Using stereophotogrammetric technology for obtaining intraoral digital impressions of implants

Guillermo Pradíes, Alberto Ferreiroa, Mutlu Özcan, Beatriz Giménez and Francisco Martínez-Rus

JADA 2014;145(4):338-344
10.14219/jada.2013.45

The following resources related to this article are available online at jada.ada.org (this information is current as of April 11, 2014):

Updated information and services including high-resolution figures, can be found in the online version of this article at:
http://jada.ada.org/content/145/4/338

This article cites **59 articles**, 1 of which can be accessed free:
http://jada.ada.org/content/145/4/338/#BIBL

Information about obtaining **reprints** of this article or about permission to reproduce this article in whole or in part can be found at: http://www.ada.org/990.aspx

Using stereophotogrammetric technology for obtaining intraoral digital impressions of implants

Guillermo Pradíes, DDS, PhD; Alberto Ferreiroa, DDS; Mutlu Özcan, DDS, DMD, PhD; Beatriz Giménez, DDS; Francisco Martínez-Rus, DDS, PhD

ABSTRACT

Background. The procedure for making impressions of multiple implants continues to be a challenge, despite the various techniques proposed to date. The authors' objective in this case report is to describe a novel digital impression method for multiple implants involving the use of stereophotogrammetric technology.

Case Descriptions. The authors present three cases of patients who had multiple implants in which the impressions were obtained with this technology. Initially, a stereo camera with an infrared flash detects the position of special flag abutments screwed into the implants. This process is based on registering the x, y and z coordinates of each implant and the distances between them. This information is converted into a stereolithographic (STL) file. To add the soft-tissue information, the user must obtain another STL file by using an intraoral or extraoral scanner. In the first case presented, this information was acquired from the plaster model with an extraoral scanner; in the second case, from a Digital Imaging and Communication in Medicine (DICOM) file of the plaster model obtained with cone-beam computed tomography; and in the third case, through an intraoral digital impression with a confocal scanner.

Results. In the three cases, the frameworks manufactured from this technique showed a correct clinical passive fit. At follow-up appointments held six, 12 and 24 months after insertion of the prosthesis, no complications were reported.

Conclusions. Stereophotogrammetric technology is a viable, accurate and easy technique for making multiple implant impressions.

Practical Implications. Clinicians can use stereophotogrammetric technology to acquire reliable digital master models as a first step in producing frameworks with a correct passive fit.

Key Words. Computer-aided design; computer-aided manufacturing; implant framework; implant impression technique; photogrammetry; stereophotogrammetry.

JADA 2014;145(4):338-344.

doi:10.14219/jada.2013.45

Restoration of dental implants remains one of the most challenging aspects of implant dentistry.[1] Although it is not clear whether prosthetic misfit could affect osseointegration,[2-4] mechanical complications of implant-supported prostheses can be avoided by achieving a good passive fit between the framework and the implants.[5-7] Passive fit is a difficult concept to define.[8] Commonly, it is accepted that passive fit relates to the gap between the implant or the abutment and the framework, but there is no agreement about the acceptable size of the gap, which usually ranges between 10 and 150 micrometers.[9,10] In short, passive fit is the minimum gap that permits a framework connection without causing strain.

To achieve a correct adaptation between the prosthesis and the implants, the first step is to obtain a highly accurate impression. Many clinical factors affect the accuracy of the impressions, such as tray type (for example, standard or customized, metal or disposable plastic), impression technique (whether one or two steps), impression material used and its particular hydrophobic or hydrophilic characteristics, mixing methods and impression disinfection.[11-21] Impressions can be made at either the implant level or the abutment level. In both

Dr. Pradíes is a professor and the chair, Department of Buccofacial Prostheses (Stomatology I), Faculty of Odontology, Complutense University of Madrid, Plaza de Ramón y Cajal, 3 Ciudad Universitaria 28040, Madrid, Spain, e-mail gpradies@odon.ucm.es. Address correspondence to Dr. Pradíes.

Dr. Ferreiroa is a lecturer, Department of Buccofacial Prostheses (Stomatology I), Faculty of Odontology, Complutense University of Madrid.

Dr. Özcan is a professor and the head, Dental Materials Unit, Center for Dental and Oral Medicine, Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, University of Zurich.

Dr. Giménez is a lecturer, Department of Buccofacial Prostheses (Stomatology I), Faculty of Odontology, Complutense University of Madrid.

