardize the process. It was decided that sectioning and soldering the cast frameworks were not going to be included in this protocol. Sectioning and soldering would likely have improved the fit of the frameworks to their respective implant restorative interfaces, but it was felt that this would have introduced additional variables regarding the quality and characteristics of the rigid connectors in the frameworks. This paper does not deny the advantages associated with sectioning and soldering relative to improved accuracy in implant frameworks. The authors felt it introduced variables that detracted from the main focus of the study—determining the accuracy of casting versus CAD/CAM technology for implant frameworks. It should also be noted that the implant restorative platforms of the patient model were scanned by the tactile probe of the scanner. This is not possible clinically, as the tactile scanner does not have clinical applicability. There likely would be additional errors in scanning casts and transferring the results to clinical situations. The authors believe that the protocol used in this study was likely more accurate than otherwise would be possible with scanning master casts alone. This eliminated potential limitations normally associated with laboratory studies by evaluating the fit of the frameworks directly on the implants and not on implant analogs in master casts. The biologic effects, if any, of less than optimally fitting implant frameworks were not evaluated.

Conclusions

The CAD/CAM bars fabricated in the present study demonstrated better precision, with respect to the volumetric misfit values, and with statistically significant differences when compared to the cast bars fabricated in this study with a conventional lost-wax technique. The virtual volumetric measurements recorded in this study between cast and CAD/CAM bars were small. CAD/CAM bars should be considered as a viable alternative to cast bars for implant frameworks. Further laboratory and clinical studies are necessary to evaluate the degree of fit obtained with other implant systems, as well as the biologic tolerance for clinically acceptable implant frameworks.

Acknowledgments

The author acknowledges Biomet 3i for providing the CAD/CAM frameworks and implant components for this study; DSG Americus-Southeast (Clearwater, FL) Dental Lab for providing the alloy and for casting the frameworks; and 3M ESPE Dental Products, St. Paul, MN for providing the impression material.

References

1. Tan K, Rubenstein J, Nicholls J, et al: Three-dimensional analysis of the casting accuracy of one-piece, osseointegrated implant-retained prostheses. Int J Prosthodont 1993;6:346-363
2. Guichet D, Caputo A, Choi H, et al: Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. Int J Oral Maxillofac Implant 2000;15:239-246
3. Romero G, Engelmeier R, Powers J, et al: Accuracy of three corrective techniques for implant bar fabrication. J Prosthet Dent 2000;84:602-607
4. Binon P, Sutter F, Beaty K, et al: The role of screws in implant systems. Int J Oral Maxillofac Implants 1994;9(Suppl):48-63
5. 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
6. May K, Edge M, Lang B, et al: The Periotest method: implant-supported framework precision of fit evaluation. J Prosthodont 1996;5:206-213
7. Calderini A, Maiorana C, Garlini G, et al: A simplified method to assess precision of fit between framework and supporting implants: a preliminary study. Int J Oral Maxillofac Implants 2007;22:831-838

8. Jemt T: In vivo measurements of precision of fit involving implant-supported prostheses in the edentulous jaw. Int J Oral Maxillofac Implants 1996;11:151-158
9. Jemt T, Book K: Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11:620-625
10. Torsello F, di Torresanto VM, Ercoli C, et al: Evaluation of marginal precision of one-piece complete arch titanium frameworks fabricated with five different methods for implant-supported restorations. Clin Oral Impl Res 2008;19:772-779
11. Riedy SJ, Lang BR, Lang BE: Fit of implant frameworks fabricated by different techniques. J Prosthet Dent 1997;78:596-604
12. Jemt T, Back T, Petersson A: Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999;12:209-215
13. Ortorp A, Linden B, Jemt T: Clinical experiences of laser-welded titanium frameworks supported by implants in the edentulous mandible. A 5-year report. Int J Prosthodont 1999;12:65-72
14. Bergendal B, Palmqvist S: Laser-welded titanium framework for implant-supported fixed prostheses: a 5-year report. Int J Oral Maxillofac Implants 1999;14:69-71
15. Ortorp A, Jemt T, Back T, et al: Comparisons of precision of fit between cast and CNC-milled titanium implant frameworks for the edentulous mandible. Int J Prosthodont 2003;16:194-200
16. Ortorp A, Jemt T: Clinical experience of CNC-milled titanium frameworks supported by implants in the edentulous jaw: a 3-year interim report. Clin Implant Dent Relat Res 2002;4:104-109
17. Ortorp A, Jemt T: Clinical experiences of computer numeric control-milled titanium frameworks supported by implants in the edentulous jaw: a 5-year prospective study. Clin Implant Dent Relat Res 2004;6:199-209
18. Al-Fadda SA, Zarb GA, Finer Y: A comparison of the accuracy of fit of 2 methods for fabricating implant-prosthodontic frameworks. Int J Prosthodont 2007;20:125-131
19. Vigolo P, Fonzi F, Majzoub Z, et al: An evaluation of impression techniques for multiple internal connection implant prostheses. J Prosthet Dent 2004;92:470-476
20. Shehab AH, Pappas M, Burns DR, et al: Comparative tensile strengths of preceramic and postceramic solder connectors using high-palladium alloy. J Prosthet Dent 2005;93:148-152
21. Goolik A: Personal Communication, Biomedical Engineering Biomet 3i, Palm Beach Gardens, FL
22. Barry C, Oetter T, Lane M, et al: Keys to CAD/CAM in small shipyards. Presented at the 1998 SNAME Annual Meeting, June, 2004
23. Szalapaj P. 3D objects. In Szalapaj P (ed): CAD principles for architectural design: analytical approaches to computational representation of architectural form. London, Architectural Press, Reed Educational and Professional Publishing, 2001