Three-Dimensional Image Correlation Analyses for Strains Generated by Cement and Screw-Retained Implant Prostheses

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ABSTRACT

Purpose: This study aimed to measure and compare strains generated by splinted implant crowns retained by cement or screws for two implants with applied load.

Materials and Methods: A stereolithic resin model was printed using computed tomography data from a patient missing all mandibular molar teeth. Two 4×6 mm implants were consecutively placed in the left side. One set of splinted cement and screw-retained crowns were made to fit the two implants. Image correlation technique was used for full-field measurement of strains using an image correlation software and two synchronized high-resolution digital cameras. A random dot pattern was applied to the model surface. Cameras recorded changes in random dot patterns as prostheses were loaded up to 400 N in vertical and oblique directions using a universal testing machine. Testing was repeated three times for cement and screw-retained prostheses. An image correlation algorithm used the dot pattern to define correlation areas or virtual strain gauge boxes. Three-dimensional coordinates of gauge box centers were determined for each recorded photograph and used to calculate strains. Strain distribution data were compared for major, minor, and von Mises strains for each loading condition, as well as peak and average strains for the field of view using an analysis of variance ($\alpha = 0.05$).

Results: Patterns and magnitudes of strain for cement- and screw-retained splinted crowns were similar under vertical loading. Neither peak nor mean strains were significantly different for the two retention methods. For oblique loading, peak strains were lower for the screw-retained crowns; however, there were no statistically significant differences between the two groups when strains were averaged throughout the entire field of view.

Conclusions: Cement retention did not improve the magnitude of transferred strains for splinted implant crowns using either loading condition.

KEY WORDS: cement, screw-retained implant prostheses, strains

INTRODUCTION

Cement versus screw retention is one of the issues in implant dentistry that has prompted debate.[1–3] Retrievability is frequently cited as the major advantage of screw retention. Residual cement resulting in soft-tissue problems may also be avoided with screw retention.[4–7] Advocates of cement retention claim improvements in esthetics, porcelain fracture resistance, and occlusion.[8–11] It has also been speculated that a more passive fit may be achieved with cement retention.[1,12] This is based on the theory that the absence of a screw eliminates the clamping force and subsequent strains introduced by screw-tightening.[1,12]

In vitro studies have reported differences in strains generated between these two prostheses types using strain gauges and photoelasticity.[13,14] Guichet and colleagues[13] developed an anatomically correct photoelastic model with three 10-mm external hex implants to explore this idea. The authors compared patterns of stress produced by five screw-retained and five cement-retained prostheses. Overall, they found that the

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three-unit cement-retained implant prostheses demonstrated lower levels of stress upon fastening with no applied load. They also compared marginal openings between the two groups. Marginal openings for the two groups were similar prior to cementation or screw-tightening, but gaps became smaller for the screw-retained group after screw-tightening. No correlation between marginal opening and ranking of stress concentration was observed.

More recently, Karl and colleagues[14] bonded strain gauges to the pontics of five screw-retained and five cement-retained prostheses for comparison of strains in vivo. Strains were measured on the prostheses during cementation or screw fixation to ITI implants (Straumann AG, Waldenburg, Switzerland) in the absence of occlusal loading. The authors found that both fixed partial denture (FPD) groups produced some strain upon placement. Although statistical analysis was not done, the cement-retained group resulted in lower strain levels at the location of the two gauges. Greater magnitudes of strain were measured at mesial gauge locations as opposed to distal for both groups.

These same investigators subsequently bonded strain gauges to an epoxy resin model with block geometry to compare the transfer of strains by three-unit and five-unit screw-retained and cement-retained, implant-supported prostheses.[15] Gauges were placed in a central position on the superior surface of the resin model immediately mesial and distal to all implants. Strain gauges were balanced after cementable abutments were secured and before placement of either cementable or screw-retained prostheses. Strain gauge measurements were recorded following cementation or screw fixation with no applied load. The authors found no statistically significant difference between the screw- and cement-retained groups for either FPD length tested. They concluded that the mechanism of retention had only a minor influence on strain at the locations measured; however, they recommended placing gauges in the resin for future studies.

Akca and colleagues[16] used strain gauges bonded to the crestal and lateral surfaces of six freshly harvested human bone segments to evaluate the effects of prostheses retention on strains transferred by two implants. Strain gauges were balanced prior to cementation or screw fixation of the prostheses to account for strains induced by misfit. Bone-level strain measurements at both strain gauge locations were not significantly different for the two prostheses designs with a 150 N vertical load application. The authors concluded that three-unit screw- and cement- retained prostheses produced similar strains.

It has been suggested that cement retention results in a more passive fit than screw retention.[1,12] This theory has been investigated to some extent using strain gauges and photoelasticity to detect strain differences at the level of bone with conflicting results.[13–16] Strain gauges provide quantitative data, but these data are limited to the gauge locations. Photoelasticity provides qualitative data for overall stress distribution, but quantitative data are lacking. The image correlation technique has only recently been used in the field of biomechanics.[17] This method allows for visualization and quantification of strains on the entire surface of a testing model.[17–19]

The purpose of this study was to measure and compare strains generated by splinted implant crowns retained by cement or screws for two implants featuring an internal connection. The hypothesis that cement-retained, implant-supported FPDs transfer less strain with applied loads will be tested. The three-dimensional image correlation method will be used.

