Effect of Implant Divergence on the Accuracy of Definitive Casts Created from Traditional and Digital Implant-Level Impressions: An In Vitro Comparative Study

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Purpose: *The purpose of this research was to compare the accuracy of definitive casts created with digital and conventional methods for implants with internal-octagon connections placed parallel or at different angles (15, 30, or 45 degrees).* ***Materials and Methods:*** *Four customized epoxy resin master casts were fabricated with two-implant analogs placed in the posterior mandible with different degrees of divergence. For the conventional (control) group, 10 traditional impressions were taken on each master cast with custom trays, open-tray impression copings, and polyvinyl siloxane; definitive stone casts were poured with type IV dental stone. For the digital group, 10 digital impressions were taken on each master cast with two-piece scannable impression copings and an intraoral digital scanner; definitive milled polyurethane casts were fabricated by the manufacturer. All four master casts and 80 control and test casts were scanned and digitized, and the data sets were compared. Any deviations in measurements between the definitive and corresponding master casts were analyzed statistically.* ***Results:*** *The amount of divergence between implants did not affect the accuracy of the stone casts created conventionally; however, it significantly affected the accuracy of the milled casts created digitally. A decreasing linear trend in deviations for both distance and angle measurements suggested that the digital technique was more accurate when the implants diverged more. At 0 and 15 degrees of divergence, the digital method resulted in highly significantly less accurate definitive casts. At 30 and 45 degrees of divergence, however, the milled casts showed either no difference or marginal differences with casts created conventionally.* ***Conclusion:*** *The digital pathway produced less accurate definitive casts than the conventional pathway with the tested two-implant scenarios. To ensure passive fit of definitive prostheses, verification devices and casts may be used when materials are produced digitally.* Int J Oral Maxillofac Implants 2015;30:102–109. doi: 10.11607/jomi.3592

Key words: *dental implants, dental impression technique, digital impression, implant divergence, parallel confocal technology*

Passive fit of prosthetic frameworks on dental implants has been considered to be critical to prevent future biologic and mechanical complications.[1] Although absolute passive fit may not be achievable and the relationship between the degree of fit and complications is yet to be established, clinicians should always aim for the best possible fit of an implant framework.[2] Many clinical and laboratory procedures are related to achieving passive fit; this includes impression techniques, definitive cast production, and prosthesis fabrication.[3,4]

Different clinical factors (implant depth[5] and interimplant angulation[6–10]), implant systems (connection type[7] or implant or abutment level[11]), and impression techniques (splinted versus nonsplinted,[12,13] different impression materials,[14] transfer versus pickup[15]) have been proposed and investigated to determine their influence on the accuracy of traditional implant impression procedures with elastomeric impression materials.[16] However, even with an accurate clinical traditional implant impression, potential discrepancies

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may be introduced during fabrication of the definitive cast because of displacement of the implant components and dimensional changes in the dental stone.[17,18] The Encode restorative system (Biomet 3i) provides an alternative method for cast fabrication by means of a digitally coded healing abutment to transfer the information about implant diameter and position to a robot, which places a corresponding implant analog in the definitive cast (Robocast, Biomet 3i).[19,20] However, the initial results with this system demonstrated that definitive casts were less accurate than definitive casts made from traditional transfer and pickup techniques.[19,20]

Many in vitro studies have demonstrated that implant angulations significantly affect the accuracy of traditional implant impression procedures with elastomeric impression materials.[6–10] A recent study showed that definitive casts fabricated with Encode abutment impressions and Robocast technology were less accurate than those created through the traditional splinted pickup impression technique with models incorporating internal-connection implants that diverged by 10 or 30 degrees.[21] More studies will be needed to develop suitable impression and accurate definitive cast fabrication techniques with angulated implants.

