Effect of Implant Angulation, Connection Length, and Impression Material on the Dimensional Accuracy of Implant Impressions: An In Vitro Comparative Study

Roberto Sorrentino, DDS, MSc, PhD;* Enrico Felice Gherlone, MD, DDS;† Gaetano Calesini, MD, DDS;‡ Fernando Zarone, MD, DDS§

ABSTRACT

Background: With regard to implant-supported prostheses, to date no technique has been proven to guarantee a completely passive fit of prosthetic frameworks. Several clinical variables may affect the precision of impressions, particularly in the presence of implants.

Purpose: To compare the accuracy of implant impressions made with different materials, lengths of impression coping connections, and not parallel position of the implants.

Materials and Methods: A calibrated testing device allowing reproducible standardized positions was used. Two control groups of master models and eight experimental groups with predetermined undercuts were used to make addition silicon and polyether implant impressions by means of the open-tray pick-up technique. Four reference distances were evaluated on each study cast by using a profile projector and a standardized measurement protocol. The data were statistically analyzed by means of three-factor analysis of variance.

Results: The impressions made in the presence of angulated implants were significantly less accurate than the ones made with parallel implants. The tested addition silicon resulted advantageous in presence of nonparallel implants whereas the polyether achieved the best results with parallel implants and standard impression copings.

Conclusions: The angulation of the implants may cause strains of impressions, probably because of the higher forces required for the impression removal. Moreover, undercuts negatively affected the impression accuracy. More accurate casts were obtained using the tested addition silicon in the presence of nonparallel implants and using a standard length connection of the copings in the presence of parallel implants, respectively.

KEY WORDS: dimensional accuracy, implant, implant angulation, impression, impression accuracy, impression coping, impression material, impression technique, parallel implants, prosthodontics

INTRODUCTION

Impression making is a critical clinical step to record accurately the three-dimensional intraoral relationships among implants, teeth, and adjacent structures.[1–4] Inaccuracies during impressions inevitably lead to laboratory errors resulting in lack of precision and misfit of prostheses, particularly in fixed and implant-supported prosthodontics.[4–6]

Differently from natural teeth, osseointegrated implants have no periodontal ligament to compensate for any inaccuracy, only showing a minimal mobility caused by the elasticity of bone tissues.[3,5] Consequently, recording the intraoral three-dimensional position of implants is a more critical task in the realization of

*Doctor, Department of Prosthodontics, University "Federico II," Naples, Italy; †professor, Department of Dentistry, University "Vita Salute San Raffaele," Milan, Italy; ‡private practice, Rome, Italy; §professor, Department of Prosthodontics, University "Federico II," Naples, Italy

Reprint requests: Prof. Fernando Zarone, A.O.U. "Federico II," Dipartimento di Scienze Odontostomatologiche e Maxillo-Facciali, Ed. 14, Via S. Pansini, 5, 80131 Napoli, Italy; e-mail: zarone@tin.it

DOI 10.1111/j.1708-8208.2009.00167.x

implant-supported than in tooth-supported prostheses to ensure an accurate relationship on the master cast.[2,4,7]

Although it is not possible to be clinically highlighted, the fit of a restoration can be considered "passive" if it does not create static loads within the prosthetic system or in the surrounding bone tissue.[2,6] It is nowadays accepted that prosthetic misfit is likely to increase the incidence of mechanical complications, just like occlusal discrepancies, screw, and abutment loosening and fracture of the prosthetic or implant components.[2,8–11] Moreover, marginal discrepancies caused by the misfit might enhance plaque accumulation, affecting soft and/or hard tissues around the implants.[12,13] As to biologic complications, the effect of misfit on the bone tissue around the implants is still controversial.[14,15] To date, most of the authors are prone to consider the passive fit of the prostheses as an advantageous factor for the long-term serviceability of the restorations; as a consequence, the importance of an accurate impression is paramount.[4,16–20]

Several studies investigated the variables affecting the accuracy of impression procedures in implant prosthodontics, such as the different direct or indirect impression techniques, the use of different impression materials, splinting or surface treatment of impression copings, the relative implant angulation, the die material accuracy, and master cast realization.[21–31] As regards framework making, to date, no method has been described in the literature to achieve consistent results in terms of a completely passive fit.[14,15,32] Distortions could be partially compensated using intraoral luting procedures.[33] Furthermore, several techniques have been proposed to reduce the distortion of the implant-supported frameworks, such as the electric discharge machining, the laser welding procedures, the computer numeric-controlled milled titanium frameworks and the computer-aided design–computer-aided manufacturing technologies.[32–40] As to the impression procedures, most of the researchers reported the open-tray pick-up technique to be more precise and predictable than the closed tray technique using repositionable copings.[9,23,41,42] Nonetheless, the open tray technique may present some disadvantages, like the possible imprecise positioning of the copings caused by, for example, vertical or rotational discrepancies.[43–45]

Most of the in vitro studies evaluated how to improve the impression accuracy in ideal conditions, with parallel implants,[1,22,41,42,46,47] whereas fewer investigations were performed to assess the effect of nonparallel implants on the final precision of the impression[21,45,48] and the influence of subgingival implant placement on the dimensional accuracy of casts.[4]

As to the impression materials, both polyethers[9,41,45,49–56] and addition silicons (vinyl polysiloxanes [VPSs])[1,42,52,53,57] have been addressed to be suitable as impression materials for multiple implant restorations, keeping the thickness of such elastomeric materials as uniform as possible[48] and, at the same time, using more rigid trays to reduce the risk of impression distortions.[16,50,58,59]

The purpose of the present in vitro study was to analyze the effect on the pick-up impression accuracy of two different variables: the length of the internal hex connections of the impression copings, and the angulations of the implants. At the same time, a comparison between two elastomeric impression materials (i.e., a polyether and a VPS) was done.

Three null hypotheses were tested:

(1) There would be no significant differences in the accuracy of the implant impressions among the groups with different impression materials.
(2) There would be no significant differences in the accuracy of the implant impressions among the groups with different lengths of the coping internal hex connection.
(3) There would be no significant differences in the accuracy of the implant impressions among the groups with different angulation of implants.

MATERIALS AND METHODS

Testing Device Construction

A stainless steel testing device previously developed by Sedda and colleagues[60] was used. It was made up of four parts: a base, a master model, an impression carrier, and a pouring carrier. The device was easily and consistently assembled and dissembled because of an accurate mechanical coupling system.

