Use of an Intraoral Laser Scanner During the Prosthetic Phase of Implant Dentistry: A Pilot Study

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The accuracy of a digital impression technique to fabricate the implant restoration and abutment for a dental implant using an intraoral laser scanner was evaluated in 36 patients who were missing a single posterior tooth in either the mandible or maxilla that was restored with a single implant. The spatial position of each integrated implant, including the surrounding anatomic hard and soft tissues of adjacent structures, was captured utilizing a special scanning abutment with an intraoral laser scanner. Data from the scanning protocol was then delivered via the Internet in the form of an STL file to the manufacturing site for the production of a custom computer-aided design abutment and crown. All 36 restorations and abutments were delivered to the patients and evaluated for marginal integrity, interproximal contact points, and occlusion. Of the 36 patients, 6 required contact adjustments, 7 required occlusal adjustments, and 3 required a gingivectomy around the implant to completely seat the restoration. Chair time for adjustments did not exceed 15 minutes. The findings suggest that an intraoral laser scanner can be used with confidence to obtain consistent and accurate digital impressions to fabricate custom restorations and abutments for dental implants.

Key Words: accuracy, laser scanner, optical impressions, digital impressions, CAD/CAM abutments and crowns

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Introduction

Dental implants have become an accepted and routine treatment alternative for patients who are missing teeth. Proper diagnosis of the potential implant receptor site has been greatly enhanced by the evolution and acceptance of three dimensional imaging technology, such as computerized tomography (CT) and lower radiation cone beam CT (CBCT) which provides clinicians with an accurate assessment of each patient's osseous anatomy. The precision of implant placement provided by integrating CBCT imaging and three dimensional (3D) interactive treatment planning software and various applications of guided surgery increases the probability that an implant restorative dentist will fabricate an ideal restoration.

Traditionally, the restorative process has required the use of fixture-level or abutment-level transfer posts to transfer the intraoral position of the dental implant to a working stone or epoxy cast for a dental laboratory technician to fabricate the definitive restoration. Transfer components were designed to be used with conventional dental impression materials and intraoral trays. With this method, discrepancies may result because of distortion of the impression materials, improper seating, or rotation of the components. Such discrepancies can result in a misfit of the abutment, the final restoration, or both. Therefore, the excellence and marginal fit of the definitive restoration is dependent upon the accuracy of the dental impression and interocclusal records. In addition, traditional laboratory procedures to fabricate custom abutments and restorations for dental implants have until recently been limited to the lost-wax casting technology.

During the prosthetic phase of implant dentistry, the goal is to fabricate an accurate, high-quality restoration and abutment with a proper emergence profile, anatomic contour, occlusion, and esthetic appeal. Therefore, the impression material must capture the details of the abutment margin, including the gingival anatomy and adjacent and opposing dentition.[1,2] Other properties that are of importance to the clinician are sufficient working and setting time, hydrophilicity, wettability, tear strength, and elastic recovery.[1–3] However, the traditional impression technique and dental impression materials may not be as accurate when used with metal or ceramic abutment materials.[4,5]

With traditional laboratory procedures, the dental laboratory technician must pour a stone or epoxy working model to fabricate the implant restoration and abutment. The lost-wax technique developed in 1907 is still currently used in many dental laboratories.[6] Inaccuracies with this technique include instability of the stone material, wax, casting investment, and alloy material. The result of such inaccuracy is a poor-fitting restoration and abutment.[5–10] To overcome these problems,

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digital impression scanning devices and computer-aided design/computer-aided manufacturing (CAD/CAM) technology has been introduced to the dental community that offers alternatives to the traditional intraoral impression and laboratory techniques.[7,8,11,12]