Digital impression techniques at the implant level have become available and have played an important role in the development of a fully digital workflow for implant restorations.[22–24] Digital impressions could offer some advantages over traditional implant impression procedures with elastomeric impression materials, such as reduced risks of distortion during impression and cast fabrication, improved patient comfort and acceptance[25] (especially in patients with a strong gag reflex), and lower costs resulting from the direct data output as a complete digital workflow.[26–29] The iTero System (Cadent iTero, Cadent Ltd) was introduced in 2007 using parallel confocal imaging technology to capture the digital impression.[26] With a scannable impression coping (scan body, Straumann), the scanned data can be imported and interpreted by computer-aided design/computer-assisted manufacture (CAD/CAM) software (Straumann Cares 8.0) in a dental laboratory to design definitive abutments and restorations without the need for definitive casts. The scanned impression can also be transmitted to a modeling center (Cadent iTero) to fabricate a milled definitive polyurethane cast.[23,24] One recent study showed that angulated implants diminish the accuracy of the impressions created with an active wavefront sampling technology–based digital impression system; however, the inaccuracy was not significant.[29] The accuracy of digital implant impressions and/or the resulting casts has not been widely studied, and variations in different digital impression systems and associated cast fabrication techniques render comparisons difficult.

The purpose of this research is to compare the accuracy of definitive casts created through a digital pathway (digital implant-level impression with two-piece scannable impression copings and an intraoral scanner) with that of casts created with a conventional pathway (traditional implant-level impression with open-tray impression copings and polyvinyl siloxane material) for internal-connection implants (RN Standard Plus implants, Straumann) using standardized parallel and divergent (15, 30, 45 degrees) master casts.

MATERIALS AND METHODS

Master Cast Fabrication

Four customized epoxy resin master casts (Paradigm Dental Models) simulating a Kennedy Class II mandible were fabricated, and two implant analogs (RN Standard Plus implant, Straumann) were placed in the posterior edentulous mandible (second premolar and second molar locations) with different amounts of mesiodistal divergence (0, 15, 30, and 45 degrees) in each master cast. The distance between the implant restorative platforms was 10 mm, and the platforms of the implant analogs were placed 1 mm coronal to the cast surface (Fig 1).

Control Group. Control group casts were made with conventional impressions as follows. Forty custom trays were fabricated with light-polymerized acrylic resin (Triad VLC Custom Tray Material, Dentsply International) with an open window over the implant analogs to allow access of the open-tray impression coping (RN synOcta impression cap with handle, Straumann) when making impressions. Ten impressions were made on each master cast (with implants diverging mesiodistally by 0, 15, 30, and 45 degrees, n = 10; = 40 in control group) with polyvinyl siloxane (Aquasil Ultra, Dentsply Caulk). Analogs (RN implant analog, Straumann) were attached to the impression copings and poured with type IV dental stone (Silky-Rock, Whip Mix). Different colors of type IV dental stone (Resin Rock, Whip Mix) were used to fabricate stone bases for all stone definitive casts. The stone bases provided a stable surface for subsequent measurements.

Test Group. Test casts were made using digital methods as follows. Two-piece scannable impression copings (Scan Body RN, Straumann) were secured to the implant analogs on the master casts under a 15-Ncm preload. The digital impressions were acquired with an intraoral digital scanner (Cadent iTero) according to the computer-guided instructions (Fig 2). Ten digital impressions were obtained for each master cast (0, 15, 30, and 45 degrees of implant divergence; total = 40). The corresponding CAD/CAM software (Straumann Cares 8.0, Straumann) was used to transmit

