COMPARATIVE ACCURACY OF THE SPLINTED AND UNSPLINTED IMPRESSION METHODS FOR INTERNAL CONNECTION

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Statement of problem. Accurate impression is essential to success of implant prostheses. But there have been few studies about the accuracy of fixture-level impression techniques in internal connection implant systems.

Purpose. The purpose of this study was to compare the accuracy of two fixture-level impression techniques in two conditions (parallel and divergent) and to assess the effect of tightening sequences and forces on stresses generated on superstructures in internal connection implant system (Astra Tech).

Material and methods. Two metal master frameworks made from two abutments (Cast-to Abutment ST) each and a corresponding, passively fitting, dental stone master cast with four fixture replicas (Fixture Replica ST) were fabricated. Ten dental stone casts for each impression techniques (direct unsplinted & splinted technique) were made with vinyl polysiloxane impressions from the master cast. Strain gauges for each framework were fixed midway between abutments to measure the degree of framework deformation on each stone cast. Pairs of strain gauges placed opposite each other constituted one channel (half Wheatstone bridge) to read deformation in four directions (superior, inferior, anterior, and posterior). Deformation data were analyzed using one-way ANOVA and the Tukey test at the .01 level of significance. And the effect of tightening sequences (right-to-left and left-to-right) and forces (10 Ncm and 20 Ncm) were assessed with ten stone casts made from parallel condition by the splinted technique. Deformation data were analyzed using paired t-test at the .01 level of significance.

Conclusions. Within the limitations of this study, the following conclusions could be drawn.

1. Frameworks bent toward the inferior side on all casts made by both direct unsplinted and splinted impression techniques in both parallel and divergent conditions.
2. There was no statistically significant difference of accuracy between the direct unsplinted and splinted impression techniques in both parallel and divergent conditions ($P>.01$).
3. There was no statistically significant difference of stress according to screw tightening sequences in casts made by the splinted impression technique in parallel condition ($P>.01$).
4. Greater tightening force resulted in greater stress in casts made by the splinted impression technique in parallel condition ($P<.01$).

Key Words

Fixture-level impression, Internal connection, Tightening sequence, Tightening force, Strain gauge

The use of dental implants for the restoration of fully and partially edentulous patients has been shown to be quite successful longitudinally.[1-4] However, the absence of passive fit may lead to failures, such as fracture and/ or loosening of screws, retention of biofilm, and even loss of osseointegration.[5,6] The clinical and laboratory variables intrinsic to the restorative treatment complicate the fabrication of prostheses with a passive fit. Among those variables, impression techniques have a decisive influence on the fabrication of accurate working casts.[7]

Several impression techniques have been suggested to achieve a working cast that will ensure the passive fit of prostheses on osseointegrated implants. Among the impression techniques presented in the literature, the splinted technique has gained popularity and has proven to be the most accurate.[7-10] To ensure maximum accuracy, Brånemark et al[11] emphasized the importance of splinting transfer copings together, intraorally, before impression making. However, other studies[12-15] found no significant differences between the values obtained with acrylic resin splinted and unsplinted copings in impression making. And Burawi et al[16] and Inturregui et al[17] reported that the unsplinted technique was more accurate than the splinted one.

Inaccurate fit may cause stress in the superstructure with different intraoral tightening sequences according to the location of the misfit.[18] Watanabe et al[19] reported that according to screw tightening sequence, there were significant differences in the magnitude of strain with the soldering method, but no differences with the passive-fit method. Nissan et al[20] reported that the presence of variable tightening sequence and force did not cause significant changes in stresses generated on the casting in the casts made from splinted impression technique.

