

Effect of dental implant angulation on the dimensional accuracy of master casts

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Abstract

Background. Making accurate impressions of dental implants and transferring their three-dimensional (3D) position to master casts is critical for the passive fit of prosthetic frameworks.

Objectives. This study aimed to assess the effect of dental implant angulation on the dimensional accuracy of master casts.

Material and methods. An acrylic model with 2 external hexagonal implants was used in this in vitro experimental study. The impressions of the model were made in 42 positions, with different angulation of the 2 implants, ranging from +15° to –15°, by means of the open-tray and closed-tray impression techniques, using a polyvinyl siloxane impression material. The spatial coordinates of the implants were measured on the X, Y and Z axes. The dimensional accuracy of the impressions made at different positions (parallel, convergent and divergent) and different angulation of the implants were determined. The data was analyzed using the one-way analysis of variance (ANOVA), Student's *t* test and Tukey's test.

Results. Casts with the lowest accuracy were obtained when the 2 implants were divergent by 25° ($R = 1.1336$). However, the position of the 2 implants had no significant effect on the dimensional accuracy of the master casts. The error rate was 0.4181 in the open-tray technique and 0.5095 in the closed-tray technique, with no significant difference between them ($p > 0.05$). The angulation of the 2 implants had a significant effect on the dimensional accuracy of the master casts ($p = 0.0001$).

Conclusions. Considering the significant effect of implant angulation in the range from +15° to –15° relative to the longitudinal axis on the dimensional accuracy of master casts, further studies are required to reach a final conclusion in this respect.

Keywords: dental implants, dimensional accuracy, dental impression technique, dental implant angulation, master cast

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Introduction

Dental implants are presently in high demand. Due to the high success rate of implant treatment, implant-supported restorations are the first choice for prosthetic treatment.¹ Biomechanically, implant-supported restorations are fabricated with the aim of achieving passive fit in the attachment of abutments and fixtures. Passive fit is imperative to ensure equal stress distribution at the bone–implant interface. Precise clinical and laboratory steps are taken to achieve passive fit.² Misfit would cause internal stresses, and their subsequent transfer to implants and the bone matrix.³ In the fabrication of implant-supported restorations, the accurate transfer of the intraoral position of the implant to the cast is much more important than it is for natural teeth.⁴ In these restorations, the applied physiological forces are transferred to the surrounding bone in a manner that is similar to what occurs in natural teeth.⁵ However, due to the absence of the periodontal ligament around a dental implant, misfit can result in destructive stresses in the bone–implant complex.³ Moreover, evidence shows that the absence of passive fit in implant-supported restorations can cause tiny bone fractures or ischemic marginal zones. The healing of these lesions involves the formation of fibrous connective tissue at the bone–implant interface and prevents osseointegration or causes peri-implant bone loss.⁵

Framework misfit can cause biological and biomechanical problems. The application of excessive load, exceeding the physiological threshold of the implant-supporting bone, can cause pain, tissue irritation, marginal bone loss, and impaired osseointegration.^{4,6} The mobility and fractures of implant components are among biomechanical problems that may occur.^{7,8}

Moreover, active fit is the primary cause of the mobility of restorations, abutment screw loosening, bone loss, and the fractures of implant components.⁹ The amount of stress that can clinically compromise the long-term stability of implants has not been determined.¹⁰ It seems that accurate impression making, the safe transfer of the impression to the laboratory without distortion and the fabrication of an accurate model are important to achieve passive fit.¹¹ The first step is to precisely record the position of the implant in the oral cavity and transfer it to the cast by making an accurate impression.¹² However, in all impression techniques, a range of errors may occur in the transfer of the implant position, and the elimination of errors in impression making is not clinically feasible.¹³ As mentioned, impression making is an important step in the fabrication of implant-supported restorations. It plays a fundamental role in obtaining the dimensional accuracy of the final cast.^{4,14} However, it should be noted that when the angulation or position of the implant are incorrect, the impression making process is difficult, and requires more time and higher precision.¹⁵

Considering the controversy regarding the dimensional accuracy of different impression techniques and the gap of information on the selection of the best impression technique for angulated implants, further studies on this topic seem imperative. This study aimed to assess the effect of dental implant angulation on the dimensional accuracy of master casts.