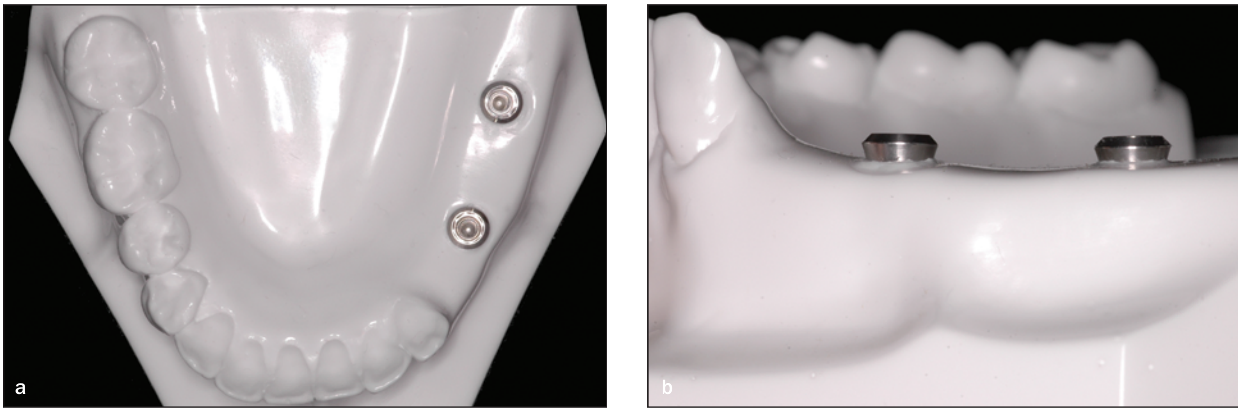

Fig 1 A master epoxy resin cast with implant analogs. (*a*) Occlusal view of master cast with 0 degrees of divergence; (*b*) buccal view of master cast with 0 degrees of divergence.