The fixture-level impression permits the selection of the most appropriate abutments in the laboratory with abutment selection kits, which is helpful for situations where vertical space and/or angulation of the abutment are difficult to determine intraorally. In addition, it facilitates replacement of the healing caps, eliminating the need to cover the abutments with temporary restorations or protective caps.[21] The lack of parallelism between implants is commonly encountered in implant prosthodontics. Making fixture-level impression in the internal connection implant system, especially Astra Tech dental implant system (Mölndal, Sweden), which is characterized by conical seal design, lack of parallelism may create an undesirable path of withdrawal, and subsequent distortion of the impression. But this distortion must be considered with the machining tolerances of a given implant system. These machining tolerances may provide information on what may be termed clinically acceptable distortions, that is, those that do not induce stress in the components during placement in the mouth.[14]

Most of the previous studies[7-10, 12-17] have attempted to compare the accuracy of various implant impression techniques at the abutment level using the external implant system. On the contrary, this study tried to assess the accuracy of two fixture-level impression techniques (direct unsplinted and splinted) for two-implant supported prostheses in two conditions (parallel and divergent). And this study aimed to assess the effect of tightening sequences and forces on stresses generated on the superstructures on working casts made by the splinted impression technique from parallel condition in the internal connection implant system.

MATERIAL AND METHODS

Fabrication of the Master Frameworks

Two stone blocks were fabricated in type IV dental stone (GC Fujirock EP; GC Europe, Leuven, Belgium) for the fabrication of two master frameworks as follows:

Parallel group: Two holes were milled 10 mm apart edge to edge in parallel relationship on one block.

Divergent group: Two holes were milled 10 mm apart edge to edge in 8-degree divergent relationship on the other block.

Four fixture replicas (Fixture Replica ST 22509; Astra Tech AB, Mölndal, Sweden) were positioned inside the holes with acrylic resin (Pattern Resin; GC Corporation, Tokyo, Japan) using milling machine so that their maximal circumference portion were flush with the surface of the stone blocks. Four abutments (Cast-to Abutment ST 22829; Astra Tech AB, Mölndal, Sweden) screwed to the fixture replicas. Two frameworks (6 mm × 4 mm × 20 mm) of rectangular section simulating prostheses were patterned with acrylic resin, and cast in type IV gold alloy (Jel-4; Jelenko, Armonk, New York, USA). The distance from the stone block to the inferior surface of the framework was 4 mm. These master frameworks were the standard to which all measurements were made.

Fabrication of the Master Cast

A linear residual ridge model was fabricated by type IV dental stone. Two pairs of two holes were made 17 mm apart between pairs and 10 mm apart between holes, edge to edge, in a straight line on the midline of ridge. Left hole had an angulation of 8 degrees toward the posterior (Fig. 1, A and B). This 8-degree angle was determined from previous trials for maximum seating angle by rigid acrylic resin beam. Previous trials showed 8-degree angle was maximum for the seating of framework made of Cast-to Abutments. Four fixture replicas were screwed to the abutments of the master frameworks. This framework/replicas were then fixed in the holes filled with acrylic resin so that maximal circumference portion of replicas were flush with the surface of the stone blocks by milling machine. Once the resin had completely set, the tops of the replicas were examined to verify that no resin had encroached onto them. After 1day of polymerization with connection of framework/replicas, low consistency vinyl polysiloxane (Examixfine; GC Corporation, Tokyo, Japan) pick-up impression was made with the master frameworks instead of the impression copings. Four fixture replicas were screwed to abutments of the master frameworks. And then, the impression was poured with vacuum-mixed type IV dental stone in accordance with the manufacturers' instructions to obtain a master cast featuring passive fit (Fig. 2). This master cast was used as the standard for all impressions.