METHODS

A stereolithic resin model (Accudental Inc, Golden, CO, USA) was printed using computed tomography data (Imaging Sciences International, Hatfield, PA, USA) from a patient missing all mandibular molar teeth. The resin (ABS transparent resin, DSM Somos, Elgin, IL, USA) used had an elastic modulus of 2,000 MPa approximating published estimates for cancellous bone (1,507 MPa).[20] Two 4×6 mm implants (Osseospeed, Astra Tech, Mölndal, Sweden) coated with a thin layer of liquid cyanoacrylate (M-Bond 200; Vishay, Malvern, PA, USA) were placed in the left side of the mandibular model. Vinyl polysiloxane (Reprosil, Dentsply Caulk, York, PA, USA) impressions were made of the mandibular model. Indirect impression posts and implant analogs (Astra Tech AB, Mölndal, Sweden) were used to transfer the position of the two implants to a definitive cast (Prima Rock, Whip Mix Corp, Louisville, KY, USA).

One set of cement and one set of screw-retained prostheses were made to fit the same mandibular model. TiDesign prefabricated engaging abutments and cast-to non-engaging abutments (Astra Tech AB) were used for the cement and screw-retained splinted crowns, respectively (Figure 1). Type III gold (Midas, JF Jelenko & Co,

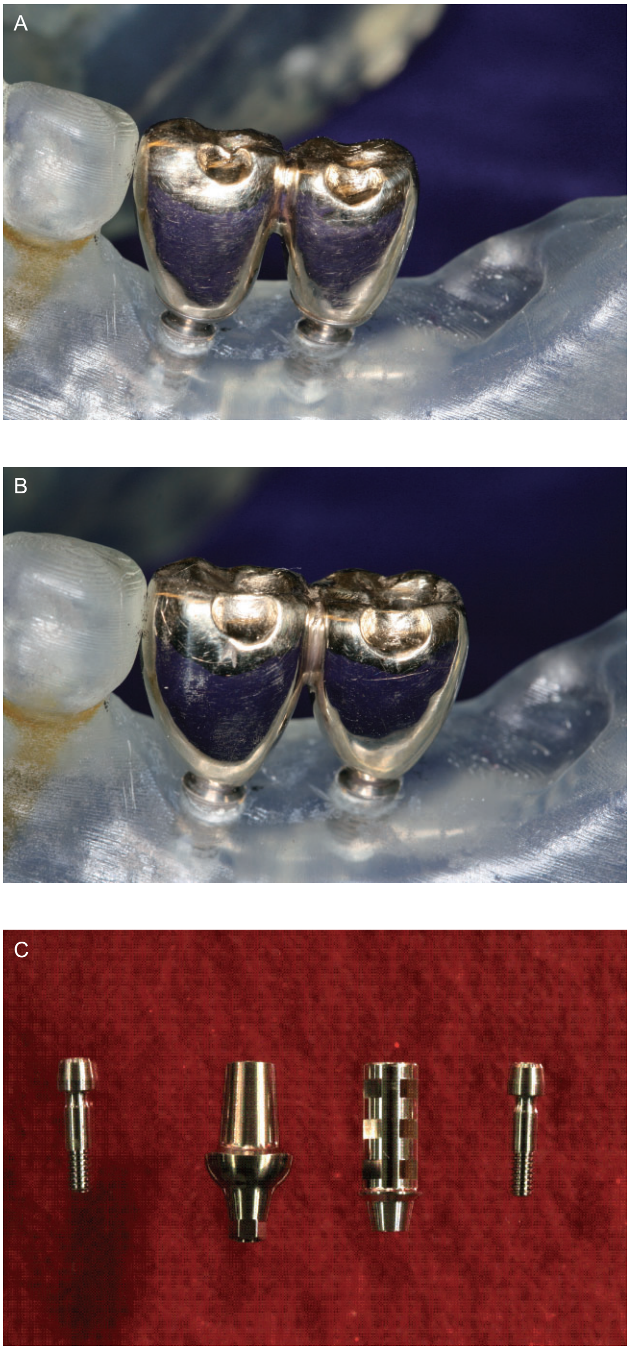

Figure 1 *A*, Cement-retained FPD. *B*, Screw-retained FPD. *C*, Abutments used for cement and screw retention. (FPD = fixed partial denture.)

New Rochelle, NY, USA), was used for all castings. The splinted FPDs ranged in height from 11 to 13 mm. Anatomical replication was achieved by making a condensation silicone (Reprosil, Dentsply Caulk) mold of the first prosthesis. Wax (MDL dental products, Seattle, WA, USA) was allowed to flow into the mold to form a subsequent pattern. Prostheses were cast, finished, polished and tried on the stereolithic model. Proximal contacts were adjusted to allow an 8-µm tin foil shim to drag between interproximal contacts without tearing.[13] Prior to testing prostheses were secured to the model using a torque driver (Astra Tech AB) set to 20 Ncm as per manufacturer recommendations. Medical adhesive silicone (Dow Corning, Midland, MI, USA) was used to retain the cementable prosthesis to ensure retrievability of crowns for subsequent testing on the same resin model.