Dr. Martínez-Rus is an associate professor, Department of Buccofacial Prostheses (Stomatology I), Faculty of Odontology, Complutense University of Madrid.

instances, there are basically three possible impression techniques: transfer, pickup and snap-on. Variations and combinations of all these techniques that are related to different impression materials or even splinted frameworks may yield changes in accuracy of the impressions.[15,22-28] According to the results of a systematic review,[24] elastomers are the recommended materials to be used for implant impressions. For situations in which the patient receives three or fewer implants, the results of studies showed no difference between the pickup and transfer techniques,[29,30] whereas for patients who required four or more implants, the results of other studies showed higher accuracy when the splinted pickup technique was used.[18,31] These impression techniques often are difficult, time consuming and inaccurate. In addition, patients can experience discomfort and even pain during any of these procedures.[32]

Since the introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) procedures in dentistry,[33] different approaches have been developed to obtain accurate digital impressions of implants. Two alternative methods of capturing data are available: digitizing the casts made from conventional impressions by scanning them in the dental laboratory (indirect data capturing) and performing intraoral scanning (direct data capturing).[34,35] In indirect data capturing, a conventional elastomeric impression is poured and the resulting model is digitized by means of an extraoral scanning device.[35] On some occasions, the digital file can even be obtained by scanning the impression, thus avoiding the need for cast fabrication.[36] The limitation of the indirect technique is that it involves intermediate steps that eventually may yield inaccuracies.

Direct data capturing involves the use of an intraoral scanner with digital photo or video technology to capture images created by the reflection of a laser light against the teeth and soft tissues in the mouth. During the last five years, dental manufacturers have released new intraoral scanning systems,[37-40] such as CEREC 3 (Sirona Dental Systems, Charlotte, N.C.), E4D (D4D Technologies, Richardson, Texas), iTero (Cadent, Carlstadt, N.J.), Lava COS (3M ESPE, St. Paul, Minn.), Trios (3Shape, Copenhagen, Denmark) and 3D Progress (MHT, Verona, Italy).

According to reports of in vitro and in vivo studies, this new generation of intraoral scanners seems to be capable of making accurate digital impressions of teeth,[38,40-42] but these scanners do not produce reliable impressions of multiple implants when they are distributed along the whole arch.[34] In addition to intraoral scanners, other devices have been developed that are based on stereophotogrammetric technology. Photogrammetry demonstrates a high level of accuracy in three dimensions (3-D) in other disciplines such as topography, naval engineering and car manufacturing. In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane can be determined by measuring the distance between them, if the scale of the image is known. Stereophotogrammetry, a more sophisticated alternative to photogrammetry, estimates the 3-D coordinates of points on an object, thus making the procedure quicker.[43] To our best knowledge, stereophotogrammetry has not been used intraorally in conjunction with digital impression techniques in dentistry.

Therefore, we undertook a study to introduce a new digital impression method that is based on stereophotogrammetric technology. In this article, we describe its use in three clinical situations; we also present how to obtain stereolithographic (STL) files of the implant positions and how to fabricate CAM milling frameworks on the basis of these files.

CASE REPORTS

Case 1. A 55-year-old woman with no medical problems was referred by the department of surgery to the prosthodontics department at the Complutense University of Madrid for prosthetic rehabilitation. Intraoral examination conducted by one of the authors (G.P.) showed six implants (4.1 × 12 millimeters) (Soft Tissue Level implants, Straumann, Basel, Switzerland) in the anterior mandible. A screw-retained, implant-supported prosthesis consisting of a titanium grade V framework was indicated. Before starting the treatment, the patient was informed about the procedure and signed an informed consent form that the university's ethics committee had approved. The laboratory technician milled the framework by using a CAM system and completed it by attaching acrylic resin teeth to the framework in a resin matrix. Two of the authors (A.F. and B.G.) used a stereophotogrammetry system combined with an extraoral scanner to obtain the digital master model.

First, two dentists (A.F., B.G.) screwed four healing abutments 4 mm in height (Straumann) into the implants, and they obtained alginate impressions of both maxilla and mandible. A laboratory technician then poured the impressions in plaster and scanned them extraorally (D 710 3D Scanner, 3Shape A/S), thus generating a first STL file. The technician obtained the second STL needed by using the photogrammetry system. This system consists of three elements:

- a laptop computer with CAD software (PIC Pro, Position Implants Correctly [PIC] Dental, Madrid) to manage the patient's personal data, to integrate its virtual library information with the STL obtained from patients and to design all types of frameworks;
- black flag-shaped abutments (PIC Abutment, PIC

ABBREVIATION KEY. CAD/CAM: Computer-aided design/computer-aided manufacturing. **CBCT:** Cone-beam computed tomography. **DICOM:** Digital Imaging and Communication in Medicine. **STL:** Stereolithographic. **3-D:** Three-dimensional.