In restorative dentistry, intraoral scanning acquisition devices have been used for the past 25 years since Duret and Preston[13] and Mormann and colleagues[14] originally pioneered dental CAD/CAM systems in the early 1970s. This was followed by the development of the CEREC system (Sirona, Salzburg, Austria), which succeeded in producing in-office ceramic restorations using CAD/CAM technology.[15] The introduction of CAD/CAM technology and intraoral scanning devices has enabled clinicians to obtain accurate digital records of the teeth and surrounding hard and soft tissue structures of the oral cavity. Currently, dentists may use one of several commercially available intraoral scanners to obtain digital impressions, including CADENT iTero (Align Technology Inc, San Jose, Calif), CEREC, E4D (D4D Technologies, Richardson, Tex), TRIOS (3 Shape, New Providence, NJ), LAVA Chairside Oral Scanner (3M ESPE, St Paul, Minn); and IOS FastScan (IOS Technologies, San Diego, Calif). With their in-office milling units, CEREC and E4D have the ability to fabricate a definitive restoration in a single office visit without the use of traditional dental elastomeric impression materials.

Triangulation of light technology

The first dental intraoral digital scanning system (CEREC) with an in-office ceramic block milling unit was based on the concept of triangulation of light, where the intersection of the light of 3 linear beams is used to locate a defined point in 3D space.[12–17] Surfaces that do not disperse light evenly, such as enamel and amalgam, or curved, noncontinuous surfaces, affect the accuracy of the triangulation scan with this technology.[17] Therefore, the use of a reflective coating or opaque powder to create a uniform light dispersion has been advocated for use during the scanning process.[18]

Parallel confocal imaging technology

CADENT iTero is a free-standing digital scanning system that provides clinicians with an accurate alternative to conventional dental impression techniques without the requirement of an in-office restoration milling unit. The refined digital system, which was first introduced in orthodontics to scan conventionally poured stone models for orthodontic applications, was then applied to conventional prosthodontics.[19,20] Using the concept of parallel confocal imaging technology used in microscopy, the iTero scanning device projects 100 000 points of red parallel laser light, which converts the reflected light into digital data.[21,22] Only objects at a focal depth of 50 μm or less are capable of reflecting light through a small filtering device. The beams of the red laser light act as optical probes when they contact the surfaces of an object and are able to record the anatomic surface details by detecting the confocal points.

The advantage of this leading-edge technology is that it is able to capture details of different surface anatomy to within 15 μm without using a reflective surface powder in the oral cavity. This property allows a clinician to place the disposable wand sheath directly on the object (tooth or abutment scanning device), which increases stability and decreases the need to rescan the patient. Various dental materials, such as enamel, gold, amalgam, and resins, can be detected and recorded with equal accuracy.

Use of such advanced technology produces an accurate 3D image of the object being scanned in virtual real time. The clinician is able to view the 3D replica once the scanning procedure is complete. The goal of this clinical pilot study was to evaluate the practical use, work flow, and technique of intraoral laser scanning to capture the position of single-tooth dental implants and the adjacent anatomic structures to fabricate custom restorations and abutments utilizing CAD/CAM technology. To complete this study, the CADENT iTero intraoral laser scanner was used to capture the digital data of 36 dental implants in the mandible and maxilla.

Integrated digital imaging and office work flow

The iTero intraoral laser scanner consists of a mobile cart on wheels that can be moved to different operatories (http://www.cadentitero.com). The handheld laser scanner (wand) releases a light stream of compressed air during the scanning procedure to prevent fogging of the lens that is attached to a proprietary data cable. The data cable is attached to a computer with a liquid crystal display monitor that processes the electronic information. The entire digital scanning process is controlled by a wireless keyboard, mouse, foot pedal, and analytical instruments that are proprietary to the manufacturer.