Material and methods

In this *in vitro* study, the impression of the mandible of a 53-year-old patient was made. The patient had implants at the sites of teeth 29 and 31. A special tray was custom-made for this patient. An accurate impression was made and a dental stone cast was fabricated. The master model was prepared by duplicating the stone cast and pouring an acrylic resin (Lucitone® Clear; Dentsply International, York, USA). At the art portion of the master model, 3 tray stops were fabricated. It should be noted that this model did not have teeth 17, 29, 30, 31, and 32, according to the Universal Numbering System. Also, at the sites of teeth 18, 19 and 28, metal balls with a diameter of 3 mm were incorporated, acting as reference points in measurements.

A metal device was designed to adjust the different angles of the impression copings. The device consisted of 2 stainless steel plates connected to each other by means of 3 vertical rods (Fig. 1). The upper plate measured 198 mm in length, 151.5 mm in width and 10.3 mm in height. The lower plate measured 197.5 mm in length, 151.2 mm in width and 18.73 mm in height. Two of the connecting rods located at the sides of the device had a diameter of 20 mm and a length of 163.5 mm, while the third rod was at the front, and measured 10 mm in diameter and 101 mm in length. In the lower plate, 2 holes with a diameter of 20 mm were made to pass the 2 side rods and connect them to the upper plate. A number 6 screw was used to tighten the rods. Both of the rods passed through the upper plate, with 3 cm of the end part of them sticking out of the device. To prevent errors, a number 18 screw was placed over the rods to tighten them (Fig. 2).



Fig. 1. Device used in the study

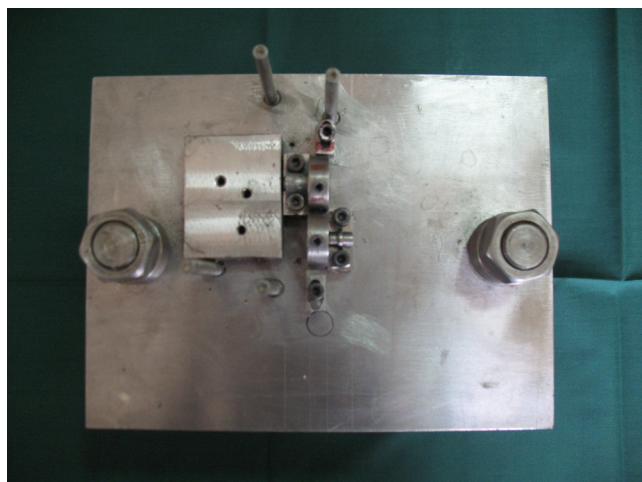


Fig. 2. Top view of the device

This device had 2 implant holders at the sites of teeth 29 and 31, which allowed changing the angulation of the implants. The implant holders were located on 2 spherical metal components measuring 22 mm in diameter and 8 mm in thickness. The location of an 8-millimeter-deep implant hole was determined using a surveyor with its axis directed at the center of the implant hole (Fig. 3). Shafts measuring 8 mm in larger diameter and 6 mm in smaller diameter were designed for the mobilization of the 2 described components. The assembly of the spherical metal component and the shaft was placed on a base measuring 25 mm in length, 10 mm in width and 11.5 mm in height. Two number 4 screws on each base attached them to the upper plate. For a better placement of the bases on the plate, 2 plates measuring 25 mm in length, 10 mm in width and 1 mm in depth were created and positioned lower than the level of the upper plate.

A plate measuring 50 mm in length, 40 mm in width and 12.3 mm in height was used to level the position of the master model and the implant holders. Four number 4 vertical rods were used around the master model

on the device to standardize the path of insertion and retrieval of the tray (Fig. 4).

The implant holders were designed so that they could angulate each implant relative to the vertical axis (perpendicular to the occlusal plane and the device) by 0° , $\pm 5^\circ$, $\pm 10^\circ$, and $\pm 15^\circ$. The center of rotation of both implant holders, which corresponded to the implant apex, was at the same level. To fix the desired angle, the position of both implant holders was secured with a metal blade. The 2 external hexagonal implants placed in the implant holders measured 4 mm in diameter and 15 mm in length (OSS415; Implant Innovations Inc., Palm Beach Gardens, USA). The impression of the master model was made using a prefabricated tray and an additional silicone impression material (A-Silicone; Zhermack, Badia Polesine, Italy), and the primary cast was poured. Two layers of base plate wax (TruWax®; Dentsply Trubyte, York, USA) were applied on the cast except for the stop points.^{8,13} The cast was duplicated and turned into a stone model to standardize the space for the fabrication of trays for all samples. A light-cured acrylic resin (Preci-Tray; YETI Dental, Engen, Germany) was used for the fabrication of trays.

