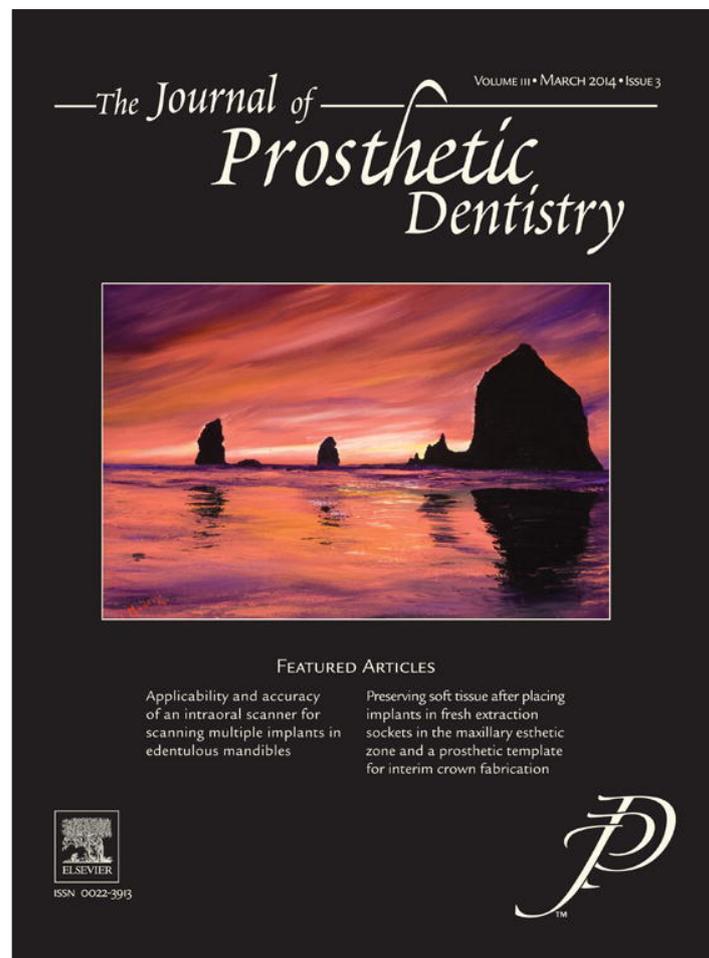


Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/authorsrights>



APPLICABILITY AND ACCURACY OF AN INTRAORAL SCANNER FOR SCANNING MULTIPLE IMPLANTS IN EDENTULOUS MANDIBLES: A PILOT STUDY

Frank S. Andriessen, DDS, MSc,^a David R. Rijkens, DDS, MSc,^b
Wicher J. van der Meer, DDS, MSc,^c and
Daniel W. Wismeijer, DDS, PhD^d

Academic Centre for Dentistry Amsterdam, Amsterdam,
The Netherlands; University Medical Centre Groningen,
University of Groningen, Groningen, The Netherlands

Statement of problem. In the past 5 years, the use of intraoral digitizers has increased. However, data are lacking on the accuracy of scanning implant restorative platforms for prosthodontics with intraoral digitizers.

Purpose. The purpose of this clinical pilot study was to assess the applicability and accuracy of intraoral scans by using abutments designed for scanning (scan abutments) in edentulous mandibles.

Material and methods. Twenty-five participants with complete mandibular overdentures retained by 2 implants and frameworks were included in this study. Scan abutments were placed on the implants intraorally and scanned with the iTero intraoral scanner. Also, scan abutments were placed on the implant analogs of the definitive casts and scanned with an extraoral laboratory scanner (Lava Scan ST scanner). Two 3-dimensional computer-aided design models of the scan abutments with predetermined center lines were subsequently imported and registered, together with each of the scanned equivalents. The distance between the centers of the top of the scan abutments and the angulations between the scan abutments was assessed. These values were compared with the measurements made on the 3-dimensional scans of the definitive casts, which were the participants' original definitive casts used for fabrication of soldered bars. The threshold for distance error was established to be 100 μm .

Results. Four of the 25 intraoral scans were not suitable for research because the intraoral scanner was not able to stitch the separate scans together. Five of the 21 suitable scans demonstrated an interimplant distance error $>100 \mu\text{m}$. Three of the 25 intraoral scans showed interimplant angulation errors >0.4 degrees. Only 1 scan showed both an acceptable interimplant distance ($<100 \mu\text{m}$) and an acceptable angulation error (<0.4 degrees).

Conclusions. Based on the intraoral scans obtained in this study, distance and angulation errors were too large to fabricate well-fitting frameworks on implants in edentulous mandibles. The main reason for the unreliable scans seemed to be the lack of anatomic landmarks for scanning. (J Prosthet Dent 2014;111:186-194)

CLINICAL IMPLICATIONS

The scans of 2 implants in edentulous mandibles made with scan abutments by using the iTero IOS system lacked sufficient overlapping and stable reference points to make them usable for implant frameworks.

With the development of intraoral scanning, a shift has occurred in impression making. Although the first intraoral digitizers were commercially available 2 decades ago, it is only recently that the popularity of these systems has grown.¹⁻⁵ In the past 5 years, 5 new intraoral digitizers have been developed and successfully introduced.¹ Increased accuracy and efficiency seems to be one explanation for the growing success. Recently

^aPostgraduate student, Section of Oral Implantology, Academic Centre for Dentistry Amsterdam.

^bPostgraduate student, Section of Oral Implantology, Academic Centre for Dentistry Amsterdam.

^cAssistant Professor, Department of Orthodontics, University Medical Centre Groningen, University of Groningen.