The base was a stainless steel quadrangular block on which three pins were welded to precisely couple into three holes drilled on each stainless steel standard tray with a numerical control machine (accuracy ±0.01 mm). On such a base, four studs allowed the carrier holding the master model to slide onto the impression trays. To leave a thickness of 3 mm of

impression material between the top of the impression copings and the tray, four stainless steel spacers were machined and positioned on the studs of the base.

The impression carrier consisted of a stainless steel quadrangular plate on which the master model was secured by means of three screws (Figure 1). The spatial position of the master model was designed in order to match the corresponding impression tray on the base of the testing machine.

The pouring carrier consisted of a stainless steel quadrangular plate on the surface facing the base of which four trapezoidal grooves were realized. Such grooves aimed at maintaining the cast obtained from the impression in a stable and repeatable position.

At the corners of both the impression and the pouring carriers, four holes were drilled with a numerical control machine (accuracy ±0.01 mm) in order to match the studs of the base and allow the master model to slide onto the impression trays in a constant and reproducible standardized position.

Typodont Construction

Two master models were realized following the same laboratory procedures. Each master model was obtained by duplicating an ideal maxillary arch (AG-3 DA Standard Typodont, Frasaco, Greenville, NC, USA) from which all teeth but the second premolars, the first, and the second molars had been removed. The residual sockets were filled with wax so that an anterior partially edentulous ridge was obtained; then an impression with an addition silicon (Elite® Double 22 Fast, Zhermack, Badia Polesine, Italy) was taken to duplicate each master model, and a first working cast was made by pouring into a preformed mold a type III dental stone (Elite® Model Fast, Zhermack), which was vacuum mixed using a mechanical spatulator (Whip Mix Combination Unit, Whip Mix Corporation, Louisville, KY, USA), and was allowed to set according to the manufacturer's instructions. Using a dedicated machine provided with screws blocking a stainless steel probe, the standardized positions of four implant analogues were defined. By means of a vertical milling machine (Alliant vertical milling machine, Alliant, Cincinnati, OH, USA), four holes were cut on both the master models matching the diameter and the length of four 3.3×13-mm standard implant steel analogues (Winsix Implant System, BioSAF, Assago, Italy). The holes were drilled at the top of the edentulous ridge, two with the mesial margin at 2.5 mm from the midline, the other two with their mesial margins at 7 mm from the distal margin of the first ones. The four implant analogues were then secured with cyanoacrylate (910 Metal Bonding General Purpose, Permabond, Pottstown, PA, USA) to each model.

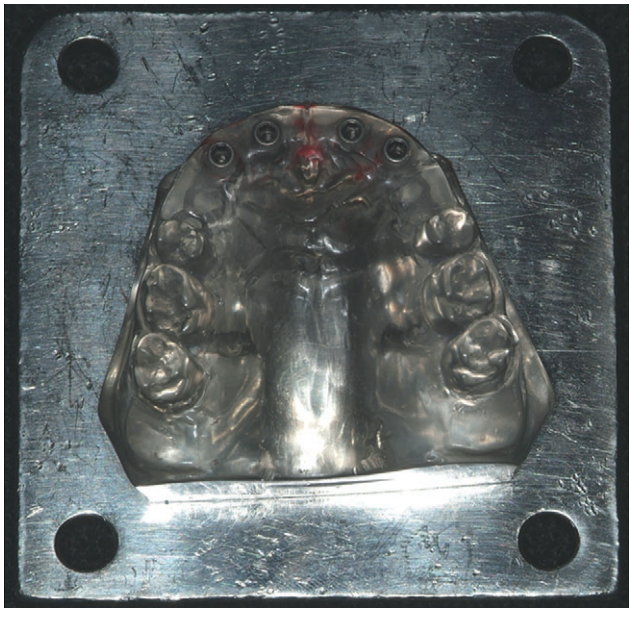

Figure 1 The master model screwed onto the impression carrier of the testing device.

Silicon indexes were used to duplicate each master model and create a second working cast per model as previously described. A gold-alloy cast framework was fabricated for each model and secured to the apical portion of the implants by means of small amounts of pattern resin (Pattern Resin LS, GC Corporation, Tokyo, Japan), in order to block the implant analogues as rigidly as possible minimizing any micromovement during the laboratory procedures (Figure 2).

In the next step, some anatomical undercuts were simulated in the experimental models: the interproximal embrasures between the second premolars and the first and the second molars had been created with a diamond bur; at the same time, a ball-shaped diamond bur with a diameter of 6 mm was used to create a ridge undercut at a distance of 5 mm from the top of the maxillary crest extended from the mesial aspect of tooth 16 to the mesial aspect of tooth 26 and 3-mm deep, breaking the ball-shaped bur through the dental stone for half of its diameter (Figure 3).

The orientations of the holes holding the implant analogues were different in the two master models: in the master model named CTR1, the longitudinal axes of

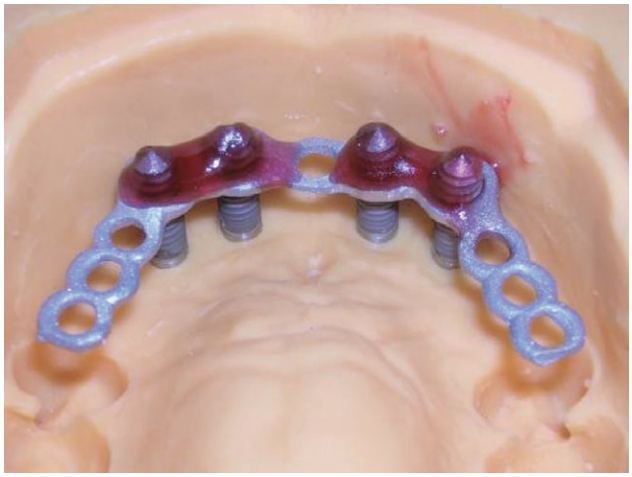

Figure 2 The gold cast framework secured by means of pattern resin rigidly blocking the implants.

Figure 4 The master model CTR1: the longitudinal axes of implants were parallel to each other and perpendicular to the edentulous plane of the typodont.

implant analogues were parallel to each other and perpendicular to the edentulous plane of the typodont (Figure 4). Conversely, in the master model named CTR2, the longitudinal axes of the anterior implant analogues had 5° convergence toward the midline whereas the longitudinal axes of the posterior implant analogues had 5° divergence away from the midline (Figure 5), thus simulating a less than ideal clinical implant positioning. The differing angle holes were cut with a precision angle block placed in the vice holding the casts.