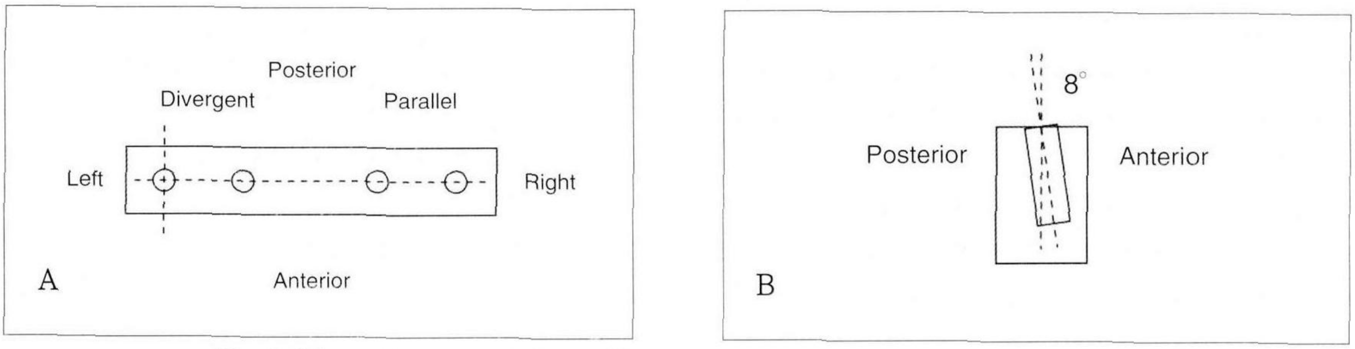

Fig. 1. Schematic representations of the master cast **A,** Superior view **B,** Left view.

Fabrication of Custom Trays

Twenty standardized 2-mm-thick custom trays were made with light-polymerizing resin (Fegura Tray; Feguramed GmbH, Buchen, Germany). For this purpose, two layers of baseplate wax spacers (Kerr, Romulus, MI, USA) were placed on the master cast, and the pick-up impression copings (Fixture Impression Pick-up ST short 22847; Astra Tech AB, Mölndal, Sweden) were covered to allow uniform thickness of the impression material. And an irreversible hydrocolloid impression (Kromafaze; Cadco Dental Products, Oxnard, CA 93033, USA) was made to obtain a single cast on which all custom trays were molded (Fig. 3). Positioning groove was made on the base of the master cast where contacting the border of the custom trays to standardize tray positioning during impression making. The tray was removed after complete polymerization and stored at room temperature for 24 hours before impression making.[22,23] Four holes were made on the upper section of the tray and sealed with clear tape to allow access to the guide pins. A total of twenty trays were made, ten trays for each technique.

Splinting of Impression Copings

For technique 2 (splinted technique), a loose floss scaffolding (Dental Floss, Johnson & Johnson, New Brunswick, NJ, USA) was constructed on pick-up impression copings, over which GC pattern resin was painted to mimic a clinical situation. After 15-minute setting, the splinted impression copings were trimmed using milling machine. Vinyl polysiloxane (Exafine; GC Corporation, Tokyo, Japan) putty impression was made to act as a mold to standardize the acrylic resin splint dimensions for each specimen (Fig. 4). The acrylic resin was mixed,

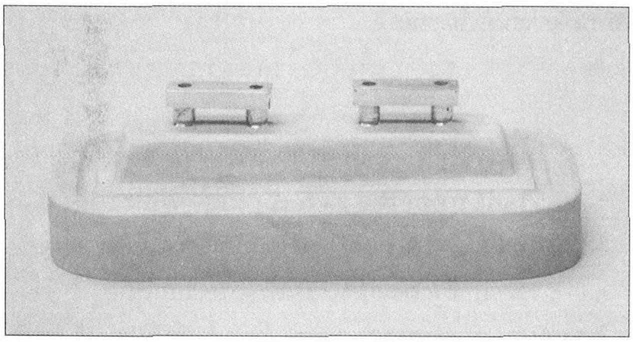

Fig. 2. Dental stone master cast with four fixture replicas and passively fitting master frameworks.

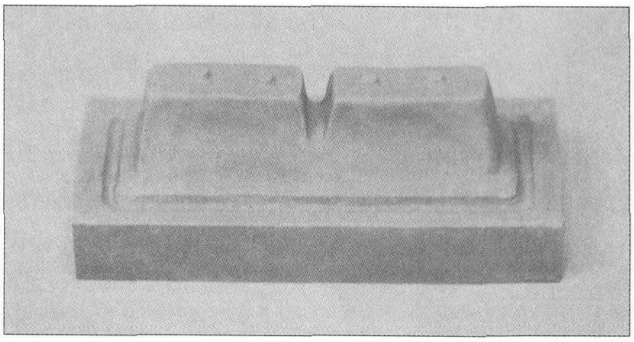

Fig. 3. Dental stone cast used as a mold to standardize the custom tray dimensions.