^dProfessor and Chair, Department of Oral Function and Restorative Dentistry; and Head, Section of Oral Implantology and Prosthodontics, Academic Centre for Dentistry Amsterdam.

published studies that have found a comparable or better general accuracy of digital scans compared with conventional impression methods confirm these observations.^{6,7}

Van der Meer et al⁶ analyzed the accuracy of the Lava COS (Lava Chairside Oral Scanner; 3M ESPE), Cerec AC (Sirona Dental Systems), and iTero (Cadent Inc; later acquired by Align Technology Inc) by determining the distance and angulation errors in vitro. The absolute distance errors ranged from 2.2 to 287.5 μm . Distance errors of the Cerec AC scanners were largest, at 79.6 μm (95% confidence interval, 31.8-127.4 μm) for distances and 81.6 μm (95% confidence interval, 49.1-114.2 μm) for 1 to 3 distances.

Another recent in vitro study concluded that the accuracy of digital impressions with the Cerec AC and the Lava COS scanners was similar to the accuracy of conventional impressions.⁷ In that study, accuracy was defined by the terms 'trueness' and 'precision'. Trueness was defined by the mean deviation of the model with respect to the true size of the object and precision by the mean deviation of the model with respect to the true size of the object. A mean trueness of $49 \pm 14.2 \mu\text{m}$ was found for Cerec AC scanners, $40.3 \pm 14.1 \mu\text{m}$ for the Lava COS, and 55 μm for traditional polyether impressions (Impregum; 3M ESPE). A mean precision of $30.9 \pm 7.1 \mu\text{m}$ was found for Cerec AC scanners, $60.1 \pm 31.3 \mu\text{m}$ for the Lava COS, and $61.3 \pm 17.9 \mu\text{m}$ for traditional polyether impressions.

Scan abutments have been developed to make it possible to scan dental implants intraorally. As of this writing, the gold standard for impressions of dental implants is a conventional impression with open- or closed-tray techniques.⁸⁻¹¹ In spite of the deformation of impression materials and expansion of dental casts, conventional impressions of implants have proved successful in clinical practice.¹²⁻¹⁶

An inaccurate impression may result in the misfit of the prosthesis, which may lead to mechanical complications such as screw loosening and fracture of the

prosthesis or implant components.¹⁷⁻²¹ Even so, obtaining absolute passive fit is practically impossible.²¹⁻²³ Minimizing the misfit to prevent complications is a generally accepted goal of prosthodontic implant procedures.²¹ Consensus on an acceptable threshold of misfit, however, has yet to be reached.^{21,24,25}

Carr et al²⁶ studied the bone response in baboons when comparing a 38- μm misfit and a 345- μm misfit without functional loads. No significant differences in bone response were found. Jemt et al²⁷ studied the correlation between marginal bone loss and framework misfit, with an average gap of 111 μm and a maximum gap of 275 μm , with functional prostheses in vivo. After 5 years, no statistical correlations had been found. These studies suggest that some form of biologic tolerance may exist between the implant and its surrounding bone when there is a certain degree of misfit.

The biologic tolerance of bone surrounding teeth is different from that of bone surrounding dental implants. Owing to the elastic nature of periodontal ligaments, teeth may move 25 to 100 μm in axial directions and 56 to 108 μm in lateral directions.²⁸ Osseointegrated dental implants are in direct contact with the surrounding bone, and therefore movement depends on the compression of the surrounding bone. This movement has been reported to be approximately 3 to 5 μm axially and 10 to 50 μm laterally.²⁸

To scan dental implants with the commercially available intraoral scanner, the use of a scan abutment is still necessary. Two studies have found a general accuracy of intraoral scanners of $<100 \mu\text{m}$.^{6,7} These studies were both in vitro studies and did not use commercially available scan abutments. Errors could be caused by the use of scan abutments, which influences the accuracy of the scan. Therefore, the aim of this in vivo pilot study was to evaluate the accuracy of the position of 2 implants in digital casts obtained from intraoral scans by using scan abutments. The intraoral scans of 25 participants were compared with the digitized analog

casts. The null hypothesis was that no significant difference would be found between the position of the implants in digital casts obtained from intraoral scans and their position in digital casts obtained from scanned analog casts.

MATERIAL AND METHODS

Participants

Participants (n=25) with complete mandibular overdentures supported by 2 implants (Straumann Standard SLA-active, Regular Neck 4.1/12 mm; Straumann AG) and splinted with frameworks were selected from an existing patient group at the Academic Centre of Dentistry Amsterdam and were asked to participate in this study. All of the participants agreed to participate, and their original definitive casts, which had been used for fabrication of soldered bars, were used as reference casts. The soldered bars, made by 1 experienced dental laboratory technician, were fabricated on these casts and were placed and loaded within 24 hours after placement of the implants. After 3 years, all of the participants were reevaluated clinically; the scan abutments were scanned intraorally by means of the iTero intraoral scanner. The study was approved by the Medical Ethical Committee of the VU University Medical Center, Amsterdam, the Netherlands.

Intraoral scanner

The intraoral scanner used in this study was the iTero (Cadent Inc) with software version 3.5.0. The iTero scanner uses a parallel confocal imaging technique to capture digital images and combine them to construct 3-dimensional (3D) images.²⁹ For implants, 5 scans of the scan abutments were needed (occlusal, 45 degrees buccal, 45 degrees lingual, mesio-proximal, and distoproximal). Additional scans were required to capture the rest of the jaw. The 3D images were stitched together to compose the complete 3D model. The camera covered a $14 \times 18 \text{ mm}$ area at a scan depth of 13.5 mm.³⁰ For this system, scanning powder was not required on the teeth or scan abutments.