The three-dimensional image correlation technique was used for full-field measurement of strain using commercial image correlation software (Vic-3D, 2007 Digital Image, Correlation version 2007.1.0, build 210, Columbia, SC, USA) and a pair of high-resolution digital cameras (Point Grey Research, Richmond, British Columbia, Canada). This provided a synchronized stereo view of the models during the experiment.[17–19] A random dot pattern was applied to external surfaces of the mandibular model and prostheses. Using an array of 1,600 × 1,200 pixels, cameras recorded changes in the random dot pattern as the models were tested. In a stereovision arrangement, each camera was independently calibrated by making images of the same target grid in different views. This common grid pattern was used to define a common world coordinate system for both cameras providing the basis for relating image positions in both cameras to a common three-dimensional location.[19]

Maximum static loads of 400 N were applied in vertical and 20-degree oblique directions to anterior and posterior splinted implant crowns simultaneously using a biaxial servohydraulic load frame, universal testing machine (Instron model 1321; Instron, Norwood, MA, USA).[21–23] Figure 2 shows the stereolithic model mounted for loading in view of the cameras. A digital protractor (Swiss Precision Instrument Inc, Garden Grove, CA, USA) was used to standardize model angulation. Three tests were done for each of the two prostheses using vertical or oblique loading for a total of 12 tests in a predetermined random order. An image correlation algorithm used the dot pattern to define correlation areas or virtual strain gauge boxes. The three-dimensional coordinates of these gauge box centers were determined for each recorded photograph and used to calculate strains throughout the entire surfaces of the models.[17–19] Average and peak strain distribution data were generated and compared for major, minor, and von

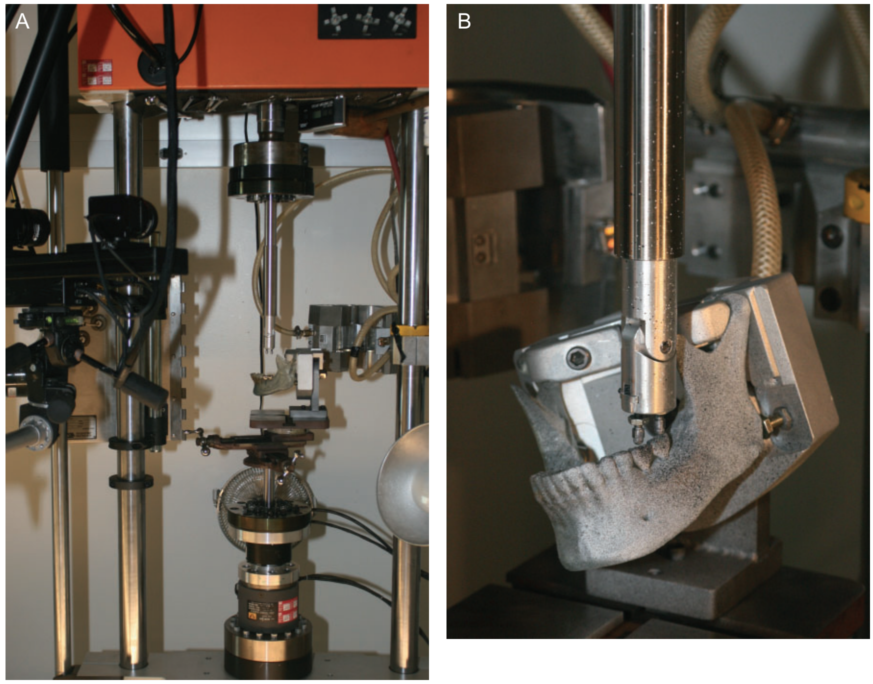

Figure 2 *A*, Universal testing machine and dual camera apparatus for vertical loading. *B*, Oblique loading position.

Mises strains for two loading conditions, as well as peak and average strains for the entire field of view using an analysis of variance using statistical software (JMP 8.01; SAS, Inc., Cary, NC, USA). All analyses were evaluated using $\alpha = 0.05$. The p values for the multiple comparisons were adjusted using a step-down Bonferroni method (SAS 9.2, SAS, Inc.).

RESULTS

In this study, major, minor, and von Mises strains were analyzed. Major strains, or maximum principal strains, were generally tensile (positive) for this application. Likewise, minor strains, or minimum principal strains were compressive (negative). Von Mises equivalent strain or von Mises strains represented a combination of all-strain components. Results revealed patterns and magnitudes of major, minor, and von Mises strains for cement- and screw-retained splinted crowns that were similar under vertical loading (Figure 3). These data appear in Table 1 with no statistically significant differences. Figure 4 compares the results graphically.

Figure 5 shows the principal strain distribution patterns for the two retentive modes for oblique loading. A visual comparison of the quantitative strain data for oblique loading shows lower strain magnitudes for the screw-retained splinted crowns (Figure 6). As shown in Table 1, there was a statistically significant difference in peak von Mises strains for the two retention methods ($p = .040$) for this loading condition; however, this difference was not significant when accounting for multiple comparisons. Peak values for major ($p = .345$) and minor ($p = .161$) were also lower in magnitude for the screw-retained, but not statistically different. Average values for major, minor, and von Mises strains throughout the entire field of view were lower in magnitude for the screw-retained crowns; however, these differences were not statistically significant ($p = .095$, .054, .069, respectively).