Before initiating the prosthetic phase of treatment, the bone level around each of the implants was evaluated with a periapical radiograph. During the second stage of surgery, the dental implant was exposed, and a transmucosal healing collar was placed on the implant to allow for soft tissue healing for a period of 2–3 weeks. With completion of the soft tissue healing period, the traditional fixture-level impression coping was substituted with a specialized implant scanning abutment (ISA; 5 Axis, Toronto, Canada) that is specific to the implant manufacturer. The ISA transfers the intraoral 3D position of the implant to the virtual digital cast through a registration process of the specific shape geometry and anatomic surface facets. The ISA allows for an accurate digital impression and provides information to the dental laboratory regarding implant platform diameter, position of the implant, and desired emergence profile. This digital impression technique also eliminates the prosthetic laboratory analog that is used in combination with the traditional dental impression and resultant master cast.

The clinical work flow starts with scanning the ISA and adjacent teeth to obtain the required surface anatomy (Figure 1). To ensure proper vertical dimension and occlusal relations, the opposing dentition is also scanned with the patient placed in maximal intercusspation. This eliminates the need to obtain the traditional bite registration for fixed prosthetic cases, reducing chair time and cost of materials. Once the arches are digitally scanned, the ISA is removed as the scanning abutment might be too high and might interfere with obtaining the bite registration of the maxillary and mandibular teeth in complete intercuspation. When obtaining the bite registration, it is extremely important that the patient is instructed to clench

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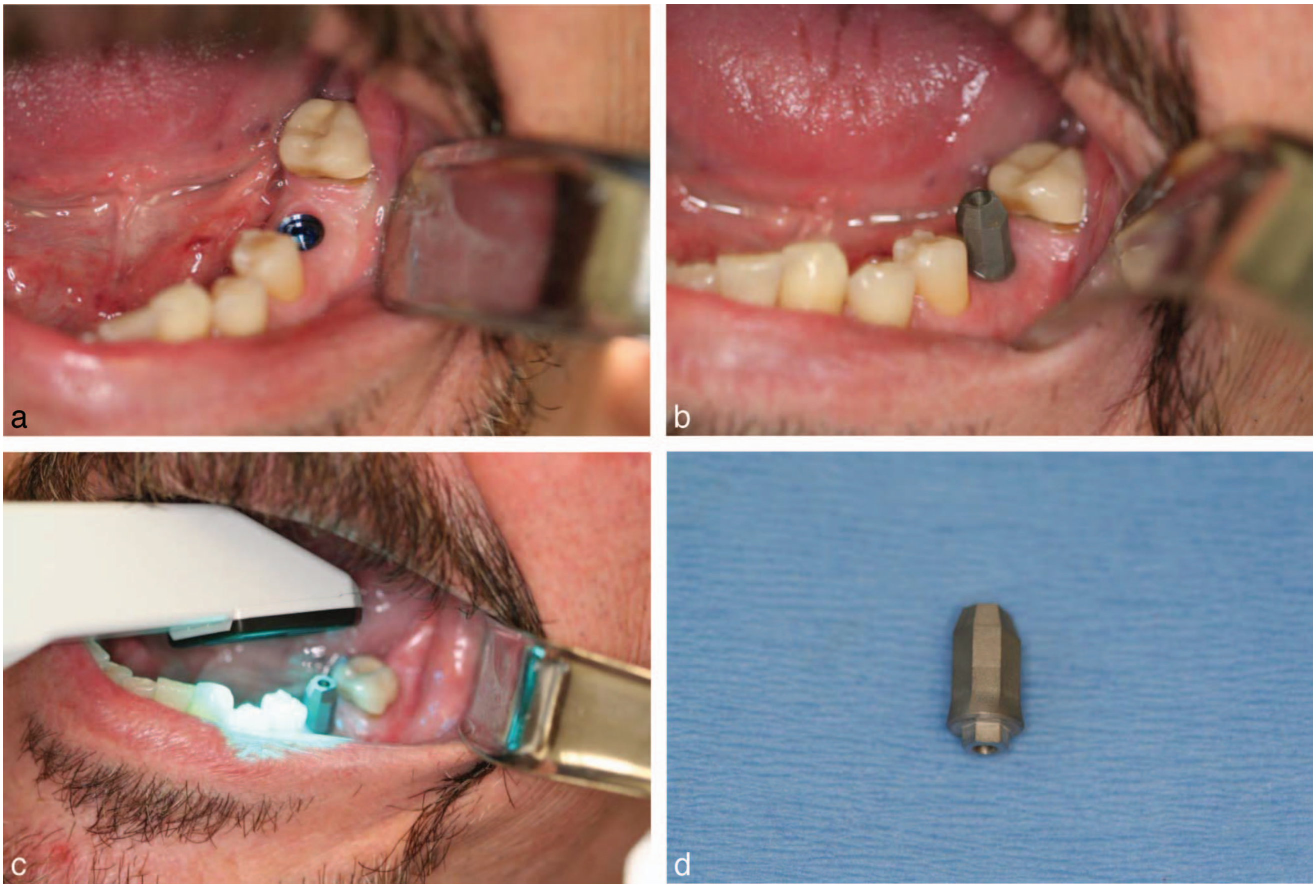