Scanning the reference casts in the laboratory

The participants' original definitive casts, which had been used for fabrication of soldered bars, were used in this study as reference casts. New scan abutments were placed onto the implant analogs in the reference casts. Scan powder (Occluspray; Selexions BV) was needed to scan the casts with an extraoral scanner (Lava Scan ST scanner; 3M ESPE).

Scanning the scan abutments intraorally

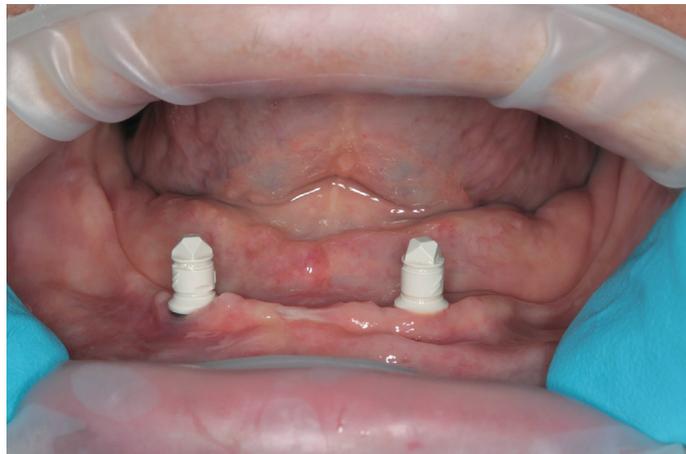
All of the participants were seen for clinical examinations and for scanning the scan abutments intraorally with the iTero intraoral scanner. The bars were removed, and scan abutments (Straumann Regular Neck scan abutment) were placed in the correct positions on both implants. The scan abutments were hand-tightened with screws (Fig. 1). The manufacturer's instructions were followed. After correct abutment positioning had been checked clinically, intraoral scans were made with the intraoral scanner. For saliva control and mouth opening, a lip and cheek retractor (OptraGate; Ivoclar Vivadent AG) was used (Fig. 2). After the intraoral scans were completed, the scan abutments were removed and the bars were replaced. The scan file was saved, and, following the manufacturer's instructions, it was sent to the iTero facility in Israel for subsequent processing.

3D measurements

The distance and the angle between the centers of the scan abutments were used to assess the accuracy of the different scanners. Each of the scans, as well as the 25 intraoral scans and the 25 extraoral scans of the reference casts, was imported into industrial reverse engineering software (Geomagic Qualify, version 12; Geomagic America), where the scan abutments were isolated as separate



1 RN Straumann Scanbody. To scan dental implants with intraoral digitizers, use of some type of scan abutment is still necessary. Scan abutment represents position of respective dental implant in intraoral computer-aided design and computer-aided manufacturing scanning procedures. Scan body consists of 3 parts: scan cap, fixation screw, and scan post. Scan post has to be placed in dental implant with fixation screw hand-tightened (maximum, 15 Ncm). After fixation of scan post, scan cap has to be placed correctly, avoiding any gap between cap and post. For accurate scan result, it is essential that Scanbody is clean and that it is not damaged or deformed.

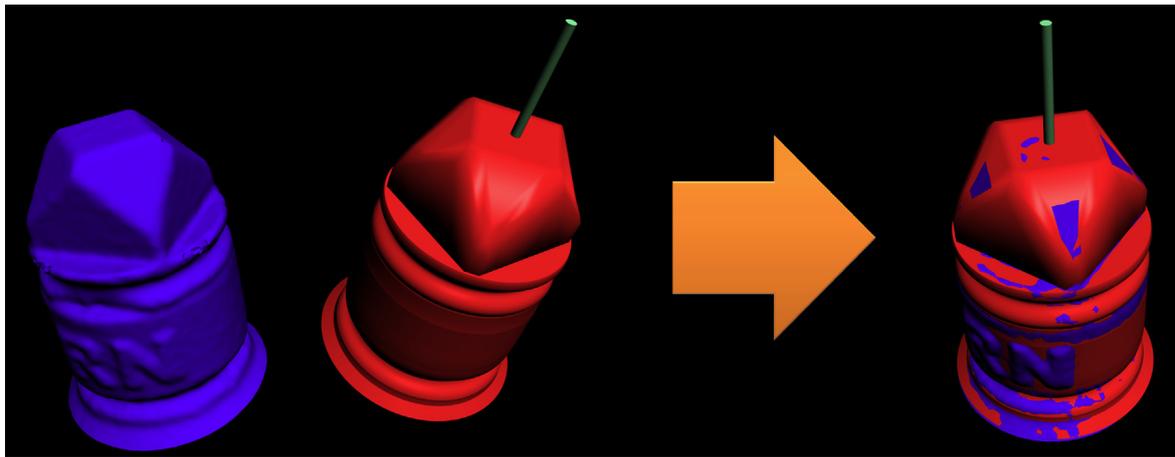


2 Scan abutments.

objects. Two 3-dimensional computer-aided design (3D CAD) models of the scan abutments with predetermined centerlines were subsequently imported and registered, together with each of the scanned equivalents (Fig. 3). This was done to secure the proper construction of the centerline of each scan abutment.