After checking the correct position and angulation of implant analogues, two definitive casts were fabricated by duplication of the second working models using a fast heat-curing transparent acrylic resin (Prothyl Gnathus, Zhermack) whose elastic modulus was the average between those of cortical and spongy bone. In the definitive casts no more implant analogues but 3.3×13 mm non-submerged standard implants with an internal hex connection (Winsix Implant System, BioSAF) were used. The four implants in each model were sequentially numbered 1 through 4 from left to right.

The two final master models were labeled and prepared for impressions.

Impression Tray Design

A total of 80 stainless steel standard stock trays were used for the study.[58,59] In each tray, seven holes were

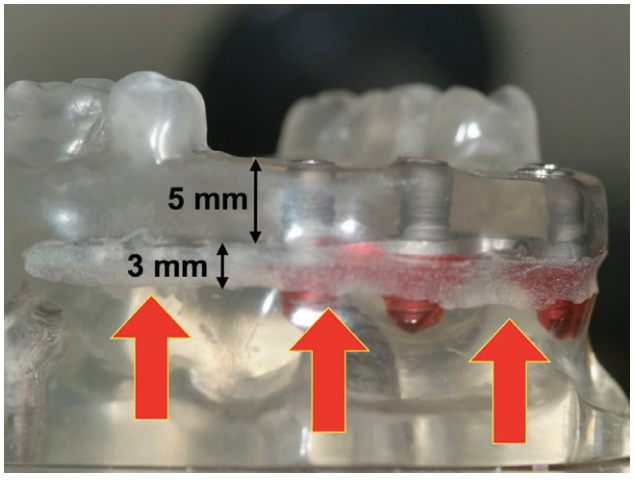

Figure 3 Bone undercut (*red arrows*) at a distance of 5 mm from the top of the maxillary crest extended from the mesial aspect of tooth 15 to the mesial aspect of tooth 25 and 3-mm deep created by means of a ball-shaped diamond bur with a diameter of 6 mm.

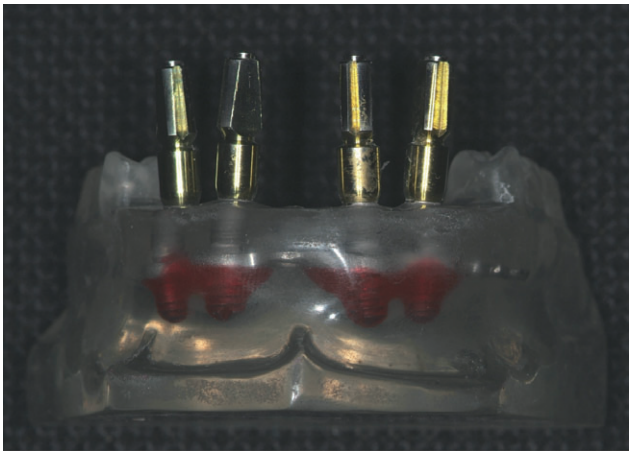

Figure 5 The master model CTR2: the longitudinal axes of the anterior implants had 5° convergence toward the midline whereas the longitudinal axes of the posterior implants had 5° divergence away from the midline.

drilled with the aid of a numerical control machine (accuracy ±0.01 mm). Three holes out of seven were realized to perfectly match the pins welded on the base of the testing machine to secure the impression trays in a unique and repeatable position. The other four holes were opened above the impression copings of the master model in order to allow an access to the corresponding coping screws; the position of such holes was determined using silicon indexes. Each hole was 2 mm wider than the impression coping screw diameter.

Each tray was measured and a performance test was rendered to ensure full coupling of the mechanical components.

Impression Procedure

On the basis of the type of impression material used, of the connection length and of the implant reciprocal angulation, two control groups and eight experimental groups were considered as shown in Table 1. A sample size of 10 was used in groups 3 to 10, yielding a total of 80 impressions, as described in the following discussion.

As to the impression materials, a polyether[9,41,45,49,51–56] (Impregum Penta™, 3M ESPE, Seefeld, Germany) and an addition silicon[1,42,52,53,57] (Elite® Implant, Zhermack) were selected for the test; both of them were medium consistency (55 shore-A). The impression materials had been stored at 23 ± 1°C and 50 ± 10% relative humidity in a temperature-controlled room until the tests were performed;[60] all the procedures were carried out in the same experimental conditions.

The impression protocol was standardized as follows. Each tray was locked on the base of the testing machine and was coated with the dedicated adhesive for the polyether (polyether adhesive, 3M ESPE) or for the addition silicon (Universal Tray Adhesive, Zhermack) 1 hour before each impression was made. Each control model, in turn, was screwed on the impression carrier. Eighty sets of four 15-mm metal squared pick-up copings (Winsix Implant System, BioSAF) were used to make the impressions. Two different lengths of the hex connection part of the coping were used (Figure 6): one-half of the sets were provided with the 2 -mm standard connection part (the same height of the coupling part of definitive abutments) whereas in the other group the copings were custom-made with a shorter insertion connection, 1-mm long, as recommended by the manufacturer. All impression copings were secured with 22 mm flat-head screws on the implants using a torque wrench calibrated at 15 Ncm; then, the copings were coated with the adhesive dedicated to the impression material used for each set of copings as previously described. Particular care was dedicated to ensure that all components were properly oriented and completely seated.

A stop clock was used to record the necessary time to load and level the impression material in the tray, load a disposable syringe (Ultradent Products, South Jordan, UT, USA), inject the impression material around the copings, seat the tray on the base of the testing machine, and allow for full setting of the impression material.

Forty medium-consistency polyether impressions and forty medium-consistency addition silicon

TABLE 1 Description of the Experimental Groups

Group	Axis	Transfer	Material
1	Parallel		CTR1
2	Nonparallel		CTR2
3	Parallel	Shortened	Impregum
4	Parallel	Standard	Impregum
5	Nonparallel	Shortened	Impregum
6	Nonparallel	Standard	Impregum
7	Parallel	Shortened	Elite Implant
8	Parallel	Standard	Elite Implant
9	Nonparallel	Shortened	Elite Implant
10	Nonparallel	Standard	Elite Implant

Figure 6 Left panel: the 2-mm standard length impression coping (the same height of the coupling part of the definitive abutments). Right panel: the 1-mm shortened length impression coping.

impressions were made in accordance to the manufacturer's directions.