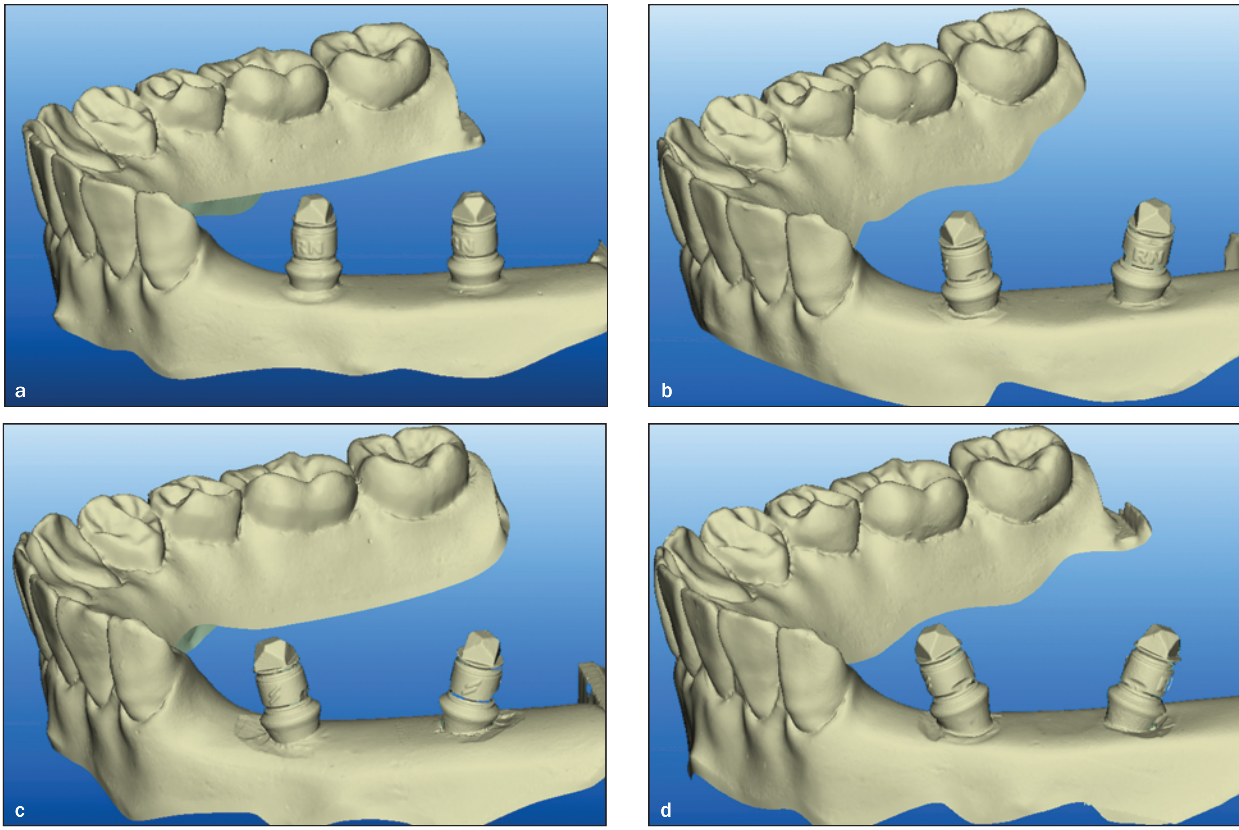

Fig 2 The test groups with the two-piece scannable impression copings. The different screenshots show completed digital impressions for implants with different amounts of mesiodistal divergence. (*a*) No divergence; (*b*) 15 degrees of divergence; (*c*) 30 degrees of divergence; (*d*) 45 degrees of divergence.

the information to the manufacturer (Cadent iTero) for subsequent fabrication of milled polyurethane definitive casts. Upon receipt of the milled polyurethane definitive casts from the manufacturer, the corresponding removable implant analogs (RN reposition analog, Straumann) were manually inserted into the milled definitive casts by one investigator. Cyanoacrylate resin (Scotch Super Glue, 3M ESPE) was used at the base of each milled definitive cast to secure the implant analogs. Type IV dental stone (Resin Rock, Whip Mix) was used to fabricate stone bases for all milled polyurethane definitive casts. The stone bases provided a stable surface for subsequent measurements.

Measurements

Four master casts and 80 definitive casts (40 conventional/control and 40 digital/test) were scanned with a proprietary scanner (Cagenix, Cagenix Inc) with a