DISCUSSION

Results of this study did not support the hypothesis that cement-retained, implant-supported FPDs transfer less strain with applied loads. Contrasting results were reported by studies comparing strains introduced during cementation or screw-fastening, implant-supported prostheses.[13,14] An in vitro study using the photoelasticity method revealed lower magnitudes of stress for the cement-retained group.[13] In addition, stress patterns for the photoelasticity study exhibited more variability for location and intensity when prostheses were screw-retained.[13] Data collected from strain gauges bonded to cement- and screw-retained

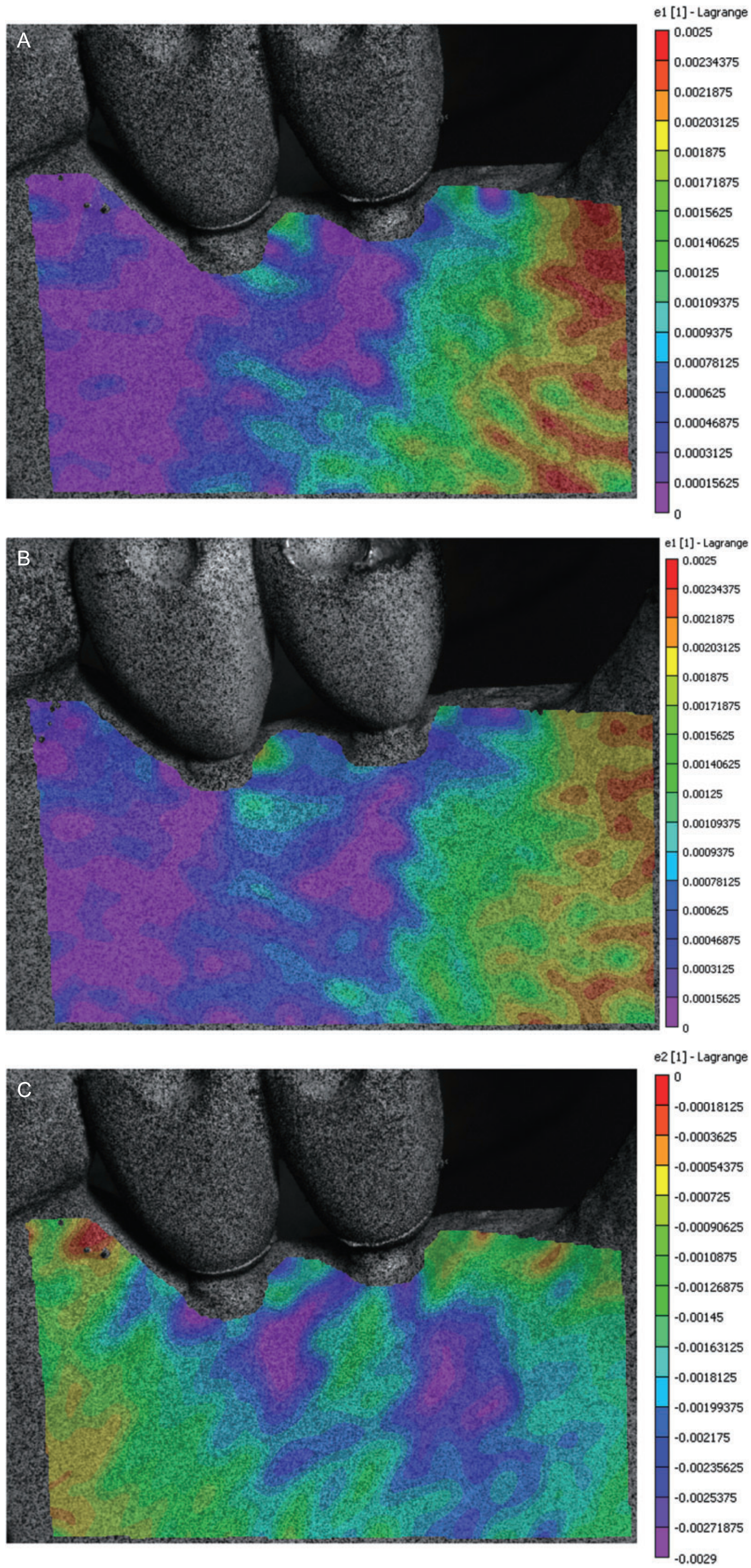

Figure 3 *A,* Patterns of strain for vertical loading on splinted prostheses, maximum principal strain for cement-retained. *B,* Patterns of strain for vertical loading on splinted prostheses, maximum principal strain for screw-retained. *C,* Patterns of strain for vertical loading on splinted prostheses, minimum principal strain for cement-retained.