To fabricate a special tray for the open-tray impression technique, all of the aforementioned steps were repeated following the placement of the direct impression copings on the primary cast. Holes with a diameter of 3 mm, a 0.5-centimeter distance from each other and a wing were created on special trays. There were 2 holes at each side (a total of 4). The 4 vertical rods were passed through the 4 holes to determine the path of insertion of the tray. A metal plate weighing 430 g¹⁶ was placed over the wing during the setting of the impression material to simulate hand pressure. The 2 implants could have 42 different positions relative to each other, with different angulation, including 6 angles for implant 5 and 7 angles for implant 7: 0° , $\pm 5^\circ$ and $\pm 10^\circ$ relative to the vertical axis for both implants; $\pm 15^\circ$ for the implant at the site of tooth 31 (implant 7), and -15° for the im-



Fig. 3. Accommodating the implant axis to the center of the implant hole by means of a surveyor

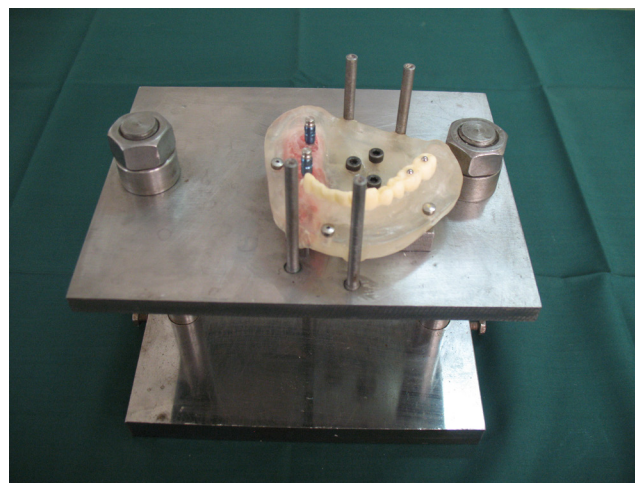


Fig. 4. Acrylic model on the device and the vertical guiding rods around it

plant at the site of tooth 29 (implant 5). Before making any impressions, the open and closed impression copings were attached to the implants of the master model. The basic three-dimensional (3D) measurements on the X, Y and Z axes were performed using a coordinate-measuring machine (CMM).

Before making the impression, a silicone adhesive material (Tray Adhesive; Zhermack) was applied on the internal margins and on 3 mm of the external margins of the fabricated tray, allowing 1 min to set, according to the manufacturer's instructions. A polyvinyl siloxane impression material (Monophase Medium Body, A-Silicone; Zhermack) was injected into the tray and around the impression copings (Fig. 5). The metal plate was placed over the wing, and the 4 vertical rods were passed through the 4 holes (Fig. 6). The tray stops matched the model stops and the tray was finally seated. After the final setting of the impression material, which took 5 min and 30 s, as stated in the manufacturer's instructions, the tray was removed from the model.

In the open-tray technique (direct pick-up coping), the direct impression copings were unscrewed prior to the

removal of the impression and were separated from the model simultaneously with the removal of the impression (Fig. 7).

In the closed-tray technique (indirect transfer coping), the indirect impression copings were screwed into the implants, and after making the impression and separating them from the model, the copings were opened and attached to the implant analogs. The analog–coping complex was then placed in the impression.

Gingifast (Zhermack) was injected around the copings in the trays before pouring the casts. The metal balls were also placed at their respective locations in the impression. The final cast was poured with type IV dental stone (Zhermack) (Fig. 8). For the purpose of standardization, the powder to liquid ratio of the dental stone was determined according to the manufacturer's instructions, and mixing was performed with a vacuum mixer (Vac-U-Mixer; Whip Mix Corporation, Louisville, USA).

After the final setting of the gypsum (45 min), the final position of the 2 implants in the X, Y and Z axes relative to the reference points was determined using CMM with an accuracy of 0.1 μm (Fig. 9). A coordinate-measuring