The polyether was machine-mixed (Pentamix™ 2, 3M ESPE) whereas the addition silicon was dispensed by means of the respective auto-mixing cartridge. For each impression, 12 mL of the material were meticulously syringed around and over the copings to ensure a complete coverage of the copings themselves; 35 mL of the same material were used to load and level the impression tray. A whole cartridge of the addition silicon was used (i.e., 50 mL); similarly, the same amount of polyether was calculated by marking the level indicator of the mixing machine.

The impression carrier of the testing machine was lowered over the impression tray until it was completely seated on the spacers positioned on the studs of the base and the tips of the copings protruded through the tray holes. A circular piece of steel weighing 1.5 kg was placed onto the impression carrier to standardize the seating load for each impression.[61,62] The materials were allowed to polymerize for 12 minutes after the start of mix, twice the manufacturer's recommended setting times to compensate for room temperature (23°C), always lower than the intraoral temperature.[16]

Once set, the impression material was trimmed at the border of the tray before the removal to allow boxing of the impressions during pouring. The master model was gently separated from the impression and the latter from the base of the testing machine. Despite the type of impression material, the copings were exposed by means of a blade and removed after the material was completely set, so that they remained in the impression when the tray was gently separated from the model.

The impressions were inspected by means of a stereomicroscope (OPMI PROergo, Carl Zeiss, Arese, Italy) under ×2.5 magnification: if any inaccuracy was identified, such as nonhomogeneous mix of the impression materials or air voids, the impression was repeated.

Cast Production Procedure

Six hours after the impression, they were rinsed under tap water for 10 seconds, gently dried, and then coated with disinfectant (Sterigum, Zhermack) and surfactant (Tensilab, Zhermack), following the manufacturer's instructions. Then, the screws were placed back into the impression copings from the top of the tray; an implant analogue was connected and tightened to the copings by means of a calibrated driver. Finally, each impression was locked again on the base of the testing machine.

Block-out material (Wonderfill, Dental Creations Ltd., Waco, TX, USA) was used to block out the junction between the impression copings and implant analogues, in order to easily remove the cast.[4]

Then, 115 g of type III gypsum powder (Elite® Model Fast, Zhermack) were mixed with 35 mL of distilled water using an electronic vacuum mixing machine (Twister Evolution Pro, Renfert GmbH, Hilzingen, Germany) at 250 rpm for 30 seconds and poured into the impression. The impressions were boxed and filled to form a 2-mm thick base. The pouring carrier of the testing machine was placed and maintained in position for the setting time indicated by the manufacturer. After allowing the stone to set for 1 hour, the block-out material was eliminated, the pouring carrier was gently removed, and the cast was carefully separated from the impression. The impression copings were not unscrewed, as they were used as references during measurements. Any debris on the copings was removed.

The casts were trimmed and marked with a code for the measurements; this information was recorded on a sheet and subsequently placed in a sealed envelope. Finally, all models were stored for 48 hours at 23°C and 50% relative humidity prior to measuring.[60]

All clinical and laboratory procedures were performed by the same operator.

Measurement Procedure

The study was designed as single blind: all measurements were made by a single calibrated examiner who ignored the previously described information about the code of each cast.

A profile projector (HB 350, Starrett Sigma, North Yorkshire, England) was used to measure linear distances[25,29] (Figure 7). The pouring carrier was secured in the holder of the device and its posterior corner was set parallel to the axis movement of the machine. Each cast was placed on it and maintained in position by means of the four reference grooves previously described.[60] Such a profile projector was provided with a screen with horizontal and vertical reference lines to allow to adjust all models to identical standardized positions, in order to assure that the copings of all casts were at the same level during the measurements. The light source of the device projected a ×10 magnified image of the cast to be

Figure 7 The profile projector used for the measurements.

measured onto a screen in the form of a shadow, so that the sharp edges of the projected silhouetted of the transfer copings were used as the reference points of measurement.[25,29] The profile projector was provided with an integrated digital readout counter and calibrated to an accuracy of ±0.5 µm.

Four distances were measured on the control acrylic resin models and on the definitive study casts (Figure 8):

(1) D1 – the distance between the external sharp edges of the projected silhouetted form of the most anterior and the most posterior right impression copings (1 and 2).
(2) D2 – the distance between the internal sharp edges of the projected silhouetted form of the most anterior left and right impression copings (2 and 3).

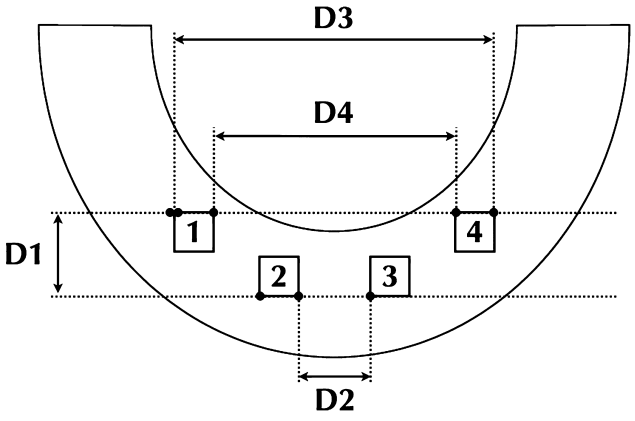

Figure 8 The reference points used to measure the distances D1, D2, D3, and D4 (as described in the text).

(3) D3 – the distance between the external sharp edges of the projected silhouetted form of the most posterior left and right impression copings (1 and 4).
(4) D4 – the distance between the internal sharp edges of the projected silhouetted form of the most posterior left and right impression copings (1 and 4).

In the present study, distortion values were determined measuring the absolute values of such distances between the master models and the study casts.