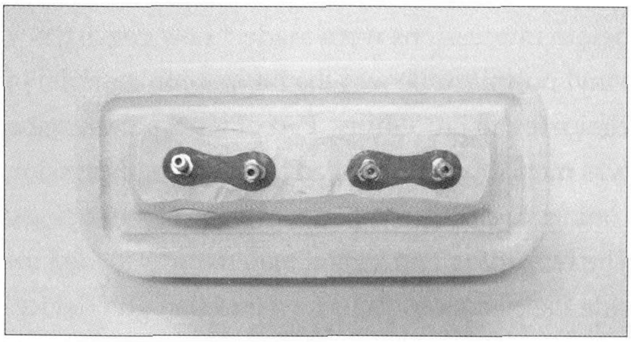

Fig. 4. Vinyl polysiloxane putty mold used to standardize the acrylic resin splint dimensions.

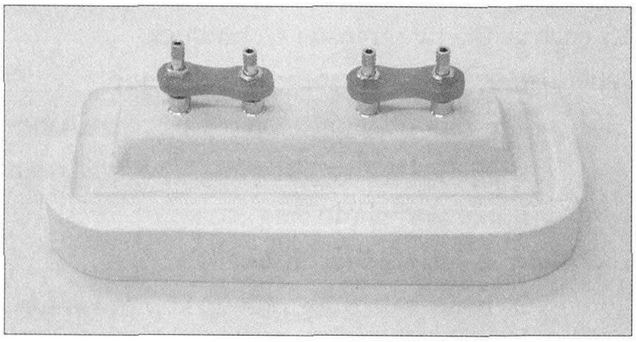

Fig. 5. Technique 2: Splinted impression copings on the master cast.

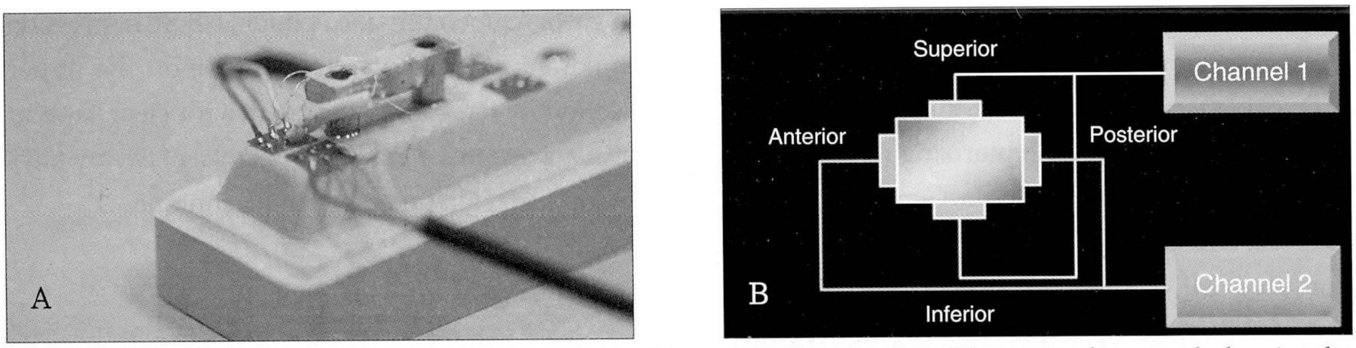

Fig. 6. A, Master framework with strain gauges on the working cast **B,** Cross section of the master framework showing the strain gauge setup.

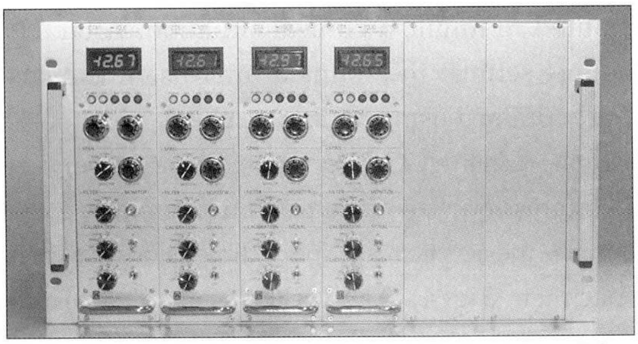

Fig. 7. Dynamic signal conditioning strain amplifier (CTA-1000).