The distance between the centerlines of the occlusal surfaces of the scan abutments was measured in the software

with a linear measurement tool. The angular deflections of the centerlines of the scan abutments were measured with an angular measurement tool. The measurements were not separated into x-, y-, and z-components, because the objects' coordinate system could not be properly matched with a world coordinate system. As no true common coordinate system exists, the different casts could only be registered in a virtual common coordinate system. Because



3 Isolated scan abutment (blue) and 3D CAD model of scan abutment with centerline (red). 3D CAD models were imported and registered, together with scanned equivalents (right). 3D, 3-dimensional; CAD, computer-aided design.

the registrations were based on the surfaces of the casts, the positions of the casts differed slightly. This introduced errors into their relative positions and made it unreliable to compare measurements in x-, y-, and z-components. Such an approach was used in another study.⁶ In the present study, the measurements were noted in a table and compared with the same measurements made with the reference analog casts.

3D comparisons

Each of the scans was imported into industrial reverse engineering software (VisCAM, version 5.1; Marcam Engineering GmbH) and evaluated for possible irregularities such as deformations and wrong stitching sutures. The observations were noted in a table.

Determined threshold for distance and angulation error

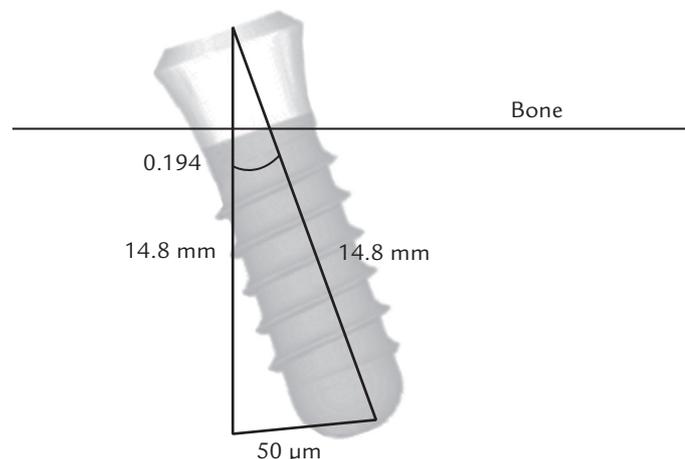
As far as the authors can determine, no evidence-based reports have been published on the maximum amount of misfit that can be tolerated in an implant-supported superstructure. Based on clinical guidelines with a biomechanical rationale,²⁸ in which the authors stated that the maximum lateral movement of an implant in bone is 50 μm , the following was postulated: The maximum biologic tolerance of bone caused by misfit of framework may be equal to the maximum lateral movement

of 1 implant in bone, which is 50 μm . A framework attached to 2 dental implants exceeds the biologic tolerance of 2 implants when the horizontal misfit is larger than 100 μm . Therefore, for dental implants, the inaccuracy of fit for a 2-implant bar attachment must not exceed $2 \times 50 \mu\text{m}$, giving a premise of 100 μm .

The maximum acceptable interimplant angulation error was calculated by using trigonometry. The fixation point of the framework on an implant was at the top of the implant. A misfit between the framework and the implant would lead

to a maximum lateral movement at the implant apex of 50 μm , which is the maximum lateral movement of an implant in bone.²⁸ The implant had a total length of 14.8 mm (12 mm rough surface + 2.8 mm smooth supracrestal surface; in this instance, the neck of the implant was supracrestal). Based on trigonometry, a maximal lateral apex movement of 50 μm would result in angulations of 0.194 degrees. ($\alpha = \tan^{-1}(0.05/14.8) = 0.194$ degrees; Fig. 4).

Between 2 implants, as used in this study, the maximum acceptable



4 Trigonometric calculation of maximum acceptable interimplant angulation error based on maximum lateral movement at implant apex of 50 μm . Fixation point between bar and implant will be at top of implant. Misfit between bar and implant will lead to lateral movement at implant apex. Implant has total length of 14.8 mm (12 mm rough surface + 2.8 mm smooth supracrestal surface), resulting in angulations of 0.194 degrees in case of maximal lateral apex movement of 50 μm ($\alpha = \tan^{-1}(0.05/14.8) = 0.194$ degrees).

interimplant angulation error would be approximately 2×0.194 degrees = 0.39 degrees. For this study, a maximum of 0.4 degrees was used as the threshold for a clinically acceptable angulation error.

Examiners

One dentist (JP), trained in intraoral scanning, removed the frameworks from the implants and did the intraoral scanning of the participants. Scanning

the analog casts was done by the researchers (FA, DR) with the help of an experienced dental technician. The digital files were checked for irregularities by the researchers (FA, DR). The measurements were done by a dentist (JM) experienced in digital imaging.

RESULTS

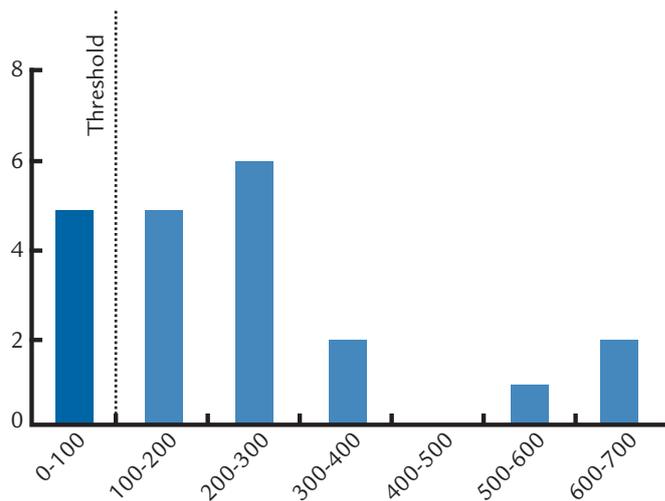
In total, 4 of the 25 intraoral scans were not suitable for research because

of a large distance between the 2 implants (the computer was not able to stitch the separate scans together) or because of a lack of stable reference points on the oral mucosa. This led to final scans with only 1 or even 3 scan abutments in the image instead of 2 scan abutments. The 21 remaining intraoral scans were digitally compared with their reference scan, the analog cast. The results have been summarized in Table I.