Figure 1. Digital impression obtained using a 5 Axis implant scanning abutment attached to a dental implant and scanned using an intraoral laser scanner. (a) BioHorizons Laser Lok dental implant without scanning abutment. (b) BioHorizons Laser Lok specific scanning abutment attached to dental implant. (c) Use of iTero intraoral optical laser scanner to scan implant scanning abutment. (d) 5 Axis dental implant scanning abutment.

his or her teeth in the maximum intercuspation position (MIP). This allows the natural teeth to be slightly depressed into the periodontal ligament in the alveolus of the jaw. This technique allows fabrication of a restoration that is in infraocclusion or slightly out of occlusion to avoid a restoration that is supraocclusal, which might result in undesirable premature occlusal contacts with the opposing dentition.[24]

During the scanning procedure of the ISA, the surrounding soft tissues, adjacent teeth and opposing dentition can be viewed with real-time images on the incorporated light-emitting diode screen. With the aid of visual and audible prompts, the operator can make the necessary adjustments to obtain an accurate intraoral digital impression in virtual real time. The computer software automatically stitches together the multiple, overlapping pictures in a transparent process known as "real-time modeling" to obtain the opposing arches in the MIP.

With each scan, the software captures 100 000 points of laser optical reference points to construct the 3D object being scanned.[20–22] Once the satisfactory digital impression is obtained, the STL file is electronically sent to an Align Technology, Inc, partner laboratory through the Internet using the proprietary computer software. The restorative driven software focuses on material (Figure 2).

Materials and Methods

Inclusion criteria to participate in this study were the need to replace a single posterior maxillary or mandibular restoration as well as the presence of adjacent teeth to allow for contact development and an opposing dentition. Digital impressions of the implant were obtained using the ISA and the iTero intraoral scanner with the Align Technology, Inc, software. Informed consent was obtained from all patients who agreed to participate in this clinical study.

An electronic laboratory prescription was completed by the dentist, which included patient information and the type of restoration to be fabricated. The electronic data from the digital impression was produced in the form of an open architecture STL file of the ISA, including the surrounding anatomic hard and soft tissues. This file was then sent electronically via the Internet to the participating dental laboratory. The laboratory completed the virtual CAD model and uploaded the design of the restoration and abutment for processing (Figure 3). The stereolithographic model and removable dies were then fabricated for completion of the restoration and abutment. Software parameters to fabricate the custom restoration and abutment were contours of the crown, emergence profile,

