Passivity of Fit and Marginal Opening in Screw- or Cement-Retained Implant Fixed Partial Denture Designs

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The relationship of stress generation upon placement of cement-retained or screw-retained implant restorations has not been thoroughly investigated. Passivity of fit and marginal discrepancies of screw- and cement-retained implant fixed partial denture (FPD) designs were determined using a photoelastic model of a partially edentulous posterior mandibular arch with 3 screw-type implants. Buccal and lingual marginal openings, measured with a traveling microscope before cementation or screw tightening, revealed no statistical difference in adaptation between designs. Screw tightening caused a reduction in marginal opening (changes significant, P < .05). The opening with the cemented FPDs was similar before and after cementation. Photoelastic evaluation of the FPDs showed that cement-retained FPDs exhibited a more equitable stress distribution than did their screw-retained counterparts. (INT J ORAL MAXILLOFAC IMPLANTS 2000;15:239–246)

Key words: *cement-retained, custom abutment, implant biomechanics, implant prosthesis, loading, passive fit, screw-retained, telescopic crown*

Implant restorations can be either screw- or cement-retained. Screw-retained designs have a well-documented history of success in edentulous patients.[1–3] An increase in treatment of partially edentulous patients has led to numerous implant-restorative concepts, including cement-retained designs.[4–7] These cement-retained designs have had limited scientific documentation.[8,9] Some have questioned the efficacy of the cement-retained designs because they deviate from the established protocol described by Brånemark.[10]

Historically, studies of implant biomechanics have focused on screw-retained restorations. Cement-retained designs have achieved broad use despite limited scientific evaluation. The non-segmented UCLA abutment addressed clinical dilemmas, such as the restoration of implants with alignment or space limitations.[11] Further modification of the UCLA concept gave rise to a philosophy of restoration utilizing individual custom abutments or preparable titanium abutments[12] used in combination with cement-retained[13] or screw-retained telescopic superstructures.[14] Lewis described the use of telescopic crowns over customized abutments for the restoration of improperly aligned implants.[15] The Nobel Biocare CeraOne[16] (Nobel Biocare, Göteborg, Sweden) was one of the first premachined cement-retained implant abutments produced for single-tooth replacement. Preparable titanium and ceramic abutments, specifically designed for cement-retained implant restorations, are now available from a variety of vendors.

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Fig 1 Photoelastic resin "patient model."

The restorative screw was designed to provide predictable retrievability and abutment-restorative joint integrity.[17] This component is eliminated in cement-retained implant restorative designs. The occlusal retaining screw has been eliminated for a variety of reasons. Rieder,[18] and later Hebel and Gajjar,[19] cited esthetics and occlusal function as principal reasons for using cement retention. Misch[20] discussed the ease of achieving passive fit when using the cement-retained design and hypothesized that an intervening cement layer may fill in framework interfacial discrepancies and assist in the transfer of load throughout the bone-implant-restorative system. To date, no study has evaluated the effect of cement retention on the abutment-restorative marginal opening or on passivity of fit.

The passive fit of restorations has been considered essential to the success of osseointegrated implant restorations. Jemt and Book[21] have produced data indicating that prosthesis misfit may be less significant than once thought. Their data on prosthetic misfits in edentulous maxillae restored with full-arch fixed prostheses showed mean prosthetic distortions of 100 µm. None of the restorations studied were considered passive. Their findings showed no significant correlation between prosthesis misfit and bone loss. The data indicate that prosthesis distortion remains over time because of the ankylotic nature of osseointegration, and the authors suggested that misfits might be associated with "prosthetic lesions." They warned against potential problems with metal fatigue, such as screw loosening and/or fracture. Also, bone response in minimal bone volumes, in poor-quality bone, or in grafted bone may be more sensitive to prosthetic misfit. No data have been presented on prosthetic misfits on implants in compromised bone situations.