Figure 1. Intraoral view of the Position Implants Correctly (PIC) (PIC Dental, Madrid) Abutments placed in the mandible in the patient in Case 1.

Figure 2. Extraoral stereophotogrammetry camera (Position Implants Correctly [PIC] Camera, PIC Dental, Madrid) at a distance of 20 centimeters from the patient's mouth in Case 1.

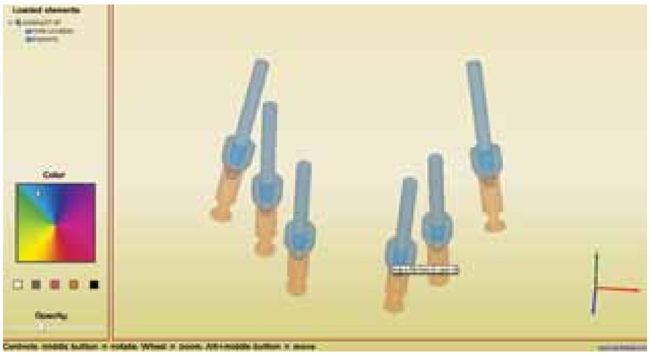

Figure 3. Position Implants Correctly (PIC) (PIC Dental, Madrid) file for the patient in Case 1, showing the angles and distances between implants. PIC files are part of PIC Pro software (PIC Dental, Madrid). Image reproduced with permission of PIC Dental.

Dental), each with four white spots that are positioned differently in each abutment for unique identification purposes (Figure 1);

- an extraoral stereo camera with an infrared flash (PIC Camera, PIC Dental) (Figure 2).

This photogrammetry device takes 64 pictures per second, with an error margin of less than 10 µm in less than 20 seconds. It identifies the spatial position of each implant without making physical contact. The 3-D data for each implant are depicted by the main vectors, just as are the different angles and distances between the rest of the implants. The final information then is stored in an STL file, called a PIC file (Figure 3).

The dentists (A.F., B.G.) began the procedure by recording the patient identification data and information regarding the type of implant and abutment to be used. The dentists then screwed six PIC Abutments into the abutments (synOcta, Straumann) and placed the PIC Camera about 20 centimeters away from the patient's mouth. In this case, four implants were close to each other, so the dentists decided to scan twice, screwing three PIC Abutments to the implants each time to facilitate the process. PIC Abutments do not have to be used in a specific buccal or lingual position. It also is not necessary to position the stereo camera in alignment with the abutment. In total, the complete procedure took approximately 4.5 minutes. Next, the dentists merged the information in the first STL file and the PIC File digitally (Figure 4) by using a best-fit algorithm. Basically, the software detects reference points that the STL files contain and fits the image obtained with the PIC camera with the digital geometry of this abutment. After that, the technician again merges this file with the file of the digital model of the soft tissues obtained from the plaster model, creating an accurate 3-D digital master model.

The laboratory technician determined the information about the spatial relationship between the maxilla and the mandible—and, therefore, the prosthetic space available—by using the previous scan and bite registration of the patient's provisional prostheses (Figure 5). The software allows the user to build a digital framework that works with the planned design. After finishing the design, the technician sent the file to the dental laboratory electronically. The technician used a computerized numerically controlled milling machine with five degrees of freedom (Hermle C20, Maschinenfabrik Berthold Hermle, Gosheim, Germany) to fabricate the titanium framework. Finally, he tested the passive fit of the framework by using the Sheffield test (one-screw test), the screw resistance test and the digital alternative pressure test (Figure 6).[44] In addition, he obtained an orthopantomograph. The dentists (A.F., B.G.) rated the passive fit between the framework and the implants highly. They noted no tension, misfit or lack of adaptation at the point at which the framework was screwed in. To set the resin teeth in the proper position, the laboratory technician obtained a physical master model in ultraviolet light–curable acrylic plastic polymethyl methacrylate by using a 3-D printer (VisiJet Stoneplast, ProJet 3510, 3D System, Darmstadt, Germany). After the patient provided esthetic approval during the try-in appointment, the technician finished the prosthesis and one of the dentists (A.F.) screwed it into the patient's mouth. The other dentist (B.G.) performed follow-ups three, six, 12 and 24 months after the insertion of the prosthesis. No screw loosening or any other mechanical and biological problems were noted.