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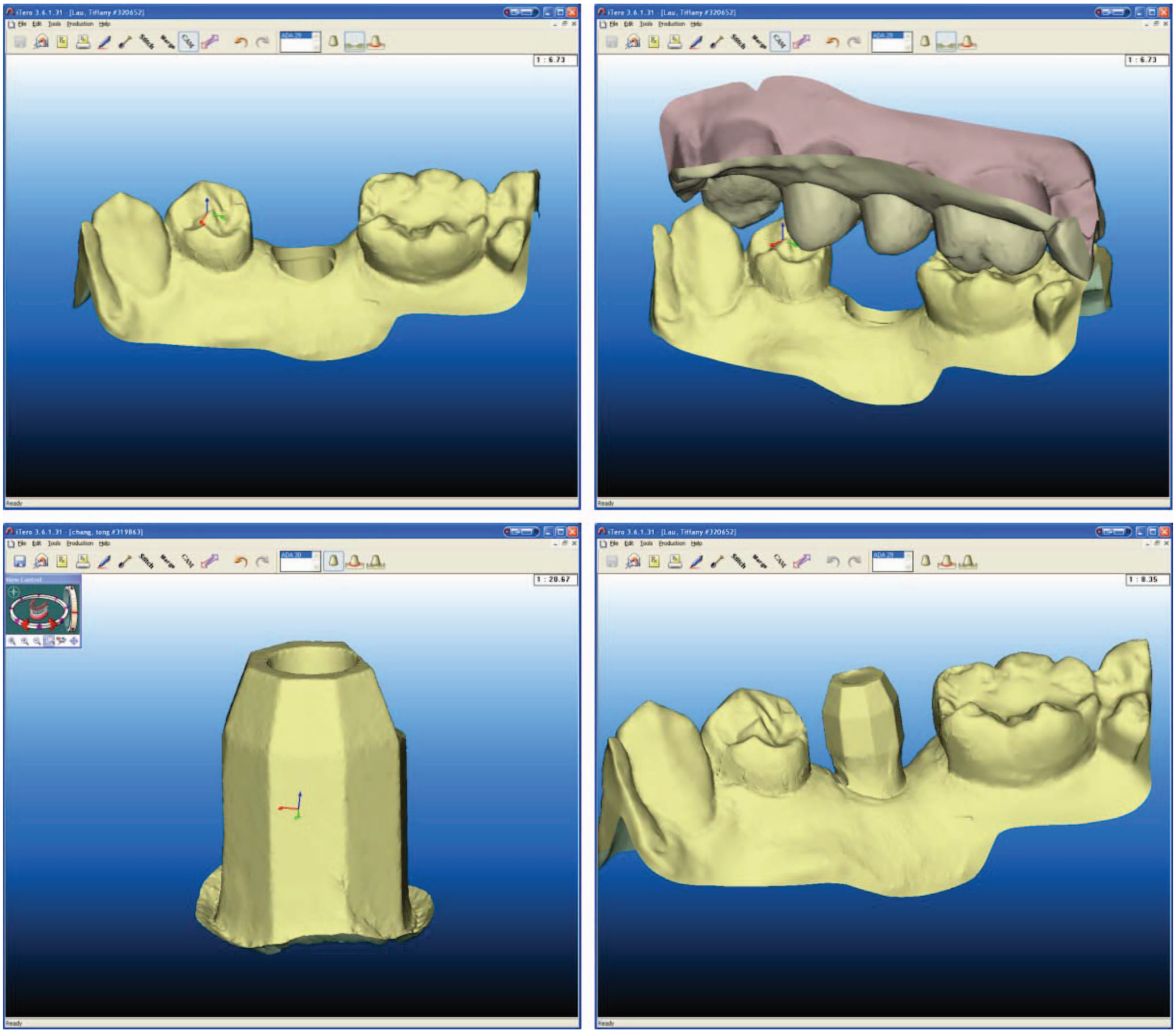

Figure 2. Digital images obtained from an intraoral laser scanner. Computer-aided design/computer-aided manufacturing technology will be used to fabricate abutment and restoration.

interproximal and occlusal contacts, and material thickness to ensure strength of the restoration to resist occlusal forces.