Conventional casting and soldering techniques have been only moderately successful in achieving passively seating restorations.[22] This has led to the development of techniques to aid in the evaluation of fit and to improve accuracy and passivity. These include magnification-assisted visual inspection, radiographic evaluation, the 1-screw test, modified impression and indexing techniques,[23] soldering, laser welding, and electrical discharge machining.[24]

Visual inspection of the restorative-abutment interfaces is commonly used to assess passive fit.[25] Assif et al[26] found that dentists who were experienced in implant procedures categorized interfacial discrepancies of equal to or greater than 30 µm as questionable or unacceptable. Conversely, interfacial discrepancies of 26 µm or less were categorized as passively fitting restorations. Strain gauges were attached in vitro to the same interfaces with previously reported similar results.[26] Jemt et al[27] used strain gauges in vivo to evaluate abutment strain in both fixed and removable maxillary prostheses and concluded that it is probably not possible to create a completely passively fitting prosthesis.

Little is known about accuracy of fit and its relationship to the character of stress transfer of cement-retained versus screw-retained implant fixed partial dentures (FPDs). The purpose of this study was to compare the marginal integrity and the stress generation during seating of cement-retained and screw-retained implant restorations.

MATERIALS AND METHODS

The condition simulated for evaluation in this study was a mandibular posterior quadrant restored with three 10-mm implants (Nobel Biocare). Implants were placed in the left first and second premolar and first molar positions (Fig 1). Ten implant (FPD) restorations were fabricated. Five FPDs utilized a screw-retained design, and 5 utilized a cement-retained design. One manufacturer was used for both abutment designs to standardize machining tolerances and the material grade of titanium (Implant Innovations Inc, Palm Beach Gardens, FL).[28] An anatomically correct skeletal form was used to create a master cast, mold, and photoelastic resin "patient cast." The resin used was a medium-modulus photoelastic resin designed to simulate healthy bone (PL-2, Measurements Group Inc, Raleigh, NC).

Accepted clinical and laboratory procedures were used in the fabrication and placement of the FPDs. An anatomically appropriate wax gingival form overlaid the photoelastic resin to simulate the thickness

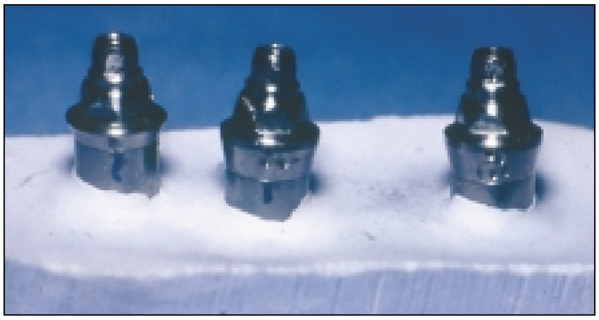

Fig 2 Conical "screw-retained abutments" on index.

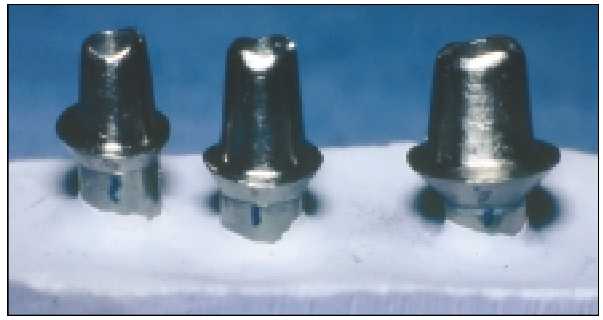

Fig 3 Preparable "cement-retained abutments" on index.

of gingival tissues during impression-making procedures. Implant level pick-up impression posts (E. P. square impression copings, Implant Innovations Inc) were oriented on the implants. A custom tray was fabricated to adapt loosely to the impression posts. A light-body polyvinyl impression was made (Extrude, Kerr, Romulus, MI). Implant analogs were secured into the impression. A silicone representing soft tissue (GI Mask, GC America Inc, Alsip, IL) was added to the internal aspect of the impression surrounding the necks of the implant analogs. The impression was then poured in vacuum-mixed die stone, and a working cast was created (Die Keen, Heraeus Kulzer, South Bend, IN). Teeth were fashioned in inlay wax in an anatomically correct manner with a 1-mm buccal cutback for porcelain application. A condensation silicone mold (Coltene, Whaledent, Mahwah, NJ) was fashioned over this FPD wax pattern to allow for multiple FPD pattern replications.