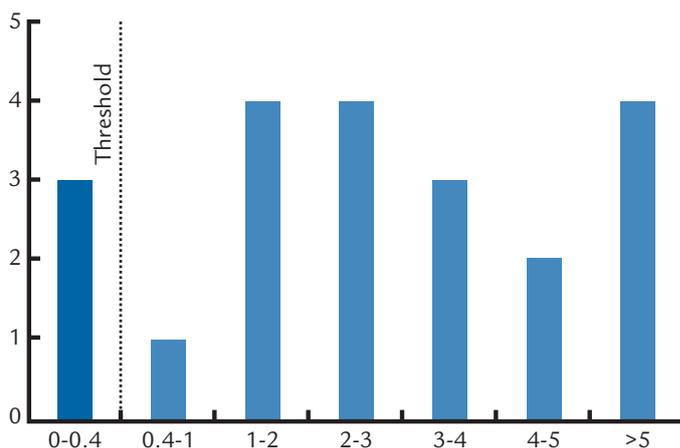
TABLE I. Interimplant distance, interimplant angulations, and optical irregularities in scans

Participant	Distance, Reference Cast (mm)	Distance, Intraoral Scanner (mm)	Distance Error (mm)	Angle, Reference Cast (Degrees)	Angle, Intraoral Scanner (Degrees)	Angulation Error (Degrees)	Optical Irregularity
1	16.339	15.813	0.526	6.862	2.740	4.122	Wrong stitching
2	22.471	22.256	0.215	6.979	9.139	-2.160	No optical irregularities
3	22.059	21.848	0.211	4.727	5.971	-1.244	Deformation
4	23.460	23.673	-0.213	12.747	9.466	3.281	No optical irregularities
5	18.024	18.003	0.021	11.336	11.837	-0.501	Wrong stitching
6	18.435	18.690	-0.255	5.323	5.446	-0.123	No optical irregularities
7	24.869	25.038	-0.169	16.074	17.702	-1.628	No optical irregularities
8	30.578	30.478	0.100	13.951	14.751	-0.800	Wrong stitching
9	22.802	22.764	0.038	6.533	12.299	-5.766	Wrong stitching
10	18.212	18.113	0.099	9.596	8.599	0.997	Wrong stitching
11	16.935	16.936	-0.001	4.413	11.264	-6.851	Wrong stitching
12	22.635	22.259	0.376	13.575	12.389	1.186	Wrong stitching + deformation
13	21.217	21.456	-0.239	7.560	11.042	-3.482	Wrong stitching
14	18.069	18.196	-0.127	10.719	1.157	9.563	Wrong placement of scan abutment
15	17.475	16.825	0.650	2.226	4.164	-1.938	Deformation
16	17.299	17.192	0.107	5.599	5.936	-0.337	Wrong stitching
17	13.758	13.698	0.060	3.587	3.911	-0.324	No optical irregularities
18	26.148	26.786	-0.638	10.091	3.393	6.698	Deformation
19	17.765	18.091	-0.326	13.832	10.642	3.190	Wrong stitching
20	20.348	20.622	-0.274	7.513	11.508	-3.995	Wrong stitching
21	15.699	15.842	-0.143	4.957	3.156	1.801	Deformation
22	ND	ND	ND	ND	ND	ND	Not possible to perform intraoral scan
23	ND	ND	ND	ND	ND	ND	Not able to make complete scan
24	ND	ND	ND	ND	ND	ND	Not able to make complete scan
25	ND	ND	ND	ND	ND	ND	Not able to make complete scan

ND, no data (not possible to make a complete scan).



5 Bars showing interimplant distance difference. On x-axis is difference between distance of implants scanned with intraoral scanner and reference cast. On y-axis is number of participants for each distance difference group. Threshold is set at 100 μm .



6 Bars showing interimplant angle difference. On x-axis is difference between angle of implants scanned with intraoral scanner and reference cast. On y-axis is number of participants for each angle difference group. Threshold is set at 0.4 degrees.

Distance

The interimplant distance, assessed by a digital measurement of the mid-center line of the 2 scan abutments, showed a distance error ranging from 21 to 638 μm compared with the reference scan (see Table I; Fig. 5). The mean of these distance errors was 226.0 μm . The distance errors occurred in both the negative and positive ranges. A difference error of <100 μm was found in 5 of the 21 scans.

Angulations

The angulation error, assessed by a comparison of the difference in implant angulations of the *in vivo* scan and the reference scan, ranged from 0.123 degrees to 9.563 degrees (see Table I; Fig. 6). The mean absolute angulation error for the scan abutments was 2.582 degrees. An angulation error <0.4 degrees was recorded in 3 of the 21 scans.

Scan irregularities

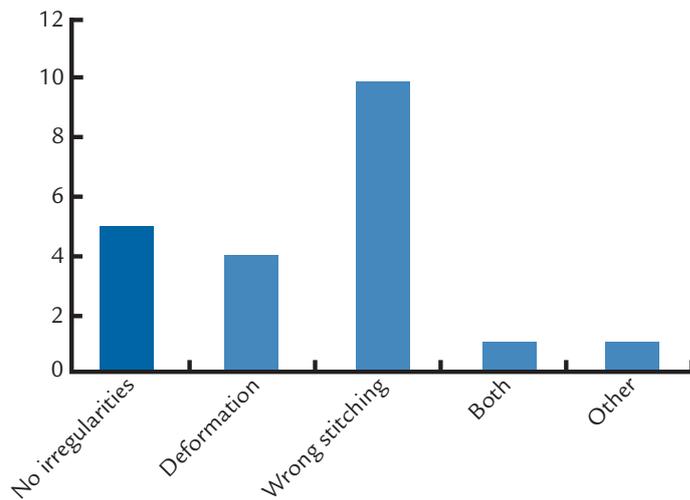
The scans were optically analyzed by the researchers to find explanations for the digitally assessed discrepancy. No optical irregularities were found on the reference scans. Figure 7 shows irregularities for each scan with the intraoral scanner.