Each dimension was measured three times and the mean was used for the sample value. A 45-minute time limit was observed for each measurement session to prevent eye fatigue.[2,63,64]

In order to assess the intraoperator error variability and to test the reproducibility of the measurements, one experimental model per group was randomly selected and the measurement of D1, D2, D3, and D4 were repeated 2 days later. The envelope containing the meaning of the codes labeled on each cast was opened only after the measurements and relative controls had been completed.[16,50]

Statistical Analysis

The mean values previously described were considered for the statistical analysis. The Kolmogorov–Smirnov test was used to verify the normality of the data distribution. A three-factor analysis of variance (ANOVA) was used to analyze the recorded data. The considered variables were the type of impression material (polyether vs addition silicon), the angulation of the implants (parallel vs nonparallel), and the length of the connection of the impression copings (2-mm standard vs 1-mm shortened); the interactions between such variables were considered as well. Because there were only two groups within each factor, there was no need to perform post hoc tests for mean differences as any significant main effect would indicate a statistically significant difference between the two groups.[50]

All data were statistically analyzed with a dedicated software (SPSS 16 for MAC OS X, SPSS Inc., Chicago, IL, USA). For all the statistical tests, the level of significance was set at $p < 0.05$.

RESULTS

As to the intraoperator error variability, the standard deviations of the randomly repeated measurements for the distance between the most anterior and the

TABLE 2 Mean Values (±SD) of the Recorded Measurements in Millimeters

Group	D1 (Anterior–Posterior Distance)	D2 (Mesial Inner Distance)	D3 (Outer Distance)	D4 (Distal Inner Distance)
1	7.37*	8.65*	28.92*	21.38*
2	7.34*	8.72*	29.13*	21.26*
3	7.15 ± 0.17	9.01 ± 0.29	28.76 ± 0.37	20.84 ± 0.38
4	7.15 ± 0.17	8.61 ± 0.16	28.96 ± 0.21	21.16 ± 0.15
5	9.11 ± 0.14	8.99 ± 0.23	31.97 ± 0.24	24.37 ± 0.26
6	9.37 ± 0.42	8.85 ± 0.32	32.37 ± 0.24	24.64 ± 0.30
7	7.41 ± 0.22	8.69 ± 0.25	28.92 ± 0.30	21.17 ± 0.37
8	7.31 ± 0.14	8.69 ± 0.03	29.19 ± 0.26	21.40 ± 0.24
9	9.06 ± 0.02	8.77 ± 0.17	32.07 ± 0.14	24.80 ± 0.09
10	9.21 ± 0.11	8.70 ± 0.18	32.31 ± 0.34	24.62 ± 0.30

*Absolute control values.

most posterior impression copings were ±0.9 μm and ±1.3 μm, respectively.

The absolute control values obtained on the control models and the mean linear measurements and standard deviations of the position of impression copings on the experimental casts are reported in Table 2.

The Kolmogorov–Smirnov test confirmed the normality of the data distribution ($p > 0.05$). The three-way ANOVA revealed significant differences for the angulation of the implants in D1 ($p < 0.0001$), D3 ($p < 0.0001$), and D4 measurements ($p < 0.0001$); no significant differences were evidenced in D2 (Tables 3–6). This demonstrates that the impressions made in the presence of angulated implants were significantly less accurate than the ones made with parallel implants.

As to the interaction effects, statistically significant differences were recorded for angulation/material ($p = 0.014$) and angulation/coping ($p = 0.048$) in D1, material/coping ($p = 0.015$) in D2, and material/coping ($p = 0.028$) in D4 (see Tables 3–6). In the presence of the angulated implants, the impressions made by means of the addition silicon resulted slightly more accurate than those made using the polyether. When the implants were parallel to each other, a standard length of the

TABLE 3 Results of the Three-Factor Analysis of Variance for D1 Measurements

	Tests of Between-Subjects Effects				
Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
Corrected model	43.164*	11	3,924	151.594	0.000
Intercept	3,251.508	1	3,251.508	12,5614.962	0.000
Material	0.037	2	0.018	0.706	0.500
Angulation	42.676	1	42.676	1,648.710	0.000
Coping	0.030	1	0.030	1.159	0.289
Material/angulation	0.249	2	0.125	4.810	0.014
Material/coping	0.038	2	0.019	0.736	0.486
Angulation/coping	0.108	1	0.108	4.184	0.048
Material/angulation/coping	0.025	2	0.013	0.490	0.617
Error	0.932	36	0.026		
Total	3,295.604	48			
Corrected total	44.096	47			

*$R^2 = 0.979$ (adjusted $R^2 = 0.972$).

TABLE 4 Results of the Three-Factor Analysis of Variance for D2 Measurements

	Tests of Between-Subjects Effects				
Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
Corrected model	0.754*	11	0.069	2,125	0.044
Intercept	3,686.384	1	3,686.384	114,235.139	0.000
Material	0.250	2	0.125	3.878	0.996
Angulation	0.060	1	0.060	1.844	0.183
Coping	0.049	1	0.049	1.511	0.227
Material/angulation	0.009	2	0.005	0.146	0.865
Material/coping	0.305	2	0.152	4.725	0.015
Angulation/coping	0.028	1	0.028	0.854	0.362
Material/angulation/coping	0.054	2	0.027	0.831	0.444
Error	1.162	36	0.032		
Total	3,688.300	48			
Corrected total	1.916	47			

*$R^2 = 0.394$ (adjusted $R^2 = 0.208$).

impression coping internal connection resulted in more precise casts, whereas, in case of tilted implants, shortened length impression copings performed better. As to the material/coping interactions, no significant differences were found using the addition silicon whereas the impressions made by the polyether resulted in more accurate using standard length impression copings.

DISCUSSION

On the basis of the recorded data, the null hypotheses 1 and 2 were accepted. Conversely, the null hypothesis 3 was rejected as the implant reciprocal angulation had a significant effect on the accuracy of the experimental casts compared with the master models.

As to the intraoperator error variability, the small standard deviations were indicative of the reliability and consistency of the measurement method.

In implant prosthodontics, making a cast reproducing the intraoral position of implants and abutments as accurately as possible is paramount, in order to limit discrepancies in fit, including those not clinically detectable by visual inspection.[1–7,16–20]

TABLE 5 Results of the Three-Factor Analysis of Variance for D3 Measurements

	Tests of Between-Subjects Effects				
Source	Type III Sum of Squares	*df*	Mean square	*F*	Sig.
Corrected model	125.246*	11	11,386	228,380	0.000
Intercept	44,902.450	1	44,902.450	900,650.884	0.000
Material	0.125	2	0.063	1.258	0.296
Angulation	124.035	1	124.035	2,487.881	0.000
Coping	0.952	1	0.952	19.096	0.933
Material/angulation	0.065	2	0.033	0.656	0.525
Material/coping	0.005	2	0.002	0.046	0.955
Angulation/coping	0.037	1	0.037	0.750	0.392
Material/angulation/coping	0.026	2	0.013	0.265	0.769
Error	1.795	36	0.050		
Total	45,029.491	48			
Corrected total	127.041	47			

*$R^2 = 0.986$ (adjusted $R^2 = 0.982$).