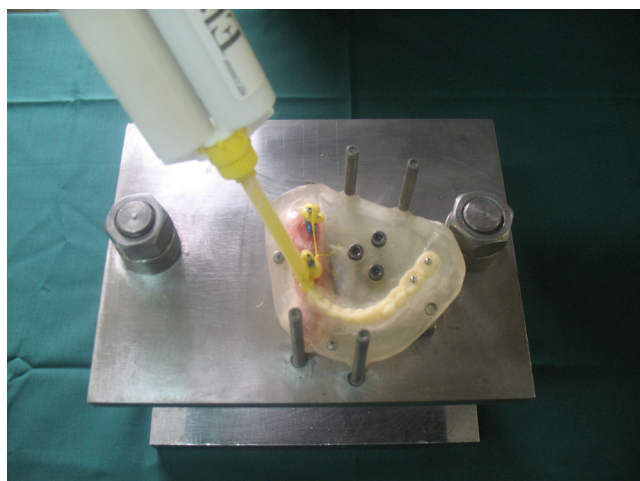


Fig. 5. Injecting the impression material over the copings

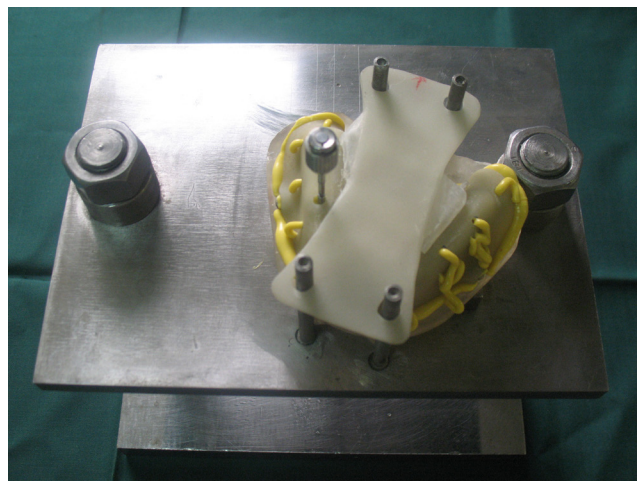


Fig. 7. Open-tray impression technique



Fig. 6. Metal plate covering the wing during impression making

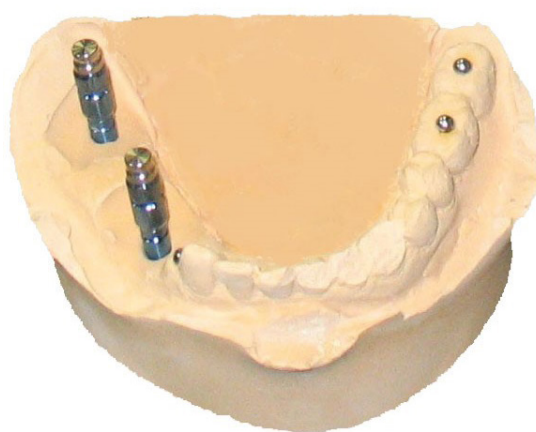


Fig. 8. Final cast

machine is a high-precision contact instrument with a 1 m × 1/8 m table and a sensitive probe that moves along the entire length and width of the table with 2 arms – vertical and horizontal. In a standard specific place on the table, there is a sphere with a fixed and reliable diameter so that the position of the probe and the tip size can be calibrated each time the probe is changed in terms of the 3 dimensions.

The sensitivity of the probe tip to contact is such that it measures the position of any point on the surface of an object relative to the standard sphere in the X, Y

and Z dimensions with an accuracy of 0.1 µm over the entire area of the table. After providing settings and defining a spherical body by means of the Trimek software (Altube-Zuia, Spain), this device is able to specify the exact coordinates of the center of this sphere in relation to the standard sphere, and also indicate its out of sphericity (Fig. 10). In this study, the coordinates of the center of the direct and indirect impression copings relative to the 3 metal balls placed at the sites of teeth 18, 19 and 28 were determined in the 3 dimensions. The measurements were performed in triplicate, and the mean values were calculated and used for the statistical analysis.

Statistical analysis

The coordinates of the center of each implant in the 3 dimensions in different impression techniques and at different angulation were determined, and differences with regard to the reference points were calculated.

The data was analyzed using the IBM SPSS Statistics for Windows software, v. 25.0 (IBM Corp., Armonk, USA). Differences in the X, Y and Z coordinates of the samples at different angulation, both in the open- and closed-tray techniques, were determined relative to the coordinates of the reference points, and the overall value in the 3 axes was calculated using the following formula (Equation 1):

$$\Delta R = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2} \quad (1)$$

where:

R – spatial position;

X, Y, Z – coordinates in the 3 axes.

This was considered to be the dimensional accuracy of each impression. The statistical analysis was carried out using the independent *t* test and the one-way analysis of variance (ANOVA). Considering the significant effect of the angulation of the 2 implants relative to each other on the dimensional accuracy of the impressions, pairwise comparisons of different angulation were carried out using Tukey's test. A *p*-value <0.05 was considered statistically significant.