Creating a final digital scan of the scan abutments was not possible in 4 of the 25 participants: in the final scan 1 or 3 scan abutments appeared in the image. Stitching errors, where the digital stitching of the photos was misaligned, were found in 10 of the 21 scans (Fig. 8). In 4 of the 21 scans, a deformation of the scan abutments was observed (Fig. 9). For 1 participant, a stitching error occurred as well as a deformation error. Five scans seemed to be optically good scans, although 1 of these scans had minor errors compared with the gold standard (distance error of 60 μm and angle error of 0.342 degrees) (see Table I; see Fig. 7).

DISCUSSION

The wide range of angulation errors and distance errors and the fact that these negated the null hypothesis of <100 μm and <0.4 degrees, with higher values for most participants, made statistical analysis irrelevant. This is the first clinical study comparing intraorally scanned scan abutments on implants with extraoral scanned analog casts. The results of this study found that a large discrepancy exists between the intraoral scans and the reference scans in situations in which 2 implants were used in the edentulous mandible. The data indicate that the null hypothesis should be rejected. In this discussion are listed the complications that arose after the scanning of 2 scan abutments by means of an intraoral scanner in an edentulous jaw.

The use of analog casts as reference casts can be debated because of the possible transformation of the impression material and the possible expansion of the cast.¹⁵ The fact that the soldered bars fabricated on these casts



7 Bars showing irregularities for each scan with intraoral scanner. On x-axis are irregularities. On y-axis is number of participants for each group.

were placed within 24 hours after implant placement accounts for these possible small differences between the casts and the in vivo situation; the implants have the ability to migrate to the best-fit position on the bar.^{25,31,32} Thus, the implants will osseointegrate into the same position as the analog implants in the cast on which the bar was fabricated. This makes the cast a reliable reference, on the condition that the bars fit their casts precisely.

Another point of debate is the choice of threshold. At this moment, no clear guidelines are available on the acceptable thresholds for misfit between superstructures and implants.^{21,24,25} However, a passive fit of the superstructure should be the main goal to avoid mechanical and biologic complications.¹⁷⁻²¹ A previous study assessed a maximum lateral implant

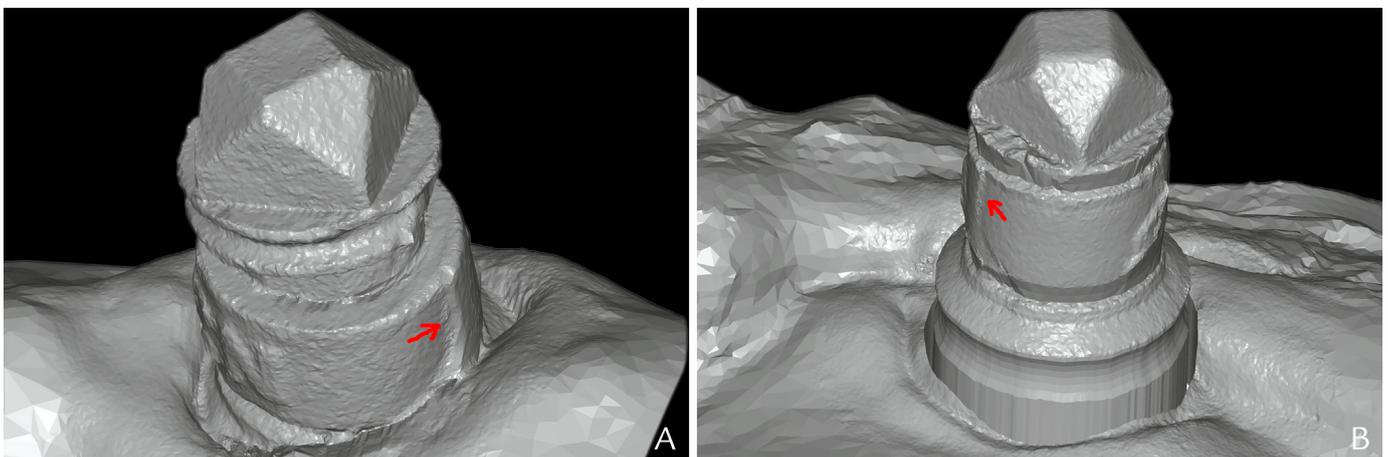
movement of 50 μm . This could indicate that every lateral implant movement due to a misfit that exceeds 50 μm will lead to a certain tension between the implant and the superstructure. The thresholds chosen in this study are based on this 50 μm maximum movement of implants.