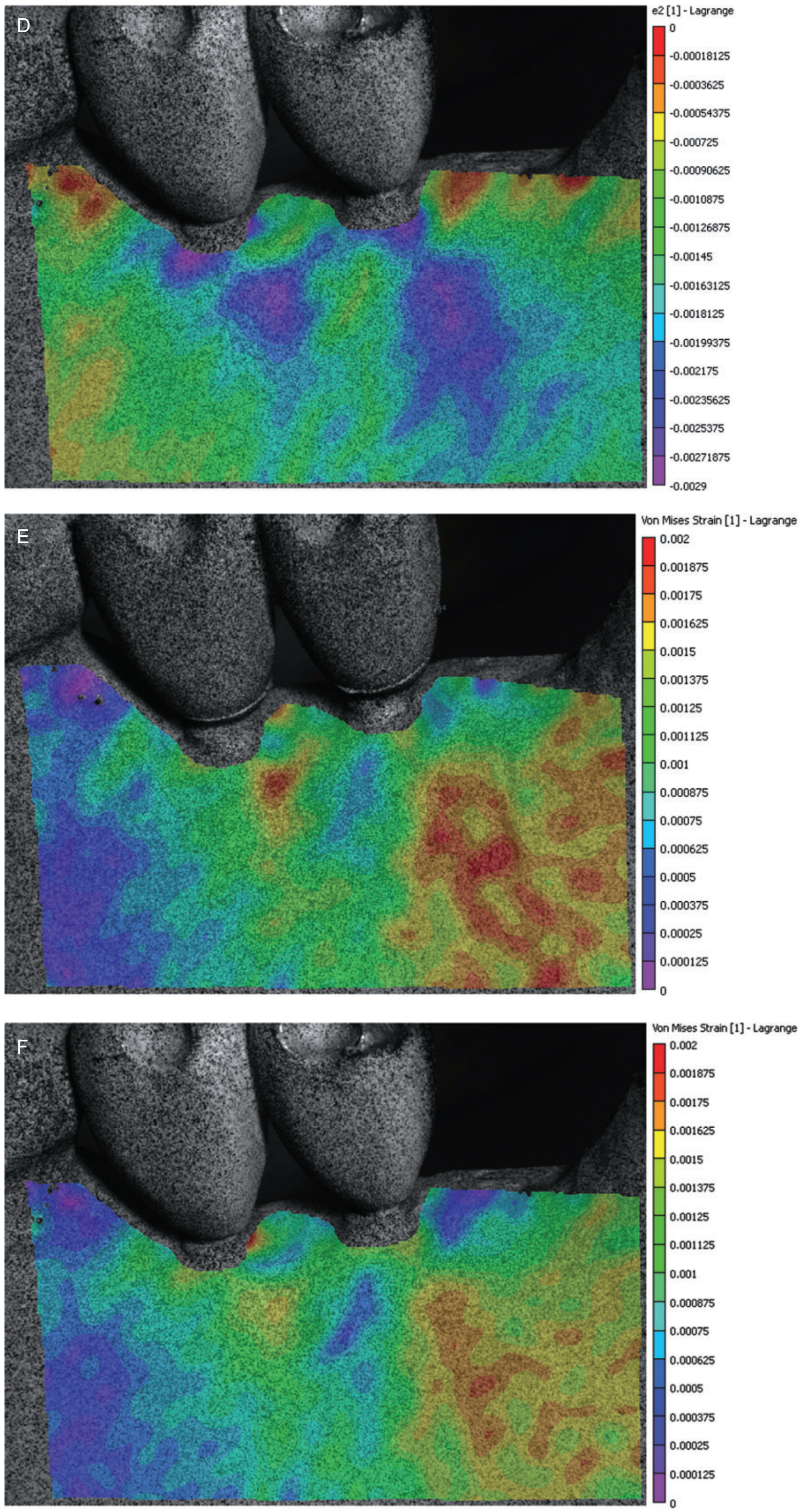

Figure 3 (*continued*) *D,* Patterns of strain for vertical loading on splinted prostheses, minimum principal strain for screw-retained. *E,* Patterns of strain for vertical loading on splinted prostheses, von Mises equivalent strain for cement-retained. *F,* Patterns of strain for oblique loading on splinted prostheses, von Mises equivalent strain for screw-retained.

TABLE 1 Peak and Average Mean Strains Transferred By Cement and Screw-Retained Prostheses

Angle (deg)	Strain	Measure	Retention	Mean	SD	*p* Value
0	E1	Average	Cement	0.000.87	0.000.03	.667
			Screw	0.000.85	0.000.05	
		Peak	Cement	0.002.89	0.000.29	.052
			Screw	0.002.33	0.000.20	
	E2	Average	Cement	−0.001.39	0.000.22	.486
			Screw	−0.001.25	0.000.23	
		Peak	Cement	−0.003.75	0.000.41	.130
			Screw	−0.003.24	0.000.22	
	von Mises	Average	Cement	0.001.02	0.000.10	.426
			Screw	0.000.94	0.000.12	
		Peak	Cement	0.002.08	0.000.06	.939
			Screw	0.002.07	0.000.20	
20	E1	Average	Cement	0.001.44	0.000.29	.095
			Screw	0.001.07	0.000.06	
		Peak	Cement	0.004.03	0.001.17	.345
			Screw	0.003.29	0.000.26	
	E2	Average	Cement	−0.001.80	0.000.31	.054
			Screw	−0.001.31	0.000.06	
		Peak	Cement	−0.004.72	0.000.19	.161
			Screw	−0.003.89	0.000.81	
	von Mises	Average	Cement	0.001.42	0.000.26	.069
			Screw	0.001.04	0.000.04	
		Peak	Cement	0.003.29	0.000.22	.040*
			Screw	0.002.72	0.000.24	

*$p < .05$.

prostheses placed in vivo also showed lower strains for cement-retained prostheses.[14] These two investigations comparing stresses or strains upon FPD placement with no applied load reported results favoring cement retention for minimizing stress or strain.[13,14]

For the present study, occlusal loads were simulated to investigate whether differences occur between cement- and screw-retained FPDs during function. The simulated load may explain why current results varied from those found in the previous two studies where no loads were used.[13,14] Under applied load, differences between the two prostheses types were most likely a negligible part of the overall strain field. It is not unreasonable for resultant strain patterns to be similar for the two types of prostheses using the same loading conditions.

For vertical loading, strains were not statistically different for the two types of prostheses in this study. These findings agree with the results published by Akca and collegues[16] for vertical loading of cement- and screw-retained prostheses using strain gauge measurements. Interestingly, gauges in the latter study were balanced prior to screw retention or cementation of the prostheses in an effort to include any strains generated by misfit. The image correlation system used for the present study was calibrated after the prostheses were placed yet results for the two studies concur showing similar strains for the two retention methods. It may be that strains introduced during placement are a relatively small part of the total strain under vertical loading.