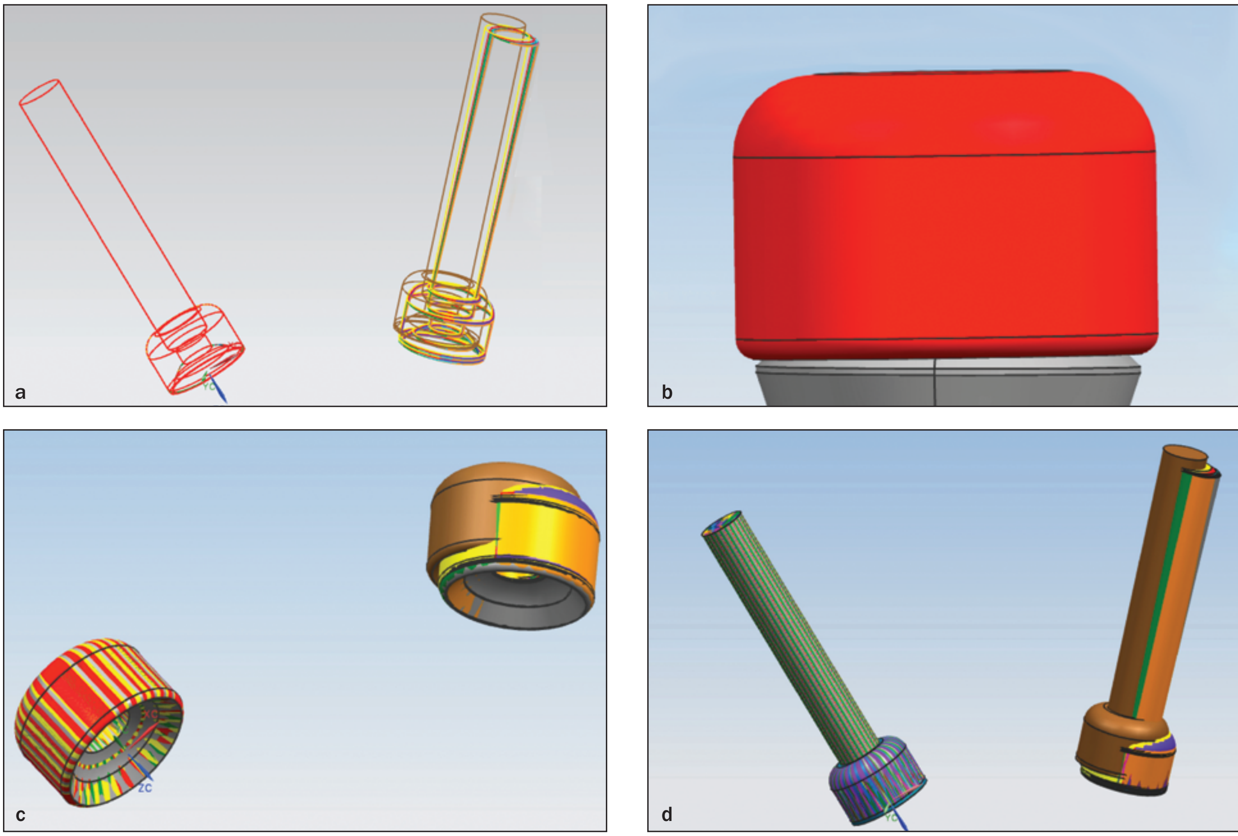

Fig 3 The individual virtual mating cylinders representing the scanned positions of implants. (*a*) The scanned implant positions. (*b*) A virtual single-screw lift test was created in the second mating cylinder. (*c*) Distance measurements were taken from the center point of virtual mating cylinders. (*d*) Angular measurements were taken from the vertical axes of mating cylinders.

noncontact laser probe and a proprietary scanning gauge (Cagenix) that was accurate to within 1 μm (Fig 3a). All the scans for individual analog positions were performed within a repeatability of under 0.1 degree and 25 μm. From the scan data, individual mating cylinders positioned on the restorative platforms were created and aligned for the subsequent measurements. All resulting scan data from the definitive casts were aligned to the corresponding master cast, where the mesially positioned mating cylinder was aligned to match the mating surface, axis, and orientation of the master cast. This process allowed for the creation of a virtual single-screw lift test, in which all of the misalignment was presented in the distal mating cylinder (Fig 3b). Distance and angle measurements were taken between the two mating cylinders without forcing them into alignment. Distance measurements were taken from the center points of the bottom cylindric mating surfaces of the mating cylinders (Fig 3c). Angular measurements were taken from the vertical axes of the second mating cylinders (Fig 3d). The results were recorded as the deviations in distance and angle measurements between each definitive cast and the corresponding master cast.

Statistical Methods

Summary statistics were generated for deviations in distance (in millimeters) and angular (in degrees) measurements, stratified by impression technique and angulation. Two-way analysis of variance (ANOVA), with implant divergence and impression technique as main effects and an interaction effect, was performed to assess the differences between two main effects using the F and *t* tests. Where significant, the effect of impression technique was analyzed separately by degrees of implant divergence by testing appropriate pairwise comparisons within the interaction model. Residual diagnostics were performed to assess the normality of the data and identify outliers.

RESULTS

Deviations in Distance

Residual diagnostics revealed two influential observations; thus, further analysis of deviations in distance excluded these two outliers. Table 1 provides the summary statistics for deviations in distance, stratified by impression technique and degree of implant

Table 1 Summary Statistics of Deviations in Distance According to Impression Technique and Implant Divergence

Impression technique/implant divergence (deg)	n	Average distance deviation (mm)	SD
Conventional			
0	10	0.084	0.050
15	10	0.068	0.043
30*	9	0.078	0.040
45*	9	0.082	0.063
Digital			
0	10	0.304	0.141
15	10	0.328	0.053
30	10	0.237	0.081
45	10	0.158	0.089

*Summary statistics used, after outlying observation(s) were excluded.