In 4 of the 25 intraoral scans, making a complete scan that would contain the 2 scan abutments in the same capture was impossible. The camera of the intraoral scanner covers a maximum area of 14 \times 18 mm for each separate photo.³⁰ For these participants, a large interimplant distance in combination with a lack of mucosal landmarks to serve as reference points made it impossible to stitch the photographs in the right position relative to one another. When the scan abutments were scanned for these participants, the

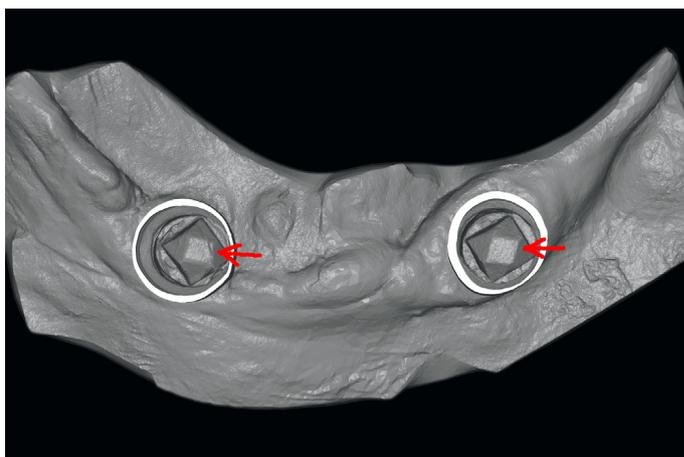
intraoral scanner combined the photographs of both scan abutments and created a scan file with just 1 scan abutment instead of 2 separate scan abutments. These incorrect scans were not included in this study. Some participants with a large interimplant distance (30 mm) were scanned successfully because of a stable mucosa with sufficiently variable height to provide sufficient reference for the intraoral scanner.

Only one other study has determined the accuracy of the iTero intraoral scanner. Van der Meer et al⁶ compared the iTero with an industrial scanner to determine its general accuracy. The distance errors of the iTero occurred in the range of 7.2 to 126.8 μm . The mean absolute angulation errors were in the range of 0.0069 to 0.6833 degrees. In that study, the distance errors and angulation errors were much smaller than in this study. However, that study was an in vitro study in which casts with fixed cylinders were scanned. The surface of these casts had a large number of stable reference points, enabling the scans to be stitched in the right position. In the current study, the major issue was to find reference points, because the mucosa did not vary much in height, which resulted in poor and unreliable scans.

Out of 25 scans, 4 were not included in the study. From 21 suitable scans, only 1 scan showed both an acceptable distance error (<100 μm) and an acceptable angulation error (<0.4 degrees). Based on these data,



8 A and B, Clear suture has been identified (red arrow) where photos were stitched.



9 Deformation of scan abutment. Top of scan abutment has square configuration. Wrong stitching of multiple captures will lead to lozenge-shaped top of scan abutment (red arrow) in some situations, which does not match real square configuration.

the iTero intraoral scanner is not at present an adequate tool for scanning 2 implants in the edentulous mandible. This intraoral scanner was not designed to make a digital scan that can be used to fabricate a bar on 2 implants.

With a point-and-click system, the 3D surfaces should be scanned with at least one-third overlap of the adjoining surface. The registration of the neighboring surfaces will be made on the basis of this overlap. If the adjacent surfaces are unstable or show little to no variation in height, it will be difficult to find the one-third overlap of the adjoining surface. This will lead to an unreliable registration. Conversely, in dentate situations, the neighboring surfaces are stable and vary in shape and height. Therefore the results of this study cannot be extrapolated to dentate participants.

In future studies, other scanners should be used, because this study focused only on 1 point-and-click system. Other technologies may produce different outcomes when edentulous participants are scanned. The number of implants can be increased, and a comparison with a traditional impression material should be added. Also, the use of 2 or more implants in dentate situations instead of in edentulous participants should be considered to determine accuracy. A new software

version for the iTero has recently been released. In this software (version 3.9), it is possible to make more photographs to create the scan, which may produce different results.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Based on the intraoral scan, the distance errors were too large to produce a well-fitting superstructure on 2 implants in an edentulous mandible.
2. The mean angular errors were too large to produce superstructures with a passive fit on 2 implants in an edentulous mandible.
3. The unreliable scans in this study were the result of poor reference points caused by mucosa with little variation in texture and height.

REFERENCES

1. Silvia L, Giordano F, Ari K, Michele C, Lapo G, Luciano B. A comparative analysis of intraoral 3D digital scanners for restorative dentistry. *Internet Journal of Medical Technology* 2008;5:1.
2. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. *Clin Oral Implants Res* 2013;24:111-5.
3. Christensen GJ. The challenge to conventional impressions. *JADA* 2008;139:347-9.
4. Christensen GJ. Will digital impressions eliminate the current problems with conventional impressions? *J Am Dent Assoc* 2008;139:761-3.
5. Stein JM. Stand-alone scanning systems simplify intraoral digital impressioning. *Compend Contin Educ Dent* 2011;56:58-9.
6. van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of intraoral dental scanners in the digital workflow of implantology. *PLoS One* 2012;7:e43312. [e-pub August 22, 2012].
7. Ender A, Mehl A. Full arch scans: conventional versus digital impressions—an in vitro study. *Int J Comp Dent* 2011;14:11-21.
8. 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;24:469-72.
9. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. *J Prosthet Dent* 2008;100:285-91.
10. Prithviraj DR, Pujari ML, Garg P, Shruthi DP. Accuracy of the implant impression obtained from different impression materials and techniques: review. *J Clin Exp Dent* 2011;3:106-11.
11. Kwon JH, Son YH, Han CH, Kim S. Accuracy of implant impressions without impression copings: a three-dimensional analysis. *J Prosthet Dent* 2011;105:367-73.
12. Johnson GH, Craig RG. Accuracy of four types of rubber impression materials compared with time of pour and a repeat pour of models. *J Prosthet Dent* 1985;53:484-90.
13. Millstein PL. Determining the accuracy of gypsum casts made from type IV dental stone. *J Oral Rehabil* 1992;19:239-43.
14. Faria AC, Rodrigues RC, Macedo AP, Mattos Mda G, Ribeiro RF. Accuracy of stone casts obtained by different impression materials. *Braz Oral Res* 2008;22:293-8.
15. Konstantinos X, Michalakis KX, Stratos A, Hirayama H, Pissiotis AL, Touloumi F. Delayed setting and hygroscopic linear expansion of 3 gypsum products used for cast articulation. *J Prosthet Dent* 2009;102:313-8.
16. Imbery TA, Nehring J, Janus C, Moon PC. Accuracy and dimensional stability of extended-pour and conventional alginate impression materials. *J Am Dent Assoc* 2010;141:32-9.
17. Sahin S, Cehreli M, Yalcin E. The influence of functional forces on the biomechanics of implant-supported prostheses—a review. *J Dent* 2002;30:271-82.
18. Wang T, Leu L, Wang J, Lin L. Effects of prosthesis materials and prosthesis splinting on peri-implant bone stress around implants in poor-quality bone: a numeric analysis. *Int J Oral Maxillofac Implants* 2002;17:231-7.
19. Kunavisarut C, Lang L, Stoner B, Felton D. Finite element analysis on dental-implant supported prostheses without passive fit. *J Prosthodont* 2002;11:30-40.
20. Sones AD. Complications with osseointegrated implants. *J Prosthet Dent* 1989;62:581-5.
21. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. *Impl Dent* 2001;10:85-92.