TABLE 6 Results of the Three-Factor Analysis of Variance for D4 Measurements

	Tests of Between-Subjects Effects				
Source	Type III Sum of Squares	*df*	Mean square	*F*	Sig.
Corrected model	148.064*	11	13.460	259.661	0.000
Intercept	25,285.851	1	25,285.851	487,784.180	0.000
Material	1.022	2	0.511	9.860	0.969
Angulation	146.336	1	146.336	2,822.933	0.000
Coping	0.053	1	0.053	1.016	0.320
Material/angulation	0.044	2	0.022	0.420	0.660
Material/coping	0.412	2	0.206	3.976	0.028
Angulation/coping	0.105	1	0.105	2.035	0.162
Material/angulation/coping	0.092	2	0.046	0.890	0.420
Error	1.866	36	0.052		
Total	25,435.782	48			
Corrected total	149.930	47			

*$R^2 = 0.988$ (adjusted $R^2 = 0.984$).

Some errors may be introduced during any of the several clinical procedures required, like an improper connection of the components, excessive dimensional changes of the impression materials, minor movements caused by unscrewing of the impression copings, and by the following screwing of the implant analogues.[4,16–20] The clinical significance of the distortion magnitude remains controversial. It is worth highlighting that throughout this study, an exact reproduction of the implant position as recorded on the control models was only once achieved (i.e., D3 in group 7). Clinically, this could mean that completely passive fit of an implant-supported prosthetic superstructure is not attainable yet, despite the impression technique and the laboratory procedures.[4,14–20,32] The clinical experience and skill of the operator still remain the most important variables to be involved.

The proper use of surfactants and disinfectants did not influence the accuracy of the impressions. The application of an adhesive agent between the impression materials and the copings probably had an important role in reducing minor movements during both clinical and laboratory procedures.[25] Both the physical retention to the impression tray and the use of adhesives play an important role in the performance of impression materials. As described in previous studies,[16,50,58,59] in the present investigation stainless steel rigid trays were used to limit impression distortions. Such stock trays were coated with the dedicated adhesive for the polyether or for the addition silicon. It is questionable if both adhesives would perform better in the presence of acrylic resin trays; nevertheless, the purpose of the present investigation was to limit and equalize the multiple variables affecting the precision of impressions.

The mechanical properties of an impression material, such as accuracy and rigidity, may influence the precision of the impression, the cast, and, consequently, final framework.[1,2,41,44,45,49,51] In this study, both polyethers and addition silicons produced similarly accurate casts, as recorded in previous papers.[1,9,41,42,45,49,51–55,57] A parallel positioning of the implants, a condition that is not always clinically achievable because of possible anatomical limitations, eased the removal of impressions, probably reducing the distortions of the material.[1,22,41,42,46,47]

Regarding the direct technique, an impression material should be provided with a sufficient rigidity, in order to hold the copings in their position during the removal force application, thus preventing incidental displacements and ensuring a minimal positional distortion between the laboratory components. Similar to other studies, both the medium body consistency polyether and the addition silicons were found to meet such a requirement. In the literature, the addition silicons showed higher yield strength and modulus of elasticity compared with the polyethers.[1,2,41,44,45,49,51] Some authors described the latter as the first choice for completely

edentulous multi-implant impressions, because of their rigidity, providing resistance to an incidental displacement of the impression copings. Nevertheless, the use of the polyethers in a partially edentulous arch could lead to an increased difficulty for an intraoral removal of the impression.[9,41,45,49,51–55] The addition silicons, because of the more favorable, lower modulus of elasticity, could be considered as a viable alternative allowing for the easy removal of the impression and reducing the permanent deformations caused by the stress between the impression material and the copings,[1,42,52,53,57] particularly when nonparallel implants are present and implants with deep internal connection are used.

The choice of an impression material should be based on the consideration of several variables, like the material accuracy, the amount of intraoral undercuts, the length of time before the impression is poured, and the experience of the clinician.

Anatomical undercuts, which are not infrequent in the clinical reality, require in the clinical practice high impression removal forces, so they were introduced in the experimental models of the present study to simulate a more realistic condition, compared with the use of test smooth, undercut-free models as used in other previous studies. Some criticism, in fact, has been moved to some research models[65,66] in that the removal forces and the consequent impression distortions in the clinical practice were to be considered much higher than the ones applied in the experimental condition, because of the absence of dental or crestal undercuts in the smooth edentulous models.

The design of the coping has to be considered another relevant factor for the impression accuracy.[25] The 1-mm shortened connection length was designed to ease the removal of the copings from the internal connection of the implants, avoiding a deep engagement of the component, a condition that is highly advisable, on the contrary, in the implant/abutment connection design. In this study, the use of a shorter internal connection of the copings resulted advantageous only when using the addition silicon in the presence of nonparallel implants, probably because the shortened connection length compensated for the higher removal stress induced by the implant angulation. On the contrary, in the presence of parallel implants or when polyether was used, the casts resulted more accurate by using standard length copings. This was probably caused by a higher stiffness of the impression materials providing higher resistance against deformations during implant analogue tightening.[9,41,45,49,51–55]

The extent of the coping length inside the impression material is another factor that seems to play an important role in terms of additional retention and resistance against displacement.[25] Nonetheless, in order to avoid additional sources of measurement error and to ensure a better data reproducibility, the present investigation did not consider the effect of subgingival depth of the implant placement on the accuracy of impressions. Such a topic was recently investigated by authors who did not show any effect of the implant depth on the accuracy of VPSs whereas less accurate impressions were made by means of medium-body polyethers in the presence of deeper implants. As it is not possible to access the subgingival part of the copings, these findings were probably because of the more limited area of the copings embedded in the impression material.[4]

The distortion of the impression is a concern inherent, in a three-dimensional way, in all of the procedures involved in the indirect dental restorations.[50,63,64] It can be regarded as absolute or relative, depending on the point of reference from which it is measured: the absolute distortion is considered when the point of reference is external, whereas a relative distortion is measured from a point that is located internal to the system.[1,9,21,42,47,51,63,64] According to several studies,[9,21,42,47,51] in the present investigation, the relative distortion was considered as a study parameter, as the resultant translational distance was measured from one coping to another. This kind of measurement can be considered more clinically relevant than the absolute distortion, as an implant-supported prosthesis usually connects all the abutments to each other.