Results

The estimation of errors in the master cast in different implant positions revealed the maximum error in the parallel position of the 2 implants, when each of them was at an angle of –10° relative to the vertical axis (*R* = 1.3665). Also, the minimum error was noted when implant 5 was at an angle of –15° and implant 7 was at an angle of 10° relative to the vertical axis of the implant (*R* = 0.0188).

The impression error values in the parallel states of the 2 implants as well as in their different convergences and divergences according to their angular positions are presented in Table 1.



Fig. 9. Coordinate-measuring machine (CMM)

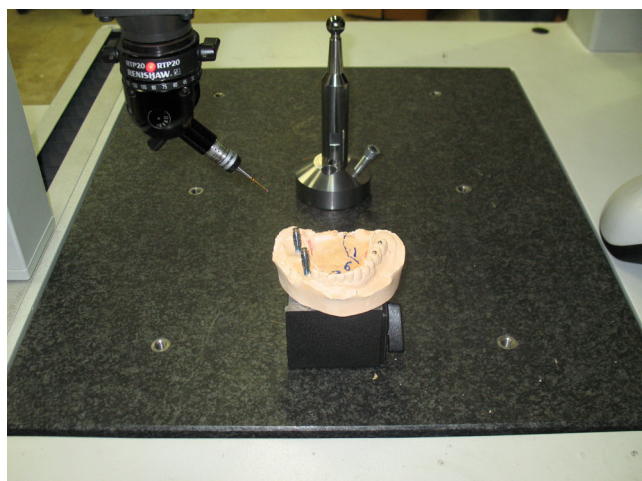


Fig. 10. Contact of the probe with the sphere

Table 1. Impression error values in the parallel, convergent and divergent positions of the 2 implants according to their angulation relative to the longitudinal axis

Position	Angulation relative to the longitudinal axis [°]		Number of positions	Impression error	p-value
	implant 5	implant 7			
Parallel	0	0	2	0.3104 ±0.04178	0.059
	5	5	2	0.7112 ±0.53412	
	10	10	2	0.0690 ±0.01858	
	-5	-5	2	0.1150 ±0.00000	
	-10	-10	2	1.3665 ±0.67123	
	-15	-15	2	0.8849 ±0.13626	
5° convergence	0	5	2	0.4360 ±0.00994	<0.001*
	-5	0	2	0.0662 ±0.02394	
	5	10	2	0.9317 ±0.16470	
	10	15	2	0.0739 ±0.01089	
	-10	-5	2	0.0229 ±0.01042	
	-15	-10	2	0.7555 ±0.05273	
10° convergence	0	10	2	0.2524 ±0.01513	<0.001*
	-10	0	2	0.0614 ±0.00740	
	5	15	2	1.2536 ±0.03511	
	-5	5	2	0.0514 ±0.02031	
	-15	-5	2	0.2557 ±0.00434	
15° convergence	0	15	2	0.5543 ±0.06516	0.578
	-15	0	2	0.2959 ±0.02914	
	-10	5	2	1.3048 ±1.78376	
	-5	10	2	0.0418 ±0.03786	
20° convergence	-15	5	2	0.0288 ±0.02071	0.005*
	-10	10	2	0.1081 ±0.02135	
	-5	15	2	0.2477 ±0.02627	
25° convergence	-15	10	2	0.0188 ±0.01102	0.086
	-10	15	2	0.1059 ±0.03732	
30° convergence	-15	15	2	0.6949 ±0.65102	-
5° divergence	0	-5	2	0.3914 ±0.06898	<0.001*
	5	0	2	0.9371 ±0.00040	
	10	5	2	0.0543 ±0.03306	
	-5	-10	2	0.7191 ±0.06766	
	-10	-15	2	0.9966 ±0.00399	
10° divergence	0	-10	2	0.2709 ±0.05986	<0.001*
	10	0	2	0.0660 ±0.01349	
	5	-5	2	0.9406 ±0.09869	
	-5	-15	2	0.9709 ±0.06278	
15° divergence	0	-15	2	0.7171 ±0.05593	0.014*
	5	-10	2	0.0940 ±0.09059	
	10	-5	2	0.0728 ±0.06300	
20° divergence	5	-15	2	0.0674 ±0.01360	0.002*
	10	-10	2	1.0299 ±0.05283	
25° divergence	10	-15	2	1.1336 ±0.06927	-

Data presented as mean ± standard deviation ($M \pm SD$). * statistically significant.