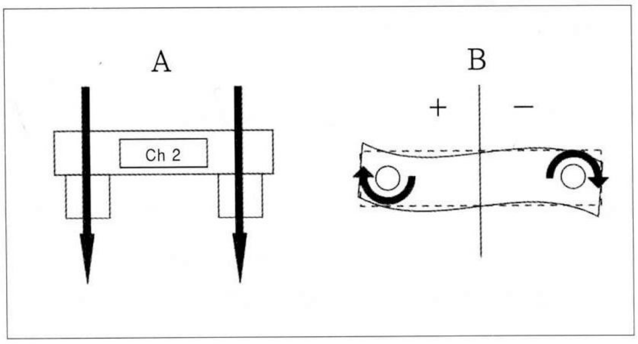

Fig. 8. Schematic representations show the effect of **A,** screw tightening direction and **B,** strain gauge position on stress level of channel 2.

poured into the mold and allowed to set for 15 minutes.[17] The splinted impression copings were removed from the master cast and the excess resin was trimmed.

Impression Procedure and Specimen Preparation

From the master cast, ten impressions were made for each of the two transfer techniques.

***Technique 1:* direct unsplinted technique**

- The pick-up impression copings were hand-tightened with guide pins. No acrylic resin splint was made.

***Technique 2:* splinted technique** (Fig. 5)

- 24 hours before use, pick-up impression copings were connected with acrylic resin. 15 minutes before the impression was taken, the acrylic resin splint was sectioned equidistant from the two copings with thin diamond disc, and reconnected with acrylic resin by bead-brushing technique.[17,24]

Impression copings were hand-tightened with guide pins onto the replicas in the master cast and then impression was made. The appropriate adhesive was applied to the custom trays 15 minutes before impressions were made.[25] Low consistency vinyl polysiloxane was the impression material of choice for all procedures. Part of vinyl polysiloxane was meticulously syringed around the impression copings to ensure complete coverage of the copings. The remaining impression material was loaded inside the custom trays using a injection gun device. The custom trays were seated with finger pressure. The impressions were allowed to set for twice

(8 minutes) the normal setting time to allow complete polymerization at room temperature instead of mouth temperature.[26] And then, the guide pins were unscrewed so that the copings remained inside the impressions when they were separated from the master cast, and the custom trays were removed. Hand-tightened fixture replicas carefully assembled into the impression copings in each set impressions. After boxing, each impression was poured with vacuum-mixed type IV dental stone to make the final casts.

Preparation of Strain Gauges

Four strain gauges (120 Ω ;gauge length 1 mm;KFG-1-120-C1-11, Kyowa, Japan) were fixed to each master framework (superior, inferior, anterior, and posterior faces midway between abutments) to measure the framework deformation of each cast. The strain gauges were bonded with a special cyanoacrylate (M-Bond 200; Vishay Micro-Measurements, Raleigh, NC, USA) with finger pressure. These strain gauges assembled longitudinally between abutments. Each pair of strain gauges that were placed opposite each other was connected to bridge box (CTB-100; Curiosity Technology, Seoul, Korea) via terminal to form a connection denoted the "half Wheatstone bridge", which constituted 1 channel for reading deformation (Fig. 6, A and B).[7] Therefore, two reading channels for each master framework were built as follows:

Channel 1: **superior - inferior**

Positive value(+) means bending toward the superior.

Channel 2: **anterior - posterior**

Positive value(+) means bending toward the anterior.

The two pairs of strain gauges were then connected to two cables. These cables led the signals to a dynamic signal conditioning strain amplifier (CTA-1000; Curiosity Technology, Seoul, Korea) (Fig. 7), that was used to supply an excitation voltage in the Wheatstone bridge, thereby improving the signals. The analog signals of electric resistance variation were converted into a digital signals via a 16-byte resolution converter (DAQCard-Al-16XE-50 National Instruments, USA) and processed by custom software (DA-1700B; Cas Korea, Seoul, Korea). Channel signals were originally measured in millivolts and then converted to microstrain units (μm/m). Measurement capability was 1 μm/m. Prior to the deformation readings on the working casts, the master framework was seated on the master cast. And the screws (Abutment screw 22568; Astra Tech AB, Mölndal, Sweden) were tightened to 10 Ncm using a torque controller (Torque Wrench 24075; Astra Tech AB, Mölndal, Sweden) so that the strain gauges were calibrated to zero. This procedure aimed to discharge any residual stress because of the impossibility of achieving passive fit of the master framework connected to the master cast.