Case 2. A 55-year-old man with no medical problems presented himself for prosthetic rehabilitation of four implants (Swiss Plus implant system 3.7 mm × 12 mm, Zimmer Dental, Carlsbad, Calif.). The clinician (G.P.) used photogrammetry to obtain a 3-D STL file (PIC file) of the implants (Figure 7); during the same visit, a dental technician made an alginate impression with the healing abutments in position and poured it in plaster. The complete impression procedure took approximately 15 minutes. He obtained a second STL file of the plaster model by using an extraoral scanner (D710 3D Scanner, 3Shape). After merging both STL files by using the best-fit function in the PIC Pro software, the dental technician obtained a virtual master model.

A laboratory technician made the virtual design of the framework for Case 2 in a different way than in the procedure described for Case 1. The dentist (G.P.) scanned the provisional removable prosthesis by means of cone-beam computed tomography (CBCT), and he incorporated the Digital Imaging and Communication in Medicine (DICOM) file as a virtual mock-up into the previously merged STL files. This allowed the laboratory technician to create the framework without the need to make a denture base. After the technician designed the framework, he used a milling strategy identical to that used in Case 1. Two operators (G.P., A.F.) observed a passive fit during the systematic clinical testing of the framework. Similar to Case 1, neither digital pressure, the Sheffield test nor the screw resistance test detected any strain, misfit or problems while the operators (G.P., A.F.) passively screwed the framework into the implants. The laboratory technician printed a physical master model by using the same technology as used in the first case. After processing the final prosthesis with the resin teeth and resin matrix, one of the dentists (G.P.) screwed the framework into the implants with a torque wrench at 30 newtons per square centimeter.

One of the dentists (G.P.) performed follow-up evaluations at three, six, 12 and 24 months after the insertion of the prosthesis. He noted no screw loosening or any other mechanical and biological problems.

Case 3. A 36-year-old man with no medical problems was referred to the prosthodontics department from the oral surgery department at Complutense University for prosthetic rehabilitation. Intraoral examination showed eight tissue-level implants in the maxilla and six implants in the mandible (Soft Tissue Level I implants, Straumann). The patient requested a fixed rehabilitation option.

As in cases 1 and 2, initially, a dentist (M.Ö.) screwed the flag abutments into the abutments and, by using the extraoral stereoscopic camera, obtained the first STL file (the PIC file). It is important to note that the PIC Pro software allows the patient to move his or her head during the impression procedure without affecting the scanning process. If any changes occur in the position of the flag abutments, the software detects them and alerts the operator. The system will interrupt the process so as to avoid producing inaccurate 3-D information; this feature guarantees that only accurate files will be processed. In fact, in this case, during the scanning process the patient moved one of the flags slightly with his tongue, and the software issued a warning that allowed us to restart the process of obtaining the first STL file.

In this clinical case, instead of making an alginate impression to register the topography of the patient's mouth, we used an intraoral scanner (3D Progress, Medical High Technologies, Verona, Italy) (Figure 8). This intraoral scanner is an open-system device with STL output. It takes 14 scans per second and uses confo-

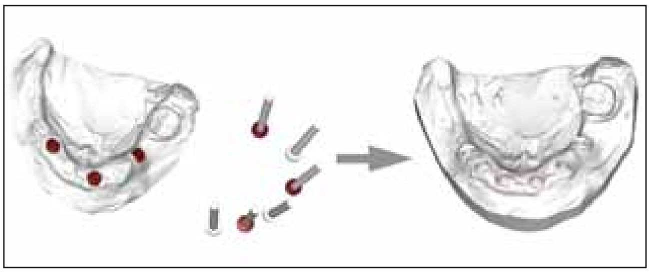

Figure 4. Case 1: best fit of the file with the three-dimensional spatial position of the implants and the stereolithographic file. The soft-tissue information was obtained by means of an alginate impression and the plaster model was digitized by means of an extraoral scan. (An intraoral digital scanner also can be used to digitize the information.)