According to the results of ANOVA and the *t* test, a significant difference was observed in 5°, 10° and 20° convergences, and in 5°, 10°, 15°, and 20° divergences.

ANOVA showed that the parallel, convergent and divergent positions of the 2 implants relative to each other had no significant effect on the impression error ($p = 0.251$). The maximum mean impression error was noted in the 25° divergent position of the 2 implants ($R = 1.1336$) (Table 2).

The effect of the angulation of implants 5 and 7 relative to the vertical axis on the impression error was significant ($p < 0.0001$) (Table 3).

The results of the pairwise comparisons of different angulation with the use of Tukey's test did not show any significant differences in the 2 subgroups described below (implant 5 vs. implant 7):

- subgroup 1 (impression error range: 0.0188–0.3104): –15° vs. 10°; –10° vs. –5°; –15° vs. 5°; –5° vs. 10°; –5° vs. 5°; 10° vs. 5°; –10° vs. 0°; 10° vs. 0°; –5° vs. 0°; 5° vs. –15°; 10° vs. 10°; 10° vs. –5°; 10° vs. 15°; 5° vs. –10°; –10° vs. 15°; –10° vs. 10°; –5° vs. –5°; –5° vs. 15°; 0° vs. 10°; –15° vs. –5°; 0° vs. –10°; –15° vs. 0°; 0° vs. 0°; and
- subgroup 2 (impression error range: 0.3914–1.3665): 0° vs. –5°; 0° vs. 5°; 0° vs. 15°; –15° vs. 15°; 5° vs. 5°; 0° vs. –15°; –5° vs. –10°; –15° vs. –10°; –15° vs. –15°; 5° vs. 10°; 5° vs. 0°; 5° vs. –5°; –5° vs. –15°; –10° vs. –15°; 10° vs. –10°; 10° vs. –15°; 5° vs. 15°; –10° vs. 5°; –10° vs. –10°.

The impression technique (open- or closed-tray) had no significant effect on the impression error in different implant positions ($p = 0.390$). Accordingly, the mean error rate was 0.4460 ± 0.4181 in the open-tray technique and 0.5245 ± 0.5095 in the closed-tray technique. The difference in this respect between the 2 techniques was not significant ($p > 0.05$) (Table 4).

Table 2. Impression error values in the parallel, convergent and divergent positions of the 2 implants relative to each other

Position	Number of positions	Impression error	<i>p</i> -value
Parallel	12	0.5761 ± 0.54887	0.251
5° convergence	12	0.3810 ± 0.37747	
10° convergence	10	0.3749 ± 0.47262	
15° convergence	8	0.5492 ± 0.84289	
20° convergence	6	0.1282 ± 0.10072	
25° convergence	4	0.0624 ± 0.05505	
30° convergence	2	0.6949 ± 0.65102	
5° divergence	10	0.6197 ± 0.37407	
10° divergence	8	0.5621 ± 0.43095	
15° divergence	6	0.2946 ± 0.33203	
20° divergence	4	0.5486 ± 0.55655	
25° divergence	2	1.1336 ± 0.06927	

Data presented as $M \pm SD$.

Table 3. Impression error values in different angular positions of implants 5 and 7 relative to the vertical axis of the implant (ANOVA)

Angulation [°]		Impression error	<i>p</i> -value
implant 5	implant 7		
0	0	0.3104 ± 0.04178	0.0001*
5	5	0.7112 ± 0.53412	
10	10	0.0690 ± 0.01858	
–5	–5	0.1150 ± 0.00000	
–10	–10	1.3665 ± 0.67123	
–15	–15	0.8849 ± 0.13626	
0	5	0.4360 ± 0.00994	
0	10	0.2524 ± 0.01513	
0	15	0.5543 ± 0.06516	
0	–5	0.3914 ± 0.06898	
0	–10	0.2709 ± 0.05986	
0	–15	0.7171 ± 0.05593	
5	0	0.9371 ± 0.00040	
10	0	0.0660 ± 0.01349	
–5	0	0.0662 ± 0.02394	
–10	0	0.0614 ± 0.00740	
–15	0	0.2959 ± 0.02914	
5	10	0.9317 ± 0.16470	
5	15	1.2536 ± 0.03511	
5	–5	0.9406 ± 0.09869	
5	–10	0.0940 ± 0.09059	
5	–15	0.0674 ± 0.01360	
10	5	0.0543 ± 0.03306	
–5	5	0.0514 ± 0.02031	
–10	5	1.3048 ± 1.78376	
–15	5	0.0288 ± 0.02071	
10	15	0.0739 ± 0.01089	
10	–5	0.0728 ± 0.06300	
10	–10	1.0299 ± 0.05283	
10	–15	1.1336 ± 0.06927	
–5	10	0.0418 ± 0.03786	
–10	10	0.1081 ± 0.02135	
–15	10	0.0188 ± 0.01102	
–5	15	0.2477 ± 0.02627	
–10	15	0.1059 ± 0.03732	
–15	15	0.6949 ± 0.65102	
–5	–15	0.9709 ± 0.06278	
–10	–5	0.0229 ± 0.01042	
–15	–5	0.2557 ± 0.00434	
–5	–10	0.7191 ± 0.06766	
–10	–15	0.9966 ± 0.00399	
–15	–10	0.7555 ± 0.05273	