Distortion may be negatively affected by the nonparallel positioning of implants as well as by the presence of physical undercuts (i.e., tooth embrasures, bone deformities), as a higher removal strength is needed, affecting the precision of the impressions.

Although not specifically considered in the present investigation, the machining tolerance, defined as the difference in rest positions between the components when they are held in place by their respective fastening screws, might represent another mechanical factor playing an important role in the distortion phenomenon.[67]

Possible limitations of the present study design were that the measured distortions did not completely evaluate the actual three-dimensional distortion of the impressions and the axial rotations of the components were not detected. Moreover, the results of the present investigation were limited to a number of four implants and may not be relevant for impressions made in the presence of higher or lower numbers of implants. Third, only internal connection implants were used, whereas external connections, like the hexagon ones, were not considered.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

(1) The presence of undercuts negatively affected the precision of the impressions.
(2) The angulation of the implants may cause strains of impressions, probably because of the higher forces required for the impression removal.
(3) In the presence of nonparallel implants, the use of addition silicons resulted in more accurate casts, particularly together with a shortened length of the connection part of the copings.
(4) In the presence of parallel implants or when the polyether was used, a standard length connection of the copings produced more accurate casts.

Further clinical investigations will be necessary to confirm the results of the present in vitro study.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare. [Correction added after online publication 24 May 2010: Conflict of Interest Statement added.]

REFERENCES

1. Barrett MG, de Rijk WG, Burgess JO. The accuracy of six impression techniques for osseointegrated implants. J Prosthodont 1993; 2:75–82.
2. Wee AG, Aquilino SA, Schneider RL. Strategies to achieve fit in implant prosthodontics: a review of the literature. Int J Prosthodont 1999; 12:167–178.
3. Conrad HJ, Pesun IJ, DeLong R, Hodges JS. Accuracy of two impression techniques with angulated implants. J Prosthet Dent 2007; 97:349–356.
4. Lee H, Ercoli C, Funkenbusch PD, Feng C. Effect of subgingival depth of implant placement on the dimensional accuracy of the implant impression: an in vitro study. J Prosthet Dent 2008; 99:107–113.
5. Jemt T. In vivo measurements of precision of fit involving implant-supported prostheses in the edentulous jaw. Int J Oral Maxillofac Implants 1996; 11:151–158.
6. Jemt T, Rubenstein JE, Carlsson L, Lang BR. Measuring fit at the implant prosthodontic interface. J Prosthet Dent 1996; 75:314–325.
7. Pesun IJ. Intrusion of teeth in the combination implant-to-natural-tooth fixed partial denture: a review of the theories. J Prosthodont 1997; 6:268–277.
8. Tan KB, Rubenstein JE, Nicholls JI, Yuodelis RA. Three-dimensional analysis of the casting accuracy of one-piece, osseointegrated implant-retained prostheses. Int J Prosthodont 1993; 6:346–363.
9. Phillips KM, Nicholls JI, Ma T, Rubenstein JE. The accuracy of three implant impression techniques: a 3-dimensional analysis. Int J Oral Maxillofac Implants 1994; 9:533–540.
10. Sahin S, Cehreli MC. The significance of passive framework fit in implant prosthodontics: current status. Implant Dent 2001; 10:85–92.
11. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004; 15:466–473.
12. Ericsson I, Persson LG, Berglundh T, Marinello CP, Lindhe J, Klinge B. Different types of inflammatory reactions in peri-implant soft tissues. J Clin Periodontol 1995; 22:255–261.
13. Leonhardt A, Renvert S, Dahlen G. Microbial findings at failing implants. Clin Oral Implants Res 1999; 10:339–345.
14. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996; 11:620–625.
15. Jemt T, Lekholm U, Johansson CB. Bone response to implant-supported frameworks with differing degrees of misfit preload: in vivo study in rabbits. Clin Implant Dent Relat Res 2000; 2:129–137.
16. Burns J, Palmer R, Howe L, Wilson R. Accuracy of open tray implant impressions: an in vitro comparison of stock versus custom trays. J Prosthet Dent 2003; 89:250–255.
17. Kohavi D. Complications in the tissue integrated prostheses components: clinical and mechanical evaluation. J Oral Rehabil 1993; 20:413–422.
18. Jemt T, Linden B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Branemark implants: from prosthetic treatment to first annual checkup. Int J Oral Maxillofac Implants 1992; 7:40–44.
19. Kallus T, Bessing C. Loose gold screws frequently occur in full-arch fixed prostheses supported by osseointegrated implants after 5 years. Int J Oral Maxillofac Implants 1994; 9:169–178.