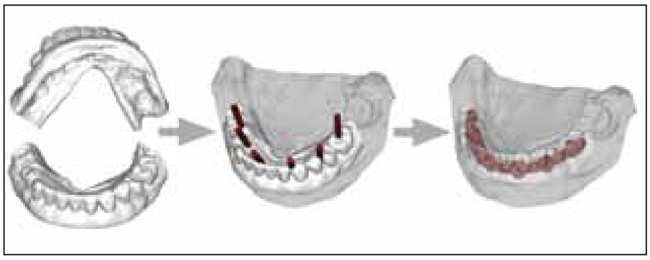

Figure 5. Stereolithographic (STL) file of the provisional prosthesis for the patient in Case 1. The STL file can enable clinicians to determine the prosthetic space and to complete the computer-aided design of the framework.

Figure 6. Verification of the passive fit through Sheffield test of the framework for the patient in Case 1 obtained by means of the photogrammetry technique.

Figure 7. Case 2: screenshot of images obtained with the extraoral stereophotogrammetry camera. The bars on the bottom left of the image indicate the progress of the registration of each implant; if some of the bar is not complete, the system issues a warning. Image reproduced with permission of Position Implants Correctly (PIC) Dental, Madrid.

Figure 8. Case 3: intraoral digital impression of the soft tissues obtained with an intraoral scanner that uses confocal technology.

cal technology without powder. Again, once the final merged file was obtained, a laboratory technician designed and milled the framework. He then used a stereolithographic master model and denture base to register the occlusal relationship and process the final prosthesis.

As described previously for cases 1 and 2, two operators (G.P., M.Ö.) carried out clinical passive fit tests. They performed follow-up evaluations at three, six and 12 months after insertion of the prosthesis. They noted no screw loosening or any other mechanical and biological problems.

DISCUSSION

In implant therapies, obtaining precise frameworks is of great importance,[1-6] and it requires making reliable impressions. In the case series presented here, we successfully created accurate CAM frameworks by using an intraoral stereophotogrammetry system that allowed us to obtain the exact 3-D position of the dental implants.

Making frameworks by using indirect CAD/CAM technology requires making a master plaster model that later is digitized by means of an extraoral scanner.[45-47] To digitize implant models via this technology, special abutments called "scanbodies" are required. Scanbodies have been shown to have limitations.[47] Moreover, the indirect implant scanning technique has to deal with systematic inaccuracies generated at each step related to the impression materials used, the impression technique (such as the pickup technique and the transfer technique), the plaster model and scanning process. In fact, the direct scanning techniques for teeth were developed to overcome the limitations of indirect scanning. Results of scientific studies of the latest generation of intraoral scanners seem to demonstrate comparable accuracy with conventional impression techniques for single crowns.[41,49,50] To scan implants intraorally, it still is necessary to use scanbodies, which need to have a specific geometric design and reflection characteristics to obtain an accurate impression. Although scanbodies have been used in indirect scanning for years, their use in intraoral scanning is practically unknown. Commercial intraoral scanbodies for different implants are available, but no clinical studies of them other than case reports are available.

Researchers found in a 2012 study that a conventional impression and white-light scanning of stone casts resulted in a more accurate fit of implant-supported prostheses than did scanning scanbodies intraorally.[48] In another study, a digitally coded healing abutment (Bellatek Encode Impression System, Biomet 3*i*, Palm Beach Gardens, Fla.) was proposed as an alternative solution to the direct and indirect implant scanning techniques.[1] In this system, an encoded abutment is screwed into the implant, an alginate impression is made and the plaster print left by the abutment is scanned directly and interpreted digitally by the CAD/CAM system. So far, this technique has been tested in vivo for single implants and in vitro for six implants.[1,51] In summary, although the technical features of the intraoral scanner system are being developed quickly, apart from experimental protocols,[52] it is not possible to obtain an accurate impression of more than three or four implants over the complete arch of the maxilla or mandible by using an intraoral scanning device.

Photogrammetry is a well known and reliable technique used in various fields that was introduced to dentistry by Lie and Jemt[53] in 1994 to analyze the distortion of implant frameworks. To date, the technique has been used in laboratory studies to measure implant positions and fit of prostheses as well as framework deformations and mucosal recession.[54-57] Jemt[55] demonstrated in 1996 that under laboratory conditions, the 3-D precision of implant center-point measurements with this technique was on average 12 µm. 3-D information also could be linked to a computer for further analysis and verification.[54,58] Photogrammetry also was proposed for 3-D modeling of a patient's face and tooth arches, occlusion registration, and treatment planning and documentation.[59] Yet, the technique never was proposed and even was suggested to be infeasible for intraoral digital impressions.[54]