22. Sahin S, Cehreli MC. The significance of passive framework fit in implant prosthodontics: current status. *Implant Dent* 2001;10:85-92.
23. de Sousa SA, de Arruda Nobilo MA, Henriques GE, Mesquita MF. Passive fit of frameworks in titanium and palladium-silver alloy submitted the laser welding. *J Oral Rehabil* 2008;35:123-7.
24. Swallow ST. Technique for achieving a passive framework fit: a clinical case report. *J Prosthet Dent* 1999;81:7-13.
25. Tahmaseb A, De Clerck R, Aartman I, Wismeijer D. Digital protocol for reference-based guided surgery and immediate loading: a prospective clinical study. *Int J Oral Maxillofac Implants* 2012;27:1258-70.
26. Carr AB, Gerard DA, Larsen PE. The response of bone in primates around unloaded dental implants supporting prostheses with different levels of fit. *J Prosthet Dent* 1996;76:500-9.
27. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous patients. *Int J Oral Maxillofac Implants* 1996;11:620-5.
28. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. *Clin Oral Impl* 2005;16:25-35.
29. Kachalia PR, Geissberger MJ. Dentistry a la carte: in-office CAD/CAM technology. *J Calif Dent Assoc* 2010;38:323-30.
30. Fasbinder DJ. Digital dentistry: innovation for restorative treatment. *Compend Contin Educ Dent* 2010;31:2-11.
31. Szmukler-Moncler S, Salama H, Reingewirtz Y, Dubruille J. Timing of loading and effect of micromotion on bone-dental implant interface: review of experimental literature. *J Biomed Mat Res* 1998;43:192-203.
32. Duyck J, Vrielinck L, Lambrechts I, Abe Y, Schepers S, Politis S, et al. Biologic response of immediately versus delayed loaded implants supporting ill-fitting prosthesis: an animal study. *Clin Implant Dent Relat Res* 2005;7:150-8.

Corresponding author:
Dr F.S. Andriessen
Wilhelminakade 36
3072 AR Rotterdam
THE NETHERLANDS
E-mail: f.andriessen@acta.nl

Copyright © 2014 by the Editorial Council for
The Journal of Prosthetic Dentistry.

NOTEWORTHY ABSTRACTS OF THE CURRENT LITERATURE

In vitro precision of fit of computer-aided design and computer-aided manufacturing titanium and zirconium dioxide bars

Katsoulis J, Mericske-Stern R, Yates DM, Izutani N, Enkling N, Blatz MB
Dent Mater 2013;29:945-53

Objectives: Optical scanners combined with computer-aided design and computer-aided manufacturing (CAD/CAM) technology provide high accuracy in the fabrication of titanium (TIT) and zirconium dioxide (ZrO) bars. The aim of this study was to compare the precision of fit of CAD/CAM TIT bars produced with a photogrammetric and a laser scanner.

Methods: Twenty rigid CAD/CAM bars were fabricated on one single edentulous master cast with 6 implants in the positions of the second premolars, canines and central incisors. A photogrammetric scanner (P) provided digitized data for TIT-P (n=5) while a laser scanner (L) was used for TIT-L (n=5). The control groups consisted of soldered gold bars (gold, n=5) and ZrO-P with similar bar design. Median vertical distance between implant and bar platforms from non-tightened implants (one-screw test) was calculated from mesial, buccal and distal scanning electron microscope measurements.

Results: Vertical microgaps were not significantly different between TIT-P (median 16µm; 95% CI 10-27µm) and TIT-L (25µm; 13-32µm). Gold (49µm; 12-69µm) had higher values than TIT-P (p=0.001) and TIT-L (p=0.008), while ZrO-P (35µm; 17-55µm) exhibited higher values than TIT-P (p=0.023). Misfit values increased in all groups from implant position 23 (3 units) to 15 (10 units), while in gold and TIT-P values decreased from implant 11 toward the most distal implant 15.

Significance: CAD/CAM titanium bars showed high precision of fit using photogrammetric and laser scanners. In comparison, the misfit of ZrO bars (CAM/CAM, photogrammetric scanner) and soldered gold bars was statistically higher but values were clinically acceptable.

Copyright © 2013 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.