Data presented as $M \pm SD$. * statistically significant.

Table 4. Mean impression error values in the open- and closed-tray techniques

Angulation [°]		Open-tray technique	Closed-tray technique
implant 5	implant 7		
0	0	0.2808	0.3399
5	5	0.3335	1.0889
10	10	0.0558	0.0821
-5	-5	0.1150	0.1150
-10	-10	1.8411	0.8918
-15	-15	0.9812	0.7885
0	5	0.4431	0.4290
0	10	0.2417	0.2631
0	15	0.5082	0.6004
0	-5	0.3427	0.4402
0	-10	0.2286	0.3132
0	-15	0.6776	0.7567
5	0	0.9374	0.9369
10	0	0.0756	0.0565
-5	0	0.0831	0.0492
-10	0	0.0667	0.0562
-15	0	0.2753	0.3166
5	10	1.0482	0.8152
5	15	1.2287	1.2784
5	-5	1.0104	0.8709
5	-10	0.0229	0.1581
5	-15	0.0770	0.0578
10	5	0.0777	0.0310
-5	5	0.0657	0.0370
-10	5	0.0435	2.5661
-15	5	0.0434	0.0141
10	15	0.0662	0.0816
10	-5	0.0282	0.1173
10	-10	0.9925	1.0672
10	-15	1.0846	1.1826
-5	10	0.0151	0.0686
-10	10	0.1231	0.0930
-15	10	0.0111	0.0266
-5	15	0.2291	0.2663
-10	15	0.0795	0.1323
-15	15	0.2346	1.1552
-5	-15	0.9265	1.0153
-10	-5	0.0155	0.0302
-15	-5	0.2587	0.2526
-5	-10	0.6713	0.7670
-10	-15	0.9938	0.9995
-15	-10	0.7182	0.7928
Total		0.4181	0.5095

Discussion

Several methods are employed to achieve passive fit in implant-supported restorations. An accurate impression without distortion is imperative to precisely reproduce the position of implants on casts. Considering the problems encountered when making the impressions of angulated implants, this study assessed the effect of dental implant angulation on the dimensional accuracy of master casts and showed that the angulation of the 2 implants (5 and 7) relative to their longitudinal axis in different positions had a significant effect on the dimensional accuracy of the final casts. Conversely, the effect of the impression technique (open- or closed-tray) in the parallel, convergent and divergent positions of the implants on the impression error was not significant. In other words, implant angulation affected the impression error.

Errors in impression making may be related to the type of impression material, the technique of impression making, the performance of the dentist, the incorrect position of impression copings, and the incorrect attachment of implant components. Although the passive fit of implants has been the topic of many investigations, the clinical significance of dimensional changes or distortion has not been adequately emphasized. Also, the acceptable range of errors in the transfer of the intraoral implant position to the dental cast has not been determined yet. The findings of this study were related to the placement of implants 5 and 7 in 42 different positions at the -15°, -10°, -5°, 0°, 5°, 10°, and 15° angles relative to their longitudinal axis, and may not be generalizable to a higher number or other angulation of implants. However, it seems that other angulation has limited application in the clinical setting.