In our case series, a stereophotogrammetry device was used for the first time, to our knowledge, for obtaining impressions of implants. In all cases, at least four implants were involved. The photogrammetry system in our study differs in some critical aspects from the intraoral scanning techniques currently in use. Intraoral scanners can obtain an STL file with all the mouth topography (that is, teeth and soft tissues), but these scanners define every new 3-D point captured without a fixed reference to the rest of the points of the resulting STL file. The amount of stitching involved in the scanning process produces an STL file that contains a number of systematic mistakes. In contrast, the photogrammetry system generates information from x, y and z points with a fixed relation to the rest of the points so the data are interrelated and cannot be separated. The STL file that is generated in this way contains information about the exact position of all the implants, but it does not contain information about the rest of the mouth's topography (that is, existing teeth or soft tissues). Therefore, it is necessary to obtain a second STL file by using an intraoral or extraoral scanner or even CBCT. The need for obtaining a second file can be interpreted as a disadvantage or a limitation of this photogrammetry system.

In Cases 1 and 2 presented in this article, we obtained the PIC file and the second STL file by using an extraoral scanner. We obtained the files from alginate impressions with conventional healing abutments. In both cases, the procedure was simple, comfortable for the patient and less time consuming than the conventional pickup splinted technique. In Case 3, we obtained the second STL file by using an intraoral scanner. To ensure the accuracy of the framework obtained using the photogrammetry system, we tested passive fit. Completing this step is regarded as crucial to prevent biological and mechanical complications.[5-7]

Passive fit can be assessed either clinically or in the laboratory.[60] Our aim was to test the accuracy of the frameworks clinically, so we applied the standard tests. It has to be emphasized that clinical methods for detecting passive fit of implant frameworks—such as digital pressure, visual inspection and radiographs—are not perfectly effective in identifying slight inaccuracies. Even the Sheffield test and screw resistance test have limited accuracy.[61] Frameworks that are clinically acceptable can exhibit a degree of misfit, so conclusions based on clinical methods have to be considered with caution. Nevertheless, the lack of any mechanical complications noted within one to two years of follow up of the patients featured in this case series suggests an accurate passive fit to some extent.

CONCLUSIONS

In this case series, the use of an intraoral stereophotogrammetry system allowed us to locate the precise 3-D position of implants to create an accurate CAD/CAM framework, providing accurate passive fit and minimizing the possibility of posttreatment complications. In addition, it is a procedure that can be done quickly and is considered to be more comfortable for patients and easier for the operators than are other conventional or digital impression methods. However, the method still requires a second STL file to provide the soft-tissue information and the use of special equipment. ■

Disclosure. None of the authors reported any disclosures.

The authors acknowledge Fresdental (Alicante, Spain) and Z-tech (Madrid) for fabricating the frameworks used in the cases described in this article.

1. Kapos T, Ashy LM, Gallucci GO, Weber HP, Wismeijer D. Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. Int J Oral Maxillofac Implants 2009;24(suppl):110-117.
2. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac 1996;11(5):620-625.
3. Smedberg JI, Nilner K, Rangert B, Svensson SA, Glantz SA. On the influence of superstructure connection on implant preload: a methodological and clinical study. Clin Oral Implants Res 1996;7(1):55-63.
4. Jemt T, Lekholm U. Measurements of bone and frame-work deformations induced by misfit of implant superstructures: a pilot study in rabbits. Clin Oral Implants Res 1998;9(4):272-280.
5. Schwarz MS. Mechanical complications of dental implants. Clin Oral Implants Res 2000;11(suppl 1):156-158.
6. Sahin S, Cehreli MC. The significance of passive framework fit in implant prosthodontics: current status. Implant Dent 2001;10(2):85-92.
7. Abduo J, Lyons K, Bennani V, Waddell N, Swain M. Fit of screw-retained fixed implant frameworks fabricated by different methods: a systematic review. Int J Prosthodont 2011;24(3):207-220.
8. Abduo J, Bennani V, Waddell N, Lyons K, Swain M. Assessing the fit of implant fixed prostheses: a critical review. Int J Oral Maxillofac Implants 2010;25(3):506-515.
9. Brånemark PI. Osseointegration and its experimental background. J Prosthet Dent 1983;50(3):399-410.
10. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6(3):270-276.
11. Bartlett DW, Greenwood R, Howe L. The suitability of head-of-implant and conventional abutment impression techniques for implant-retained three unit bridges: an in vitro study. Eur J Prosthodont Restor Dent 2002;10(4):163-166.
12. De La Cruz JE, Funkenbusch PD, Ercoli C, Moss ME, Graser GN, Tallents RH. Verification jig for implant-supported prostheses: a comparison of standard impressions with verification jigs made of different materials. J Prosthet Dent 2002;88(3):329-336.
13. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. An evaluation of impression techniques for multiple internal connection implant prostheses. J Prosthet Dent 2004;92(5):470-476.
14. Akca K, Cehreli MC. Accuracy of 2 impression techniques for ITI implants. Int J Oral Maxillofac Implants 2004;19(4):517-523.
15. Naconecy MM, Teixeira ER, Shinkai RS, Frasca LC, Cervieri A. Evaluation of the accuracy of 3 transfer techniques for implant-supported prostheses with multiple abutments. Int J Oral Maxillofac Implants 2004;19(2):192-198.
16. Vigolo P, Majzoub Z, Cordioli G. Evaluation of the accuracy of three techniques used for multiple implant abutment impressions. J Prosthet Dent 2003;89(2):186-192.
17. Wenz HJ, Hertrampf K. Accuracy of impressions and casts using different implant impression techniques in a multi-implant system with an