The implant abutment can be milled using CAD/CAM technology as titanium, zirconium, or a hybrid (metal connection/ zirconium post). The definitive restoration can be custom milled as an all-ceramic restoration or a porcelain fused to metal restoration using traditional laboratory procedures. Milled CAD/CAM custom polyurethane resin models are also available to restorative dentists for the purpose of checking the final fit of the restoration before delivering it to the patient. Such milled CAD/CAM resin models are more durable and resistant to deformation, shrinkage, expansion, chipping, and fracture compared with stone models.[4,5] The result is a more accurate fitting restoration with little to no chairside adjustment.[5] The final custom abutment shape is milled in the polyurethane model, eliminating the need to work directly on the final abutment in the laboratory. This advanced technology may help avoid the inaccuracies associated with using traditional hand-processed laboratory techniques, such as investing, casting, divesting, sandblasting, and polishing. Two examiners (C.Y.S.L. and N.W.) separately evaluated 36 implant restorations and their abutments of maxillary and mandibular posterior restorations for marginal integrity, interproximal contacts, and occlusal accuracy.

Results

Clinical parameters were evaluated for each completed abutment and restoration before delivery to the patient. Upon delivery to the patient, each adjustment of the restoration was monitored and time recorded. The overall esthetic appearance of the patient was also observed and recorded. Using the following parameters (Table) all restorations and their corre-

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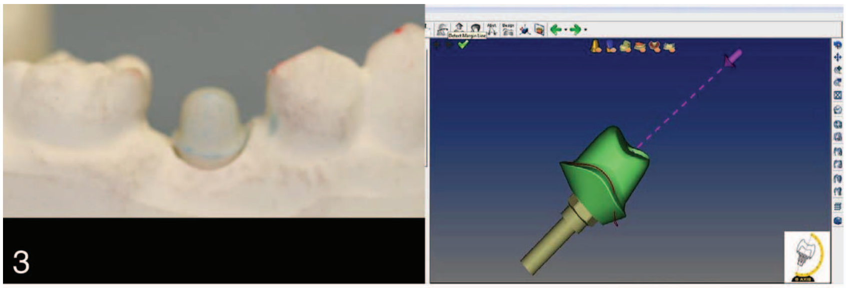

FIGURES 3–5. FIGURE 3. Stereolithographic models and dies fabricated from computer-aided design/computer-aided manufacturing technology to produce all-ceramic restoration. **FIGURE 4.** Computer-aided design/computer-aided manufacturing fabricated custom ceramic abutment and restoration. **FIGURE 5.** All-ceramic restoration in the tooth 29 area (Issaquah Dental Laboratory, Issaquah, Wash) showing an excellent esthetic result.

sponding abutments were evaluated as follows: marginal integrity with the abutment margin, interproximal contact points \with dental floss, and occlusion with articulation paper. The following conditions were noted:

_____Marginal Integrity: _____Restoration is or is not at level of abutment margin.
_____Interproximal Contact: _____Present or absent.
_____Occlusion: _____Clinically satisfactory or unsatisfactorily.

No restorations or abutments were returned to the dental laboratory for adjustment or remake. All 36 restorations and their corresponding abutments were delivered to the patient in a single office appointment. Of the 36 patients, 13 required adjustment of the restoration. Average chair time for adjustment was 5 to 15 minutes. Six patient restorations required adjustment of the interproximal contacts, and 7 patient restorations required occlusal adjustment. Of the 7 patients who needed occlusal adjustment, 3 required gingivectomy procedures because of tissue blanching and pain that prevented a complete seating of the custom abutment to the recommended 30 Ncm screw tightening.

DISCUSSION

Traditional elastomeric impressions have been used to fabricate implant restorations and abutments since Branemark and colleagues[25] described their surgical and prosthetic protocol more than 40 years ago. Ganz et al[4] and Priest[5] showed the inaccuracies of copings that were fabricated via the conventional indirect method on stone and epoxy dies created from impressions of titanium abutments as well as the accuracy of coping fabrication via a direct method on the metal itself. The use of digital intraoral scanning eliminates the traditional analog of intraoral dental impressions in conventional crown and bridge dies. The results of digital acquisition through optical scanning have been consistent and accurate.