Present results showed that peak minor and von Mises strains encompassed larger surface areas for the anterior as opposed to posterior implant regardless of retention mode or loading condition. Karl and colleagues[14] also measured higher strains at mesial strain gauges locations as opposed to distal for both cement- and screw-retained prostheses secured intraorally. These similarities may be at least partially explained by the presence of a mesial proximal contact for both studies.

For oblique loading, peak von Mises strains were significantly different for the two prostheses types. These

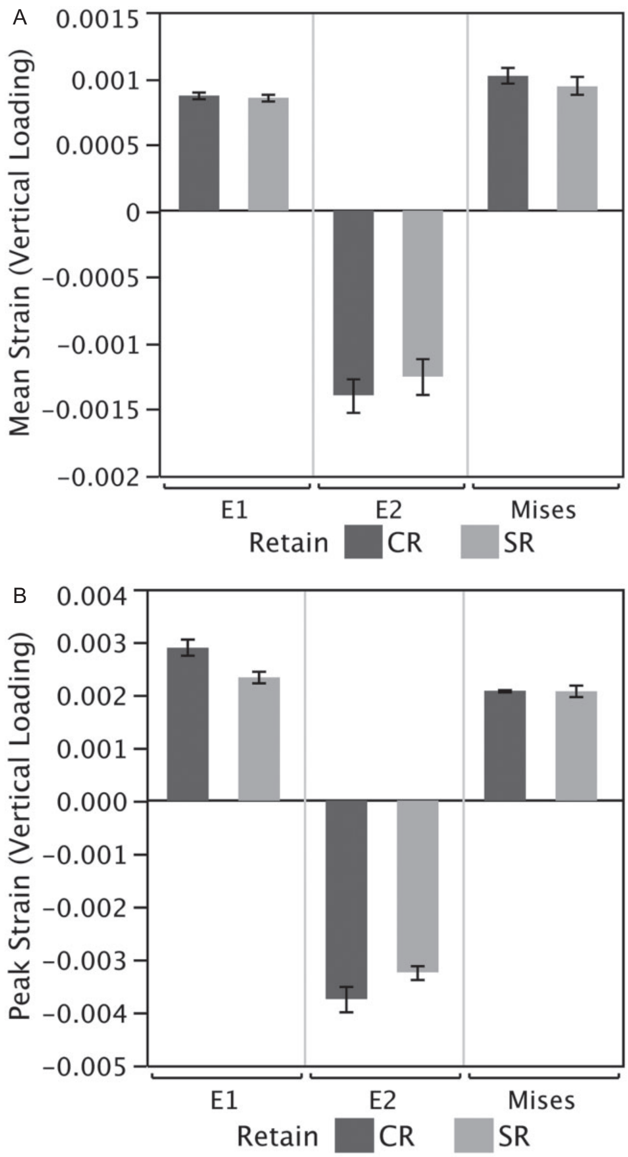

Figure 4 *A,* Mean major (E1), minor (E2), and von Mises strains for cement-retained (CR) and screw-retained (SR) splinted crowns with vertical loading. *B,* Peak strains for cement-retained (CR) and screw-retained (SR) splinted crowns with vertical loading.

strain values, as well as major and minor strains, were actually lower for the screw-retained group. Previous studies investigating strains for the two retention methods did not incorporate oblique loading. Therefore, current results could not be compared with other findings. Theoretically, the directional force applied during oblique loading would be expected to produce compressive strains on the lingual of the model and tensile strains on the facial. The facial tensile strains are visible in Figure 5, A and B. Additional cameras were not used to record strains on the lingual surface of the model. Facial views showing the major (tensile) strains were thought to be of greater importance as bone overload has been shown to occur at lower levels for tensile strain.[24]

The three-dimensional image correlation technique has the advantage of providing both qualitative and quantitative strain data for the entire surface of a testing specimen.[17–19] Prior to its use, quantitative data for an experimental model was available only through strain gauges. Strain gauges provide excellent data but are limited to gauge locations only. Historically, photoelasticity was used to provide an overall view of strain locations for an experimental model, but quantitative data were lacking. A limitation to the three-dimensional image correlation method is that it provides data for the surface of the model that is in view of the cameras only. For the present study, strains on the lingual of the mandible were not measured because the cameras were set up at a fixed location with the facial of the model in view.

It should also be noted that a silicone adhesive was used to ensure retrievability and allow multiple tests. Temporary cements are widely used by practitioners who want the option of removing cement-retained implant crowns for maintenance.[25] There are many choices for temporary cements and selection may depend on the clinical situation.[25] Strain distributions are likely to remain similar for any of the cement options as long as they prevent movement of the prostheses with respect to the implants. For the present study, aggressive crown removal may have damaged the model so an adhesive with minimal retention was selected. The fact that strain patterns were so similar for cement- and screw-retained prostheses suggests that the cement used had minimal effect on the strain distribution.

Results of this study did not provide evidence to support selection of cement retention to minimize strains; however, the method was limited in its ability to replicate clinical osseointegration or dynamic bite forces. Prospective clinical comparisons of cement- and screw-retained FPDs for a patient population with bilateral edentulous areas are needed to validate current results.