In this study, no specific ascending or descending patterns were noted regarding the impression error in the different angulation of the 2 implants to obtain a definite conclusion in this respect. However, in total, the effect of implant angulation on the impression error was significant ($p = 0.0001$). The significant effect of implant angulation on the dimensional accuracy of the final casts highlights the importance of this topic, especially because implants are placed in angulated positions in many patients. Despite the significance of this topic, studies addressing this issue are limited. Carr¹⁷ and Assuncao et al.¹⁸ reported that angulated implants had lower dimensional accuracy than straight implants, while another study evaluating 3 implants determined that the implant angle had no significant effect on the dimensional accuracy of casts.¹⁹ It seems that when a higher number of implants with different angulation is used, the dimensional changes of the impression material increase.⁴ Conrad et al. evaluated the accuracy of impression techniques when 3 angulated implants were placed at 3 corners of a triangle at angles of 5°, 10° and 15° (convergent or divergent relative to the central implant).⁴ They dem-

onstrated that the implant angle had a significant effect on the dimensional accuracy of casts.⁴ Their findings are in line with the present study, although we used 2 implants and evaluated the 0° angle as well. Carr compared the dimensional accuracy of the final casts obtained with 2 impression techniques for 2 divergent implants (15°).¹⁷ The author showed that this divergence had no significant effect on the dimensional accuracy of impressions. However, straight implants had slightly higher dimensional accuracy than angulated implants. This finding was attributed to the proximity of implant locations (11 mm). In contrast to the present study, the author evaluated only one implant angle.¹⁷ Choi et al. assessed the accuracy of 2 impression techniques for parallel or 8° divergent internal hexagonal implants, and showed that the accuracy of implant impressions was the same in both impression techniques and a degree of divergence up to 8° had no significant effect on the accuracy of impressions.¹⁹ The non-significant effect of the degree of convergence/divergence on the dimensional accuracy of impressions was confirmed in this study.

This study found no significant difference in the dimensional accuracy of the casts when the open- and closed-tray impression techniques were compared. A review of the literature revealed that in the presence of 4 or more implants, the open-tray technique often provides higher accuracy than the closed-tray technique.²⁰ However, studies on 3 or fewer implants mainly found no significant difference between the impression techniques in terms of dimensional accuracy.^{7,10,17} The results of the current study confirm this finding. Since some degrees of error and deformity are inevitable in both techniques, attempts must be made to minimize distortion during different phases of impression making as well as during the transfer of the implant position to the final cast in order to fabricate stress-free implant-supported restorations.^{21,22} Carr found no significant difference between the open- and closed-tray impression techniques when making the impressions of 2 implants with 15° divergence.¹⁷ Conrad et al. evaluated 3 implants and reported a similar level of distortion and deformity for the 2 impression techniques.⁴ Herbst et al. found no significant difference in dimensional accuracy between different impression techniques.⁷

Similar to previous research, this study showed that the distances measured on the original model could not be ideally transferred to the final cast, and that the spatial coordinates of the implants changed relative to each other when transferred to the cast.^{10,23,24} The reason might be the movement of the metal copings when opening or closing the guiding rods or attaching the analog,^{10,25} the dimensional changes of the gypsum,²⁶ the shrinkage of the acrylic resin when the copings were connected to each other,^{10,25,26} changes in the impression material,²⁵ the depth of implant placement,²⁷ soft tissue adhesion (since it could modify the mucosal aspect around the

implant),²⁸ the duration of the use of the dental stone,²⁹ the implant–abutment interface,³⁰ machining tolerance (0.6–136 µm),²⁰ or the operator's error, which is minimally 30 µm in the laboratory setting, but may increase in the oral environment.³¹ Moreover, different methodologies can yield variable results. The designed experimental models (metal or acrylic), different measuring devices, the distances measured relative to the reference points, and different methods of attachment of metal copings can all affect the results. Also, some studies measured the distances in only the X and Y dimensions, while others, including the current study, measured dimensional changes in all 3 dimensions of X, Y and Z, and calculated the spatial position (R), which would enhance the comparison of the results of studies.


There are limitations to this study. It evaluated only 2 implants in a limited range of angulation. Also, the effect of the type of impression material on the dimensional accuracy of casts was not evaluated. Future studies with a higher number of implants, a larger range of angulation (>15°) and different impression materials are required to better elucidate this topic and find a definite conclusion, generalizable to the clinical setting while controlling for a higher number of confounders.


Conclusions

Within the limitations of this in vitro study, the results showed a significant effect of implant angulation (implants 5 and 7) in the range from –15° to +15° on the dimensional accuracy of impressions. The open- and closed-tray techniques were not significantly different in this respect. Under similar conditions, it seems that the closed-tray technique may be preferred due to the ease of use, patient comfort and accuracy comparable to that obtained with the open-tray technique.

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