The first FPD design investigated was the screw-retained FPD, based on the E. P. conical abutments (Implant Innovations Inc) (Fig 2). The abutments and gold cylinders were placed onto the working cast and a resin FPD framework was initiated (G. C. Pattern Resin, G. C. Dental Industrial, Tokyo, Japan). The framework was sectioned and then enclosed in the silicone mold assembly. A wax injection technique ensured accuracy for the multiple FPD replications. These steps were repeated until 5 screw-retained wax FPD frameworks were complete.

The second FPD design considered was the cement-retained FPD based on the E. P. 2-piece abutment posts (Implant Innovations Inc) (Fig 3). The abutments were placed onto the working cast and modified according to the manufacturer's recommendations to allow for occlusal and axial clearance, cervical emergence, taper, and path of draw. A uniform total taper of 6 degrees was achieved using a precision-milling machine (F-1 milling machine, Ney/Degussa, Bloomfield, CT). The abutments were then polished to a medium-high rubber-wheel finish. Five resin copings were made for each abutment without the use of die spacer. The copings were then positioned on the abutments and assembled in the silicone mold. Wax was subsequently injected into the mold, forming the wax FPD frameworks. Five replicas were completed.

An implant cast verification index was fabricated to verify the implant orientation and abutment relationships. It was used to orient the individual restorative units prior to investing and casting. The index was fabricated as follows. Three square implant level impression posts were secured to the patient's photoelastic resin cast and joined together with dental floss and acrylic resin (Relate, Parkell, Farmingdale, New York, NY). Implant replicas were added to the impression posts, the verification assembly was seated in a patty of improved stone (Colorburst, Econotek Inc, Orange, CA), and the stone was allowed to harden. Fixed partial denture wax patterns were sectioned interproximally and were rejoined on the implant verification index with a cyanoacrylate gel (Zap-it, Dental Ventures of North America, Yorba Linda, CA) prior to spruing and investing.

The investment, burnout, and casting techniques were standardized. Patterns were sprued and invested individually in a phosphate-bonded investment (Cera-Fina, Whip Mix Corp, Louisville, KY) according to a 1-piece casting technique described by White.[22] Following bench curing and burnout, the investment rings were cast in a gold-palladium alloy (Silhouette 550SL, Argen Alloys Inc, San Diego, CA). Devesting was completed in the usual manner with minimum use of aluminum oxide air abrasives on critical interfaces. Castings were treated according to manufacturer's recommendations for each abutment system. Burs were used under laboratory

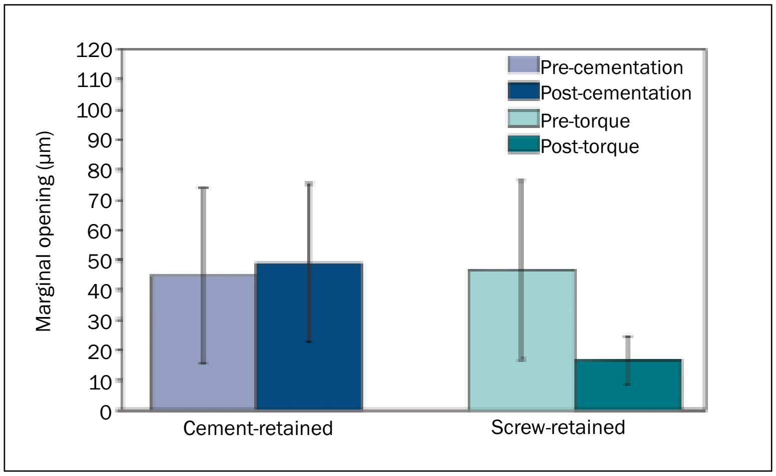

Fig 4 Cumulative marginal openings for all FPDs.

microscopes to eliminate internal casting inaccuracies. Protective polishing caps covered the interfaces and reduced the risk of inaccuracy.