internal hex connection. Int J Oral Maxillofac Implants 2008;23(1):39-47.
18. Lee Y, Heo SJ, Koak JY, Kim SK. Accuracy of different impression techniques for internal-connection implants. Int J Oral Maxillofac Implants 2009;24(5):823-830.
19. Browne V, Flewelling M, Wierenga M, et al. Sterilization analysis of contaminated healing abutments and impression copings. J Calif Dent Assoc 2012;40(5):419-421.
20. Raviv E, Hana J, Raviv R, Harel-Raviv M. A clinical report on the use of closed tray, hex-lock-friction-fit implant impression copings (published online ahead of print April 17, 2012). J Oral Implantol. doi:10.1563/AAID-JOI-D-11-00056.1.
21. Tarib NA, Seong TW, Chuen KM, Kun MS, Ahmad M, Kamarudin KH. Evaluation of splinting implant impression techniques: two dimensional analyses. Eur J Prosthodont Restor Dent 2012;20(1):35-39.
22. Phillips K, Nicholls J, Ma T, Rubenstein J. The accuracy of three implant impression techniques: a three-dimensional analysis. Int J Oral Maxillofac Implants 1994;9(5):533-540.
23. Spector MR, Donovan TE, Nicholls JI. An evaluation of impression techniques for osseointegrated implants. J Prosthet Dent 1990;63(4):444-447.
24. Hsu CC, Millstein PL, Stein RS. A comparative analysis of the accuracy of implant transfer techniques. J Prosthet Dent 1993;69(6):588-593.
25. Inturregui JA, Aquilino SA, Ryther JS, Lund PS. Evaluation of three impression techniques for osseointegrated oral implants. J Prosthet Dent 1993;69(5):503-509.
26. Assif D, Nissan J, Varsano I, Singer A. Accuracy of implant impression splinted techniques: effect of splinting material. Int J Oral Maxillofac Implants 1999;14(6):885-888.
27. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100(4):285-291.
28. Lee YJ, Heo SJ, Koak JY, Kim SK. Accuracy of different impression techniques for internal-connection implants. Int J Oral Maxillofac Implants 2009;24(5):823-830.
29. Howell KJ, McGlumphy EA, Drago C, Knapik G. Comparison of the accuracy of Biomet 3i Encode Robocast Technology and conventional implant impression techniques. Int J Oral Maxillofac Implants 2013;28(1):228-240.
30. Gallucci GO, Papaspyridakos P, Ashy LM, Kim GE, Brady NJ, Weber HP. Clinical accuracy outcomes of closed-tray and open-tray implant impression techniques for partially edentulous patients. Int J Prosthodont 2011;24(5):469-472.
31. Stimmelmayr M, Güth JF, Erdelt K, Happe A, Schlee M, Beuer F. Clinical study evaluating the discrepancy of two different impression techniques of four implants in an edentulous jaw. Clin Oral Investig 2013;17(8):1929-1935.
32. Güth JF, Keul C, Stimmelmayr M, Beuer F, Edelhoff D. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig 2013;17(4):1201-1208.
33. Mörmann WH, Brandestini M, Lutz F. The Cerec system: computer-assisted preparation of direct ceramic inlays in 1 setting (in German). Quintessenz 1987;38(3):457-470.
34. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204(9):505-511.
35. Eliasson A, Ortorp A. The accuracy of an implant impression technique using digitally coded healing abutments. Clin Implant Dent Relat Res 2012;14(suppl 1):e30-e38.
36. Quaas S, Rudolph H, Luthardt RG. Direct mechanical data acquisition of dental impressions for the manufacturing of CAD/CAM restorations. J Dent 2007;35(12):903-908.
37. Garg AK. Cadent iTero's digital system for dental impressions: the end of trays and putty? Dent Implantol Update 2008;19(1):1-4.
38. Kachalia PR, Geissberger MJ. Dentistry a la carte: in-office CAD/CAM technology. J Calif Dent Assoc 2010;38(5):323-330.