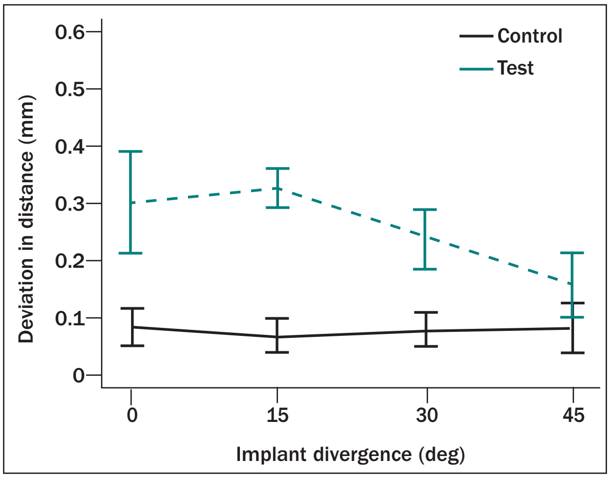

Fig 4 Average deviations in distance and 95% confidence intervals according to impression technique and implant divergence.

Table 2 Comparisons of Deviations in Distance Measures

	Difference (mm)	Standard error	*P* value
Digital vs conventional			
0 deg	0.221	0.035	< .001
15 deg	0.260	0.035	< .001
30 deg	0.159	0.036	< .001
45 deg	0.075	0.036	.037
Linear trend			
Conventional	0.006	0.112	.960
Digital	–0.530	0.109	< .001

Table 3 Summary Statistics of Deviations in Angular Measurements According to Impression Technique and Angulation

Impression technique/implant divergence (deg)	n	Average angular deviation (deg)	SD
Conventional			
0	10	0.612	0.240
15	10	0.710	0.296
30	10	0.718	0.622
45	10	0.810	0.500
Digital			
0	10	1.598	0.543
15	10	2.261	0.433
30	10	0.722	0.276
45	10	1.248	0.752

divergence. Results from the two-way ANOVA model suggested significant differences in impression technique ($P < .001$) and implant divergence ($P = .008$) and an interaction effect ($P = .003$). Because of the interaction, the difference in deviations in distance was compared by impression technique and then by implant divergence. Table 2 and Fig 4 show that there was a significant difference in deviation for each configuration of the implants (0, 15, 30, and 45 degrees of divergence) between the conventional and digital groups ($P < .05$ for all implant divergence). Additionally, Table 2 displays the estimates of differences for the comparisons of interest. There was evidence of a strong decreasing linear trend ($P < .001$) in deviations in distance across different degrees of implant divergence for the test group; however, this effect was not evident for the conventional casts ($P = .960$). This suggests that the deviations decreased with increasing implant divergence ($P < .001$) for the digital casts.

Deviations in Angulation

Table 3 provides the summary statistics for angular deviations, stratified by impression technique and implant divergence. In contrast to the deviations in distance measures, there were no outliers in the deviations in angular data. Results of two-way ANOVA exhibited significant effects for overall impression technique ($P < .001$) and implant divergence ($P < .001$), as well as an interaction ($P < .001$). Since there was a significant interaction, the difference in angular deviations was compared by impression technique and then by implant divergence. Table 4 and Fig 5 show significant differences in deviations in angle at implant divergences of 0 and 15 degrees ($P < .01$), as well as 45 degrees ($P = .049$), between the conventional and digital groups. No significant difference in angular deviations was found for the 30-degree implant divergence setup ($P = .984$) between control and test groups. Table 4 displays the estimates of differences for the comparisons of interest. The deviations in angular measurements across different degrees of implant divergence were not statistically different for the conventional casts ($P = .386$); however, for the digital casts, there was a suggestion that the deviations decreased with increasing implant divergence ($P < .001$).