Comparison of Impression Techniques

The master frameworks were seated on each cast, and screws were tightened with the same tightening sequence (right to left) of 10 Ncm. Readings were made twice for each channel on each cast for both impression techniques. To guarantee the same degree of screw wear, one sample per technique was measured once at a time. After the first readings of the twenty specimens were completed, a new series of readings was performed using the new set of screws. Each set of readings was taken two times. The two measurements of framework deformation for each specimen were averaged for statistical analysis. And the vector values, the square roots of square sum of two channel strain values, were calculated. Deformation data were analyzed using one-way ANOVA (analysis of variance) and Tukey HSD multiple comparison test at the .01 level of significance.

Comparison of Tightening Sequences and Tightening Forces

The master framework for the parallel group was seated onto the specimen made by the splinted technique. The abutment screws were tightened on each cast with the other sequence (left to right) at 10 Ncm and 20 Ncm, and readings were made. The two measure-ments of framework deformation for each specimen were averaged for statistical analysis. And the vector values, the square roots of square sum of two channel strain values, were also calculated. Deformation data were analyzed using paired t-test at the .01 level of significance.

RESULTS

Table I presents the mean and standard deviation (SD) of deformation (μm/m) for the two channels and vector for each group / technique by the same tightening sequence (right to left) and tightening force (10 Ncm). One-way ANOVA showed statistically significant differences between group / technique in channel 2 (P<.01) but not in channel 1 and vector (P>.01). Deformation data of channel 2 were analyzed using Tukey HSD multiple comparison test to locate the source of difference. Divergent group exhibited statistically lower deformation than parallel group regardless of impression technique (P<.01).

Table II presents the mean and standard deviation (SD) of deformation (μm/m) for each tightening sequence (right to left and left to right) by the same tightening force (10 Ncm), and for each tightening force (10 Ncm and 20 Ncm) by the same tightening sequence (left to right) on working casts made by the splinted impression technique from parallel group. Paired t-test showed statistically significant difference between the variable tightening sequence

Table I. Comparison of deformation (μm/m) for group / technique

	Mean and SD of Group / Technique				
	Parallel / Unsplinted	Parallel / Splinted	Divergent / Unsplinted	Divergent / Splinted	p-value [1)]
	n=10	n=10	n=10	n=10	
Channel 1	-1237.0 ± 256.2	-1228.1 ± 135.9	-1213.3 ± 319.6	-1095.6 ± 196.3	.514
Channel 2 [2)]	120.4 ± 28.8 [a]	124.6 ± 17.6 [a]	68.4 ± 23.2 [b]	59.1 ± 17.1 [b]	.000
Vector	1243.6 ± 257.2	1234.4 ± 136.6	1215.3 ± 320.2	1097.0 ± 196.8	.493

1) Statistical significances were tested by one-way ANOVA among group / technique.
2) The same letters indicate non-significant difference (Tukey HSD multiple comparison test .01 level of significance).

Table II. Comparison of deformation (μm/m) for tightening sequences & tightening forces (Paired t-test)

	Tightening sequence			Tightening force		
	Mean and SD			Mean and SD		
	Right-to-left	Left-to-right	p-value	10 Ncm	20 Ncm	p-value
	n=10	n=10		n=10	n=10	
Channel 1	-1228.1 ± 135.9	-1292.7 ± 183.8	.057	-1292.7 ± 183.8	-1371.0 ± 157.1	.000*
Channel 2	124.6 ± 17.6	110.6 ± 14.6	.003*	110.6 ± 14.6	121.0 ± 13.3	.001*
Vector	1234.4 ± 136.6	1297.4 ± 184.3	.062	1297.4 ± 184.3	1376.9 ± 157.4	.000*

* Statistically significant at .01 level of significance.

only in channel 2 (P<.01) and between the variable tightening force in channel 1, channel 2, and vector (P<.01).