CONCLUSION

Within the limitations of this in vitro study, cement retention did not improve the magnitude of transferred strains for splinted implant crowns using vertical or oblique loading condition. The hypothesis that cement-retained, implant-supported fixed partial dentures

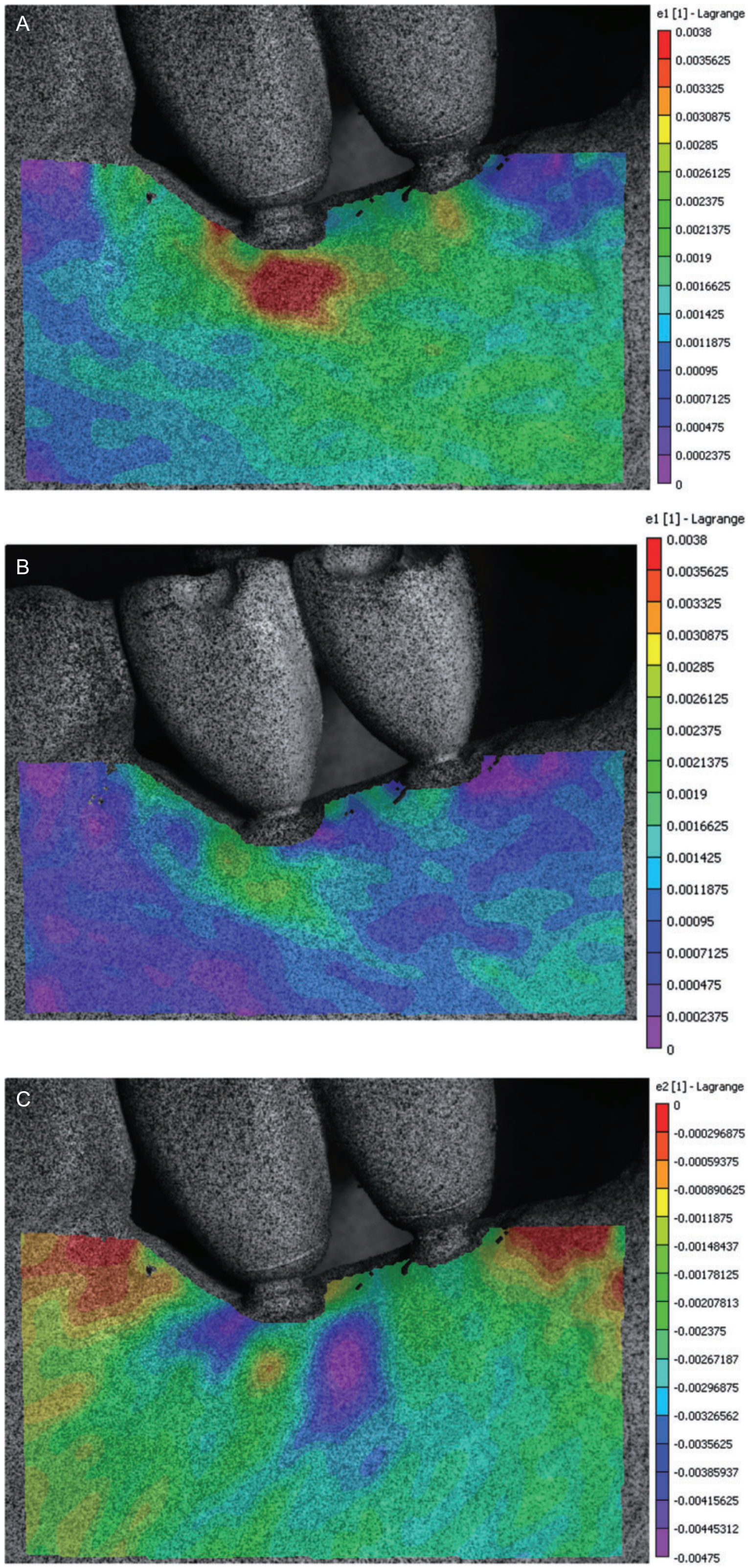

Figure 5 *A,* Patterns of strain for oblique loading on splinted prostheses, maximum principal strain for cement-retained. *B,* Patterns of strain for oblique loading on splinted prostheses, maximum principal strain for screw-retained. *C,* Patterns of strain for oblique loading on splinted prostheses, minimum principal strain for cement-retained.