DISCUSSION

The definitive stone casts created through conventional methods showed consistent angular and distance measurements in all groups, with no significant differences. In other words, the amount of divergence between two implants (0, 15, 30, or 45 degrees) did not affect the accuracy of definitive stone casts fabricated from traditional polyvinyl siloxane open-tray impressions. Although there are many potential errors introduced in the conventional pathway, such as dimensional changes in the impression, custom tray, and stone materials, as well as inaccurate repositioning and connection of impression copings and implant analogs during impression taking and stone cast fabrication, there was no significant effect on the accuracy of definitive stone casts between parallel and angulated two-implant scenarios. This result is in line with some previous studies[10,17] that showed that the axial angulation of two or three implants, within 15 degrees of divergence, was not associated with inaccuracy in definitive stone casts created from impressions using custom trays, polyvinyl siloxane material, and nonsplint open-tray impression copings. Although some studies have suggested that rigidly splinted internal-connection impression copings can improve the accuracy of definitive casts,[12,13] removal of such rigidly splinted impression copings may be impossible in some clinical situations with severely divergent implants.[30] The result of the current study validates the use of a nonsplint open-tray impression technique for two internal-connection implants with divergence up to 45 degrees.

Other studies showed that angulations of the implants may cause distortion of impressions.[6,7] However, four or more implants were used in these studies, and it seems that the effect of implant divergence on the accuracy of impressions may be amplified by an increased number of internal-connection implants because of the higher forces required to remove the impression tray and the amount of stress generated in the impression.[6,7,13] The varying results among different studies of the accuracy of definitive stone casts fabricated from angulated implants and conventional methods may be a result of the employment of different numbers of implants, different prosthetic connection mechanisms, and different evaluation methods.

This study demonstrated that, regardless of different amounts of implant divergence, the definitive milled casts fabricated through the digital method tested showed more deviations in angular and distance measurements than stone casts created conventionally. The amount of divergence between the two implants (0, 15, 30, and 45 degrees) also significantly affected the accuracy of milled casts created digitally.

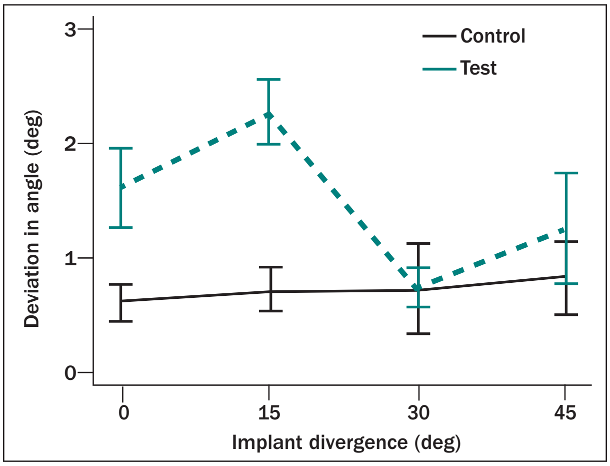

Fig 5 Average deviations in angular measurements and 95% confidence intervals according to impression technique and implant divergence.

Table 4 Comparisons of Interest for Angular Deviations

	Estimate (deg)	Standard error	*P* value
Digital vs conventional			
0 deg	0.986	0.218	< .001
15 deg	1.551	0.218	< .001
30 deg	0.004	0.218	.984
45 deg	0.438	0.218	.049
Linear trend			
Conventional	0.602	0.690	.386
Digital	–2.588	0.690	< .001

At 0 and 15 degrees of implant divergence, the digital method resulted in a highly significant negative effect on the accuracy of definitive casts. At 30 degrees of divergence, casts made with the digital method showed no difference in deviations of angular measurements versus casts fabricated with the conventional method. At 45 degrees of divergence, the digital pathway showed only marginally significant differences in deviations of both distance and angular measurements versus casts fabricated conventionally. The result suggests that the digital method produced more accurate definitive casts when the divergence between two implants was greater than 30 degrees. This result is not comparable with a previous study on the accuracy of a digital impression system (Lava Chairside Oral Scanner, 3M ESPE) showing that the accuracy of digital impressions was not significantly affected by the angulations of the implants.[29] However, a complete comparison between these two studies is not possible. First, there was no control group (with a conventional fabrication method) in the previous study, and only differences in distance were measured. Second, different digital impression systems with two distinct scanning mechanisms and technologies were used. Finally, the previous study compared only the accuracy of scanned results, and the current study measured the accuracy of the definitive casts created through the digital pathway. Additional errors may be introduced, for example, in the digital modeling process of original scanned data, during CAD/CAM definitive cast milling, or during manual insertion of the implant analogs into the definitive casts. These additional errors may also have caused the two influential observations (two excluded outliers) seen in the measurements of deviations in distance in the present study. However, it created grounds for equal comparison between the stone casts and the milled casts. This study has also provided different clinically relevant information, since a fully virtual pathway may not be possible for all treatment options, and the physical definitive casts are still required for different treatment modalities.