To evaluate the practical use and accuracy of the intraoral laser scanner with CAD/CAM technology, an in vivo study with the clinical parameters was selected because it reflects the daily challenges dentists encounter in private practice. An in vitro study using typodonts such as those used to teach students in dental school would have provided similar mechanics but would not have offered realistic conditions of the oral environment, such as the constant flow of saliva, soft tissue replication, adjacent hard tissues (enamel of the teeth), and opposing dentition of each patient in this protocol. In vivo studies allow for accurate assessment of technique because the situation reflects the true clinical working conditions of the oral environment that definitely affect the quality of dental restorations.

However, in vitro studies are important in order to obtain a physical reference, a master model, and the ability to record both the reference and replicas with the same digitization method in a real-life clinician presentation.[26,27] In one study using 10 dry skulls, the authors attempted to determine the validity and reproducibility of measurements on stereolithographic models and 3D digital dental models using an intraoral laser scanner. The authors concluded that use of stereolithographic and digital models made with an intraoral laser scanner is valid and can reproduce accurate measurements for measuring distances between the dentition.[28]

With every restoration, the goal is to produce a quality restoration (Figure 4) with good internal fit and controlled thickness of the cement space.[29,30] It is generally accepted that a marginal gap discrepancy of 150 μm or less is considered clinically acceptable, although there is no clinical definition of an acceptable restoration fit.[31–34] Using a replica technique and CEREC technology, Tsitrou and colleagues[31] recorded crown gaps in the range of 91–105 μm. Restorations with Procera

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TABLE

Clinical parameters used to evaluate computer-aided design/computer-aided manufacturing restoration (n = 36)

Patient	Parameter*	Time (min)†	Remarks
1			
2			
3			
4	Interproximal contact	5	
5	Occlusion	8	
6			
7			
8	Interproximal contact	5	
9	Occlusion	8	
10	Interproximal contact occlusion	5, 5	
11	Occlusion	7	
12			
13			
14			
15	Interproximal contact	5	
16			
17			
18			
19			
20			
21	Occlusion	15	Gingivectomy
22			
23			
24	Occlusion	11	Gingivectomy
25			
26			
27			
28			
29	Occlusion	15	Gingivectomy
30	Interproximal contract	12	
31			
32			
32			
34			
35	Interproximal contact	6	
36			

* Marginal integrity indicates whether the margin of restoration is or is not at the margin of abutment, interproximal contact indicates whether proximal contact is present or absent with the adjacent tooth, and occlusion indicates whether occlusion was satisfactory or unsatisfactory with opposing tooth.

† Time was measured in minutes to adjust the restoration to clinical acceptability.

AllCeram crowns on posterior teeth recorded marginal gaps between 90 and 145 μm.[32]

For the purposes of this study, marginal integrity of the restoration was evaluated with the abutment without measuring the marginal gap at extreme magnification. Although recurrent caries was not observed at the implant restoration/abutment interface, the authors evaluated marginal integrity based on observing whether the margin of the restoration reached the abutment margin.

Currently, CAD/CAM technology is able to decrease marginal accuracy to within 50 μm.[33] The authors hypothesize that the marginal gap using digital impressions could be smaller compared with traditional elastomeric impressions, as reported by Syrek et al.[34] With digital impressions, an STL data file is created; therefore, the working stone model and its associated shortcomings, such as waxing, investing, and casting during the fabrication of the restoration, are eliminated. Instead, a CAD/CAM generated stereolithographic model with dies is created that eliminates the working stone model in the laboratory process and results in an extremely accurate and esthetically pleasing restoration (Figure 5). Using the LAVA COS System, Seelbach et al[35] concluded that digital impression techniques can be regarded as a clinical alternative to conventional impressions for fixed dental restorations. However, it must be noted that these studies were even more demanding than the present study, as they were capturing tooth margins for crowns and not scanning implant abutments, which have a predefined margin and specific geometric shape.