DISCUSSION

Dental implants are less mobile than natural teeth. The natural tooth can move up to 100 μm within its periodontal ligament, thus compensating for a certain degree of misfit of a fixed partial denture, whereas an osseointegrated implant has extremely limited movement in the range of 10 μm.[27,28] If prostheses do not fit passively on implants, high stress concentrations will be produced when screws are tightened. So accurate impression technique is more important in implant-associated restorations than in conventional ones.

Two impression techniques evaluated in this study have been used for the fabrication of multiple implant-supported prostheses. Although there have been lots of disputes in the dental literature concerning the accuracy of transfer techniques, no consensus has been reached yet. An often-debated issue still exists concerning implant impression techniques, whether to splint impression copings or not.

With respect to the comparison of the direct unsplinted versus splinted impression techniques, the present findings showed that both techniques produced the similar deformation in both parallel and divergent groups except channel 2. The splinting has been shown to be a primary factor for increasing the fitting precision of the restorative complex regardless of the impression materials.[8,9,16,20,29,30] The common practice of splinting the direct transfer copings with acrylic resin is an attempt to stabilize the copings against rotation during analog fastening and to control the relationship between implants in a rigid fashion.[31] However, a definite advantage for this practice has not been shown in other studies.[32] Humphries et al[12], Hsu et al[13], Phillips et al[14] and Herbst et al[15] found no significant differences between the values obtained with acrylic resin splinted versus unsplinted copings in impression techniques. Burawi et al[16] reported that the splinted technique exhibited more deviation from the master cast than the unsplinted one. And Inturregui et al[17] found that unsplinting of transfer copings in the direct technique was the most accurate transfer method. Splinting of transfer copings would provide greater transfer precision because of the splinting stability during both the impression removal and replica connection.[9,20,29] Nevertheless, distortion could result from the residual polymerization shrinkage of the resin used for splinting.[17]

The contradictory results for impression accuracy that have been reported in the literature may be partially explained by the use of different methodologies to assess accuracy.[7] Classic methods of assessing superstructure fit, including manual rocking of alternating closing sequence, visual inspection, and radiographs, are technique-sensitive and subjective.[20] Some experiments[12,29] used microscopy to measure the displacement of analogs in the test specimens in comparison to the master cast at selected points. However, since inaccuracy was expressed in only two dimensions, information was lost. Furthermore, the assessment of total assembly fit was impossible.[7] On the other hand, strain gauges enable the measurement of deformation in multiple directions with high sensitivity. In previous studies,[9,20] four strain gauges were fixed on the superior surface of the framework to measure deformation during screw tightening. This linear setup (quarter Wheatstone bridge) of strain gauges on the superior surface allowed readings of only vertical deviation for upward and downward deformation. Two half Wheatstone bridge connections, composed of two strain gauges on opposite sides enabled the measurement of framework deformation in four directions. This concept has three main advantages.[7] Firstly, the electric signal is amplified. Secondly, this connection compensates for temperature variation.

And thirdly, this connection provides information for the direction of bending. So this connection is more advantageous in evaluating the deformation of the framework than quarter Wheat-stone bridge which was used in most of previous studies.

In this study, the master frameworks bent toward the inferior side on all casts made by both direct unsplinted and splinted impression techniques in both parallel and divergent conditions. This result may be partially explained by movement of replicas in the specimens due to setting expansion of dental stone.[7,9] Another factor discovered was that the master framework, when connected to the master cast, was stressed even though it was designed to have a "perfect passive fit" by pick-up impression. Possible reasons for these stresses could be attributed to (1) movement of replicas in master cast due to setting expansion of dental stone; (2) tightening of the frameworks to the replicas, because the replica positioning was not carried out with the torque wrench at 10 Ncm; (3) minimal misfit of screws and Cast-to Abutments.[7,9] Thus, it would seem logical to apply the same torque and tightening sequences throughout the fabrication process, starting with connection of the fixture replicas to the impression copings on removal of the impression from the oral cavity, continuing through all laboratory procedures, and finishing with placement of the superstructure on the implants in the oral cavity.[9] In the present study, the same effect was observed.