Biomet 3i introduced the Encode restorative system and Robocast technology. In this system, healing abutments with specific occlusal surface codes (Encode healing abutments) are used to replace impression copings, and replicas of coded healing abutments on the initial definitive casts can be interpreted by a digital scanner into the positions and orientations of implants.[19] A robotic arm can then place and secure the implant analogs on the initial definitive casts (Robocasts). This pathway eliminates the need for an implant-level impression, and the definitive impression can be made with digital impression systems or with traditional elastomeric impression materials. Although many advantages have been proposed with this technique, including minimized trauma to the peri-implant soft tissue, reduced chair time, and less potential for error during impression and cast fabrication, limited data are available regarding this protocol.[19–21] Conflicting information has been published regarding the effect of angulated implants on the Robocasts fabricated from the Encode system. However, the different publications agreed that the Encode/Robocast technique resulted in definitive casts that were less accurate than definitive casts made from traditional open- and closed-tray impression techniques for both parallel and angulated implant model scenarios.[19–21]

In this study, the definitive casts created through the digital pathway with two-piece scannable impression copings and an intraoral digital scanner (Cadent iTero, Cadent Ltd) were demonstrated to be less accurate in this study, especially in the scenarios with 0 and 15 degrees of implant divergence. The use of digital technology to obtain milled polyurethane definitive casts for multiple-unit restorations may potentially lead to framework fit that is less accurate than with conventional methods. To ensure passive fit of the definitive prosthesis, a verification device and cast may be used in a digital workflow.[31] With additional development of intraoral scanners and CAD/CAM systems, the verification device and cast may be unnecessary. Clinicians can also perform a framework trial insertion to verify the accuracy of the definitive cast. Additional laboratory and clinical research is indicated to compare the accuracy of definitive casts created from different digital impression systems and its relevance to clinical care.

CONCLUSION

In this laboratory-based study, the accuracy of definitive casts created using a digital pathway (digital implant-level impression with two-piece scannable impression copings and intraoral scanner) and those created using a conventional method (traditional implant-level impression with open-tray impression copings and polyvinyl siloxane material) using standardized parallel and divergent (by 15, 30, or 45 degrees) master casts was compared. The digital pathway produced less accurate definitive casts, with larger distance and angular deviations on all tested two-implant models, and the amount of divergence between the two implants significantly affected its accuracy. Specifically, within the limitations of this laboratory-based analysis, it can be concluded that:

1. The divergence between the two implants (0, 15, 30, and 45 degrees) did not affect the accuracy of definitive stone casts created through traditional implant-level impressions made with open-tray impression copings and polyvinyl siloxane ($P = .970$).
2. The divergence between the two implants (0, 15, 30, and 45 degrees) significantly affected the accuracy of definitive milled casts created through a digital implant-level impression technique with two-piece scannable impression copings and an intraoral scanner ($P < .001$). A decreasing linear trend ($P < .001$) in deviations for both distance and angle measurements suggested that the digital pathway produced more accurate definitive casts when the two implants diverged more.
3. At 0 and 15 degrees of implant divergence, the digital pathway resulted in highly significantly less accurate definitive casts compared with the conventionally created casts. At 30 and 45 degrees of implant divergence, the casts made digitally showed either no difference (30 of divergence, deviations in angular measurements; $P = .984$) or only marginal differences (45 degrees of divergence, deviations in distance measurements, $P = .037$, and deviations in angular measurements, $P = .049$) compared to those created conventionally.

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