In the present study, similar results were obtained. All crowns were found to have acceptable margin integrity. Minimal adjustment of interproximal contacts and occlusion was needed. If adjustment was needed, it was because the contact points were too tight. There were no open contacts. As of the date this article was submitted, there have been no failures or remakes of the restorations reported in this study using the laser scanner to obtain digital impressions.

Adjustment related to the size of the abutment and crown restoration was required in 3 of the 36 patients (C.Y.S.L.). When using a custom CAD abutment with a morphologic emergence profile, tightening of the abutment screw to fully seat the abutment would significantly blanch the gingiva and cause pain. The size discrepancy for proper emergence profile could prevent complete seating of the abutment and restoration. In all 3 patients, gingivectomy procedures under local anesthesia infiltration relieved the tissue and allowed for complete seating of the abutment onto the implant. This issue was encountered with the first 3 patients enrolled in this study and was determined to be to the result of clinician inexperience in using this leading-edge technology and not properly instructing patients to clench their teeth into the MIP. Once patients were instructed on the desired MIP, this problem was resolved and did not recur. For each digitally scanned implant restoration, an average of 0–15 minutes was needed to adjust the restoration to clinical function. The patients that required the gingivectomy procedure to permit seating of the abutment took the longest adjustment (15 minutes).

This technology has disadvantages. There is a definite learning curve with the digital impression system, and this will vary as each manufacturer has different protocols. During the initial learning phase, a longer time is needed to acquire each scan. However, through repetition, the doctor and office staff gain clinical experience and become comfortable using this advanced technology. Scan time decreases with continued use.

A major disadvantage for each office is the initial cost of purchasing the laser scanning device. In addition, dental laboratories that are not digitally equipped for each specific laser scanner will be unable to receive electronic data from the dentist's office to fabricate the restoration and abutment. Finally, there is a cost to produce a CAD/CAM-generated custom implant restoration and abutment. However, as of this writing, we are now in clinical trials using the implant manufacturer's prefabricated abutment. The prefabricated abutment is attached to the implant and digitally scanned instead of the specific ISA. With this modification of the

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protocol to incorporate the use of a prefabricated stock abutment, we are able to decrease the dental laboratory cost for the restoring dentist. It is anticipated that cost will likely decrease in the immediate future as the clinical and laboratory work flow become standard procedures for both conventional and implant dentistry. The cost will be offset by the savings in impression material, decreased clinician chair time, and fewer remakes of restorations.[35]

Conclusion

This clinical pilot study demonstrated that an intraoral laser scanner can be used with confidence to obtain consistent accurate digital impressions to fabricate custom restorations and abutments for single-tooth dental implants. The advantage of using this leading-edge technology is the elimination of potential errors during the acquisition phase's real-time view for the clinician refining the impression procedure. This study demonstrated that the technology will eliminate the need for impression materials, eliminate the need to obtain a bite registration, and decrease dentist chairside working time. Because of the impressive results of this advanced technology, the present clinical study has been expanded to include multiple single units, fixed partial dentures, and anterior restorations. The new data will be separately evaluated as part of a larger study in progress.

Abbreviations

3D: three dimensional
CAD/CAM: computer-aided design/computer-aided manufacturing
CBCT: cone beam computerized tomography
CT: computerized tomography
ISA: implant scanning abutment
MIP: maximum intercuspation position

Note

Dr Natalie Wong claims payment and lectures for BioHorizons. Dr Scott Ganz lectures and claims payment for Imaging Sciences, Inc. and Materialise Dental. All other coauthors report no financial interest in the products or information listed in the article.

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