In this study, deformation data of channel 2 were relatively small compared with those of channel 1, and showed that divergent group exhibited statistically lower deformation than parallel group regardless of impression techniques. However, in 2-implant model, strain values of channel 2, composed of two strain gauges on anterior and posterior sides, are not determined by deformation of the master frameworks. But those are determined by the location of strain gauges between two abutments because of the direction of screw tightening force and the friction between screws and Cast-to Abutments (Fig. 8, A and B). In this study, in spite of efforts to locate the strain gauges in the midway between two abutments, the strain gauges on the anterior and posterior sides may be not located in the center. And those of parallel group may be located more apart from the center than those of divergent group. This was supported by the result that deformation of channel 2 was significantly different according to the screw tightening sequence.

Fabricating an implant-supported prosthesis is seemingly very similar to fabricating a conventional fixed prosthesis. One difference that can exist is the problem of nonparallel implants and the accurate transfer of these relationships to a working cast. Any nonparallel movement of the impression coping places the impression material under stress. Less than ideal elastic recovery from the deformation caused by such stress may result in an inaccurate relationship of working cast implants.[31,33] But the data presented in this study doesn' t support such an explanation within 8-degree divergent relationship.

In previous studies,[18,19] inaccurate fit caused stress in the superstructure with different intraoral tightening sequences according to the location of the misfit. And Nissan et al[20] reported that the use of variable tightening sequences and forces did not cause significant change in stresses generated on the framework in the casts made by the splinted impression technique. In this study, variable screw tightening sequences didn' t produce significantly different deformation except in channel 2, but variable screw tightening forces resulted in significantly different deformation in both channels in spite of using the splinted impression technique. This difference according to screw tightening forces revealed the inaccuracy of impression, and this inaccuracy may be exaggerated in the internal connection system compared with the external connection system because of the difference of the joint structure that more contact surface is not parallel to the screw axis. So accurate impression technique may be more important in the internal connection system than the external connection system, especially when the nonsegmented, screw-retained restoration such as the master framework of this study is considered.

The use of fixture replicas instead of implants on the master cast offered no disadvantage, as the focus was a comparison of two impression techniques. And the impression material chosen was a single material, vinyl polysiloxane for the purpose of investigation, as the attention was on impression technique accuracy and not material accuracy.

The term passive fit, with regard to the relationship of a prosthetic superstructure to its underlying implants or abutments, appears with increasing regularity in the literature. Brånemark[2] described passive fit existing at a level of accuracy that enabled the immature bone to mature or remodel in response to occlusal loads following prosthesis connection. He suggested that passive fit exists when the gap between the abutment and the superstructure is less than 0.01 mm. However, no definition or parameters have been established as to what constitutes a passive fit, as yet.[9]

From the results of this study, there was no difference between the direct unsplinted and splinted impression techniques in both parallel and divergent conditions. However, the fit between superstructure and fixture replicas could not be described as passive. The definition of clinically acceptable value for passivity represents an ultimate goal of implant impression studies. Nevertheless, evidence of the real outcomes of strains within the prosthesis/implant/bone complex still is not available.[7] Further studies are needed to define the clinically acceptable strain value and clinical acceptability of a given technique.

And, because of the limitation of the methodology, only 8-degree divergent relationship was evaluated in this study. But, for the purpose of studying the effect of the structural difference between external and internal connection implant system on the accuracy of fixture-level impression techniques, more researches should be performed for more divergent relationship.

CONCLUSIONS

Within the limitations of this study, the following conclusions could be drawn.

1. Frameworks bent toward the inferior side on all casts made by both direct unsplinted and splinted impression techniques in both parallel and divergent conditions.
2. There was no statistically significant difference of accuracy between direct unsplinted and splinted impression techniques in both parallel and divergent conditions ($P>.01$).
3. There was no statistically significant difference of stress according to screw tightening sequences in casts made by the splinted impression technique in parallel condition ($P>.01$).
4. Greater tightening force resulted in greater stress in casts made by the splinted impression technique in parallel condition ($P<.01$).

There appears to be no clinical advantage in using the more time-consuming technique of splinting impression copings with autopolymerizing acrylic resin within the limitations of this study.

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