20. Tolman DE, Laney WR. Tissue-integrated prosthesis complications. Int J Oral Maxillofac Implants 1992; 7:477–484.
21. Carr AB, Master J. The accuracy of implant verification casts compared with casts produced from a rigid transfer coping technique. J Prosthodont 1996; 5:248–252.
22. Assif D, Nissan J, Varsano I, Singer A. Accuracy of implant impression splinted techniques: effect of splinting material. Int J Oral Maxillofac Implants 1999; 14:885–888.
23. Vigolo P, Majzoub Z, Cordioli G. In vitro comparison of master cast accuracy for single-tooth implant replacement. J Prosthet Dent 2000; 83:562–566.
24. Daoudi MF, Setchell DJ, Searson LJ. A laboratory investigation of the accuracy of two impression techniques for single-tooth implants. Int J Prosthodont 2001; 14:152–158.
25. Vigolo P, Majzoub Z, Cordioli G. Evaluation of the accuracy of three techniques used for multiple implant abutment impressions. J Prosthet Dent 2003; 89:186–192.
26. Akca K, Cehreli MC. Accuracy of 2 impression techniques for ITI implants. Int J Oral Maxillofac Implants 2004; 19:517–523.
27. Assuncao WG, Filho HG, Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004; 13:358–366.
28. Naconecy MM, Teixeira ER, Shinkai RS, Frasca LC, Cervieri A. Evaluation of the accuracy of 3 transfer techniques for implant-supported prostheses with multiple abutments. Int J Oral Maxillofac Implants 2004; 19:192–198.
29. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. An evaluation of impression techniques for multiple internal connection implant prostheses. J Prosthet Dent 2004; 92:470–476.
30. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. Master cast accuracy in single-tooth implant replacement cases: an in vitro comparison. A technical note. Int J Oral Maxillofac Implants 2005; 20:455–460.
31. Cehreli MC, Akca K. Impression techniques and misfit-induced strains on implant-supported superstructures: an in vitro study. Int J Periodontics Restorative Dent 2006; 26:379–385.
32. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. J Prosthet Dent 1999; 81:7–13.
33. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 2008; 19:119–130.
34. Riedy SJ, Lang BR, Lang BE. Fit of implant frameworks fabricated by different techniques. J Prosthet Dent 1997; 78:596–604.
35. Jemt T, Linden B. Fixed implant-supported prostheses with welded titanium frameworks. Int J Periodontics Restorative Dent 1992; 12:177–184.
36. Schmitt SM, Chance DA. Fabrication of titanium implant-retained restorations with non traditional machining techniques. Int J Prosthodont 1995; 8:332–336.
37. Linehan AD, Windeler AS. Passive fit of implant-retained prosthetic superstructures improved by electric discharge machining. J Prosthodont 1994; 3:88–95.
38. LaBarge KW. Electrical discharge machining. J Dent Technol 1997; 14:19–22.
39. Ortorp A, Jemt T, Bäck T, Jälevik T. Comparisons of precision of fit between cast and CNC-milled titanium implant frameworks for the edentulous mandible. Int J Prosthodont 2003; 16:194–200.
40. Kelly JR. Developing meaningful systematic review of CAD/CAM reconstructions and fiber-reinforced composites. Clin Oral Implants Res 2007; 18(Suppl 3):205–217.
41. Hsu CC, Millstein PL, Stein RS. A comparative analysis of the accuracy of implant transfer techniques. J Prosthet Dent 1993; 69:588–593.
42. Humphries RM, Yaman P, Bloem TJ. The accuracy of implant master casts constructed from transfer impressions. Int J Oral Maxillofac Implants 1990; 5:331–336.
43. Daoudi MF, Setchell DJ, Searson LJ. A laboratory investigation of the accuracy of the repositioning impression coping technique at the implant level for single-tooth implants. Eur J Prosthodont Restor Dent 2003; 11:23–28.
44. Liou AD, Nicholls JI, Yuodelis RA, Brudvik JS. Accuracy of replacing three tapered transfer impression copings in two elastomeric impression materials. Int J Prosthodont 1993; 6:377–383.
45. Carr AB. Comparison of impression techniques for a five-implant mandibular model. Int J Oral Maxillofac Implants 1991; 6:448–455.
46. Herbst D, Nel JC, Driessen CH, Becker PJ. Evaluation of impression accuracy for osseointegrated implant supported superstructures. J Prosthet Dent 2000; 83:555–561.
47. Spector MR, Donovan TE, Nicholls JI. An evaluation of impression techniques for osseointegrated implants. J Prosthet Dent 1990; 63:444–447.
48. Eames WB, Sieweke JC, Wallace SW, Rogers LB. Elastomeric impression materials: effect of bulk on accuracy. J Prosthet Dent 1979; 41:304–307.
49. Carr AB. Comparison of impression techniques for a two-implant 15-degree divergent model. Int J Oral Maxillofac Implants 1992; 7:468–475.
50. Ceyhan JA, Johnson GH, Lepe X. The effect of tray selection, viscosity of impression material, and sequence of pour on the accuracy of dies made from dual-arch impressions. J Prosthet Dent 2003; 90:143–149.
51. Wee AG. Comparison of impression materials for direct multi-implant impressions. J Prosthet Dent 2000; 83:323–331.
52. Berg JC, Johnson GH, Lepe X, Adán-Plaza S. Temperature effects on the rheological properties of current polyether and

polysiloxane impression materials during setting. J Prosthet Dent 2003; 90:150–161.
53. Lu H, Nguyen B, Powers JM. Mechanical properties of 3 hydrophilic addition silicon and polyether elastomeric impression materials. J Prosthet Dent 2004; 92:151–154.
54. Assif D, Fenton A, Zarb G, Schmitt A. Comparative accuracy of implant impression procedures. Int J Periodontics Restorative Dent 1992; 12:112–121.
55. Assif D, Marshak B, Schmidt A. Accuracy of implant impression techniques. Int J Oral Maxillofac Implants 1996; 11:216–222.
56. Inturregui JA, Aquilino SA, Ryther JS, Lund PS. Evaluation of three impression techniques for osseointegrated oral implants. J Prosthet Dent 1993; 69:503–509.
57. Schneider RL, Wee AG. Fabricating low-fusing metal casts for more accurate implant prosthodontics. J Prosthodont 1996; 5:301–303.
58. Millstein P, Maya A, Segura C. Determining the accuracy of stock and custom tray impression/casts. J Oral Rehabil 1998; 25:645–648.
59. Rueda LJ, Sy-Munoz JT, Naylor WP, Goodacre CJ, Swartz ML. The effect of using custom or stock trays on the accuracy of gypsum casts. Int J Prosthodont 1996; 9:367–373.
60. Sedda M, Casarotto A, Raustia A, Borracchini A. Effect of storage time on the accuracy of casts made from different irreversible hydrocolloids. J Contemp Dent Pract 2008; 9:59–66.
61. Davis R, Schwartz R, Hilton T. Marginal adaptation of castings made with dual-arch and custom trays. Am J Dent 1992; 5:253–254.
62. Davis RD, Schwartz RS. Dual-arch and custom tray impression accuracy. Am J Dent 1991; 4:89–92.
63. Nicholls JI. The measurement of distortion: theoretical considerations. J Prosthet Dent 1977; 37:578–586.
64. Nicholls JL. The measurement of distortion: concluding remarks. J Prosthet Dent 1980; 43:218–223.
65. Dixon DL, Breeding LC, Moseley JP. Custom impression trays. Part II: removal forces. J Prosthet Dent 1994; 71:316–318.
66. Sotiriu M, Hobkirk JA. An in vivo investigation of seating and removal forces associated with recording impressions in dentate patients. J Prosthet Dent 1995; 74:455–462.
67. Kim S, Nicholls JI, Han CH, Lee KW. Displacement of implant components from impressions to definitive casts. Int J Oral Maxillofac Implants 2006; 21:747–755.