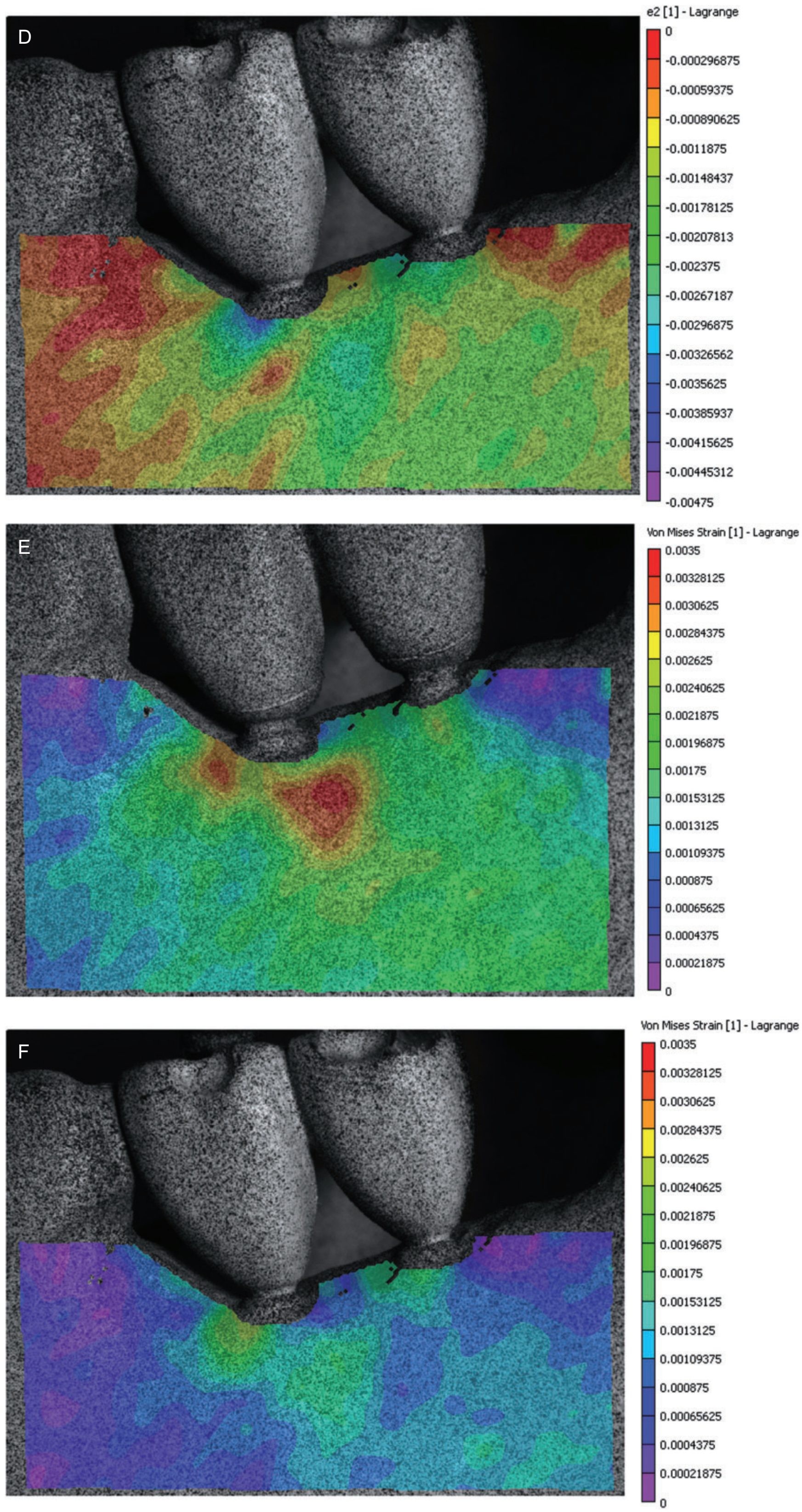

Figure 5 (*continued*) *D,* Patterns of strain for oblique loading on splinted prostheses, minimum principal strain for screw-retained. *E,* Patterns of strain for oblique loading on splinted prostheses, von Mises equivalent strain for cement-retained. *F,* Patterns of strain for oblique loading on splinted prostheses, von Mises equivalent strain for screw-retained.

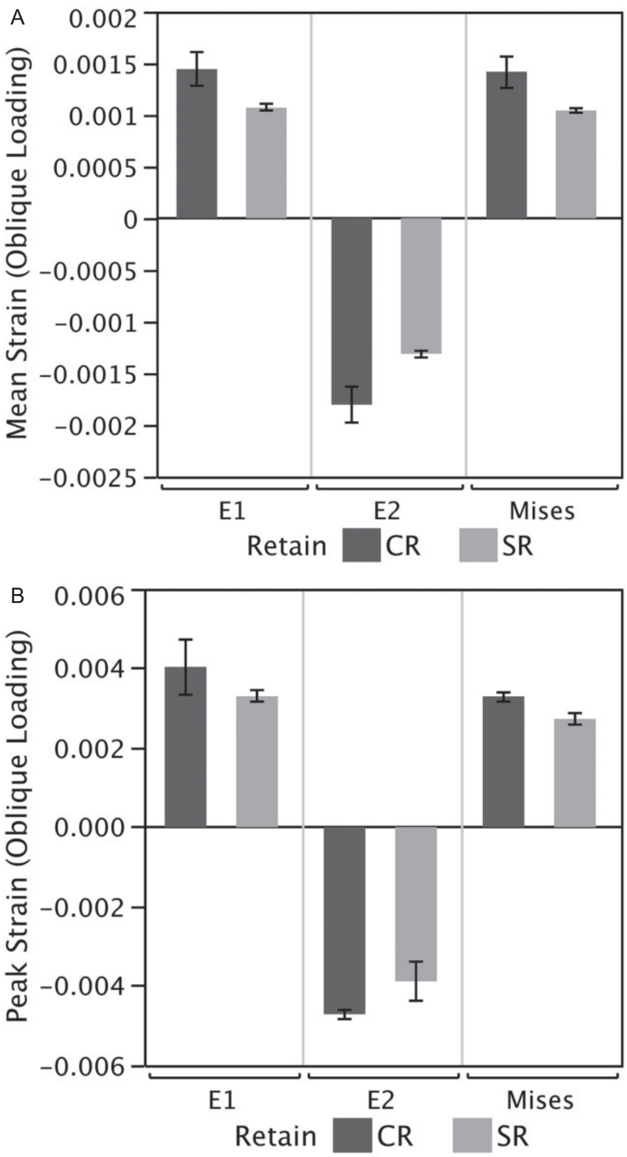

Figure 6 *A,* Mean major (E1), minor (E2), and von Mises strains for cement-retained (CR) and screw-retained (SR) splinted crowns with oblique loading. *B,* Peak strains for cement-retained (CR) and screw-retained (SR) splinted crowns with oblique loading.

transfer less strain to the bone during function was not supported.

DISCLOSURE

Implant parts used in this study were donated by Astra Tech Dental; however, the authors have no financial interest in the company.

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