39. Wiedhahn K. The impression-free Cerec multilayer bridge with the CAD-on method (in English, German). Int J Comput Dent 2011;14(1):33-45.
40. Mehl A, Ender A, Mörmann W, Attin T. Accuracy testing of a new intraoral 3D camera (in English, German). Int J Comput Dent 2009;12(1):11-28.
41. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38(7):553-559.
42. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res 2013;24(1):111-115.
43. Mikhail EM, Bethel JS, McGlone JC. Introduction to Modern Photogrammetry. New York: Wiley; 2001:473.
44. Ercoli C, Geminiani A, Feng C, Lee H. The influence of verification jig on framework fit for nonsegmented fixed implant-supported complete denture. Clin Implant Dent Relat Res 2012;14(suppl 1):e188-e195.
45. Chan DC, Chung AK, Haines J, Yau EH, Kuo CC. The accuracy of optical scanning: influence of convergence and die preparation. Oper Dent 2011;36(5):486-491.
46. Vlaar ST, van der Zel JM. Accuracy of dental digitizers. Int Dent J 2006;56(5):301-309.
47. Nouri M, Massudi R, Bagheban AA, Azimi S, Fereidooni F. The accuracy of a 3-D laser scanner for crown width measurements. Aust Orthod J 2009;25(1):41-47.
48. Stimmelmayr M, Güth JF, Erdelt K, Edelhoff D, Beuer F. Digital evaluation of the reproducibility of implant scanbody fit: an in vitro study. Clin Oral Investig 2012;16(3):851-856.
49. Ender A, Mehl A. Full arch scans: conventional versus digital impressions—an in-vitro study. Int J Comput Dent 2011;14(1):11-21.
50. Scotti R, Cardelli P, Baldissara P, Monaco C. Clinical fitting of CAD/CAM zirconia single crowns generated from digital intraoral impressions based on active wavefront sampling (published online ahead of print Oct. 17, 2011). J Dent 2011.
51. Giménez B, Ozcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth (published online ahead of print July 24, 2013). Clin Implant Dent Relat Res 2013. doi:10.1111/cid.12124.
52. Moreno A, Giménez B, Ozcan M, Pradíes G. A clinical protocol for intraoral digital impression of screw-retained CAD/CAM framework on multiple implants based on wavefront sampling technology. Implant Dent 2013;22(4):320-325.
53. Lie A, Jemt T. Photogrammetric measurements of implant positions: description of a technique to determine the fit between implants and superstructures. Clin Oral Implants Res 1994;5(1):30-36.
54. Jemt T, Lie A. Accuracy of implant-supported prostheses in the edentulous jaw: analysis of precision of fit between cast gold-alloy frameworks and master casts by means of a three-dimensional photogrammetric technique. Clin Oral Implants Res 1995;6(3):172-180.
55. Jemt T. In vivo measurements of precision of fit involving implant-supported prostheses in the edentulous jaw. Int J Oral Maxillofac Implants 1996;11(2):151-158.
56. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11(5):620-625.
57. Jemt T, Bäck T, Petersson A. Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999;12(3):209-215.
58. Jemt T, Bäck T, Petersson A. Photogrammetry: an alternative to conventional impressions in implant dentistry? A clinical pilot study. Int J Prosthodont 1999;12(4):363-368.
59. Waters K, Terzopoulos D. The computer synthesis of expressive faces. Philos Trans R Soc Lond B Biol Sci 1992;335(1273):87-93.
60. Ortorp A, Jemt T, Bäck T. Photogrammetry and conventional impressions for recording implant positions: a comparative laboratory study. Clin Implant Dent Relat Res 2005;7(1):43-50.
61. Mulcahy C, Sherriff M, Walter JD, Fenlon MR. Measurement of misfit at the implant-prosthesis interface: an experimental method using a coordinate measuring machine. Int J Oral Maxillofac Implants 2000;15(1):111-118.