Fixed partial denture specimens were placed on the patient model using a standard protocol. The screw-retained test specimens were subjected to their manufacturers' recommended torque values for seating of the implant restorative abutment screws (20 Ncm, Vident, Baldwin Park, CA) and gold screws (10 Ncm, Nobel Biocare) utilizing mechanical torque-controlling devices. A progressive and sequential increase in torque was used when assembling and disassembling the FPDs. The cement-retained specimens were seated using a zinc oxide–eugenol temporary cement (Temp-Bond, Kerr, Orange, CA) under a 4.5-kg load for 1 minute, followed by a 0.9-kg load for 2 minutes, and then bench set. Excess cement was removed prior to testing. Each specimen was evaluated under the same conditions.

The protocol called for an evaluation of the marginal accuracy of the FPDs using a traveling measuring microscope (Gaertner, Chicago, IL). The FPD specimens were seated on their corresponding abutments and a jig was fashioned to enable accurate repositioning of the abutment-restorative complex upon the microscope stage. Restorative margins were oriented perpendicular to the direction of travel of the stage. Fiducial marks were made to identify the mid-buccal and mid-lingual of each abutment-restorative interface. To simulate a clinical try-in, a spring with a standard compression of 0.5 kg was placed on the center occlusal table to stabilize the castings prior to seating (without torque in the screw-retained FPDs and without the cement in the cement-retained FPDs). Three measurements were made for each of the 3 abutments from both the buccal and lingual aspects of all the FPDs. Then the restorations were delivered to the test model as previously described (screw torque or cement), and the measurements were repeated for all of the test samples.

The data were analyzed to determine the mean marginal openings and standard deviations for each of the 10 FPDs. Additional analysis compared the cement-retained cumulative data against the screw-retained cumulative data. Analysis of variance was used to determine whether significant differences existed between the groups. Tukey multiple range analysis was used to determine differences among groups.

Test FPD samples were then evaluated for stress generation upon screw tightening or cementation. Prior to any evaluation, the photoelastic resin cast was determined to be free of residual stress. The FPD being tested and the photoelastic bone cast were immersed in mineral oil and photographed in polarized light according to previously published techniques.[29] Each specimen was photographed. In subsequent tests, the specimens were assembled when the baseline freedom from residual stress was achieved in the patient model. Test repetition was completed for all restorations. Photographic data were analyzed and ranked in order of increasing stress for comparison.

RESULTS

Microscopic Marginal Analysis

Cumulative margin data for all 10 prostheses are summarized in Fig 4. Prior to screw tightening or cementation, mean marginal openings were similar for both groups (screw-retained before = 46.7 ± 29.8 µm; cement-retained before = 45.0 ± 29.1 µm; no statistical differences, $P < .05$). Upon screw tightening, the screw-retained group margins closed an average of 65% to a mean marginal opening of 16.5 µm (screw-retained before = 46.7 ± 29.8 µm; screw-retained after = 16.5 ± 8.1 µm, which was statistically different from all other groups, $P < .05$). Upon cementation, the restorations showed a weak trend toward opening that was not statistically significant (cement-retained before = 45.0 ± 29.1 µm; cement-retained after = 49.1 ± 26.3 µm; not statistically different from other predelivery groups, $P < .05$). Similar trends existed when the data were separated by anterior, middle, and posterior abutments.

Photoelastic Analysis

Under pretest, non-loaded conditions, the photoelastic resin cast was free of residual stress. When torque was applied to the gold screws, stress transfer into the bone model was noted in 4 of the 5 screw-retained FPDs and was highly variable in location and intensity (Fig 5, S1–S5). The highest stress (1½ fringes) was seen at the center implant supporting one of the screw-retained FPDs (Fig 5, S5). The apically localized stress at the center implant communicated to the distal surface of the anterior implant and to a lesser extent, to the mesial surface of the posterior implant. The lowest stress levels (less than ½ fringe order) were seen with 1 each of the screw-retained and cement-retained FPDs (Fig 5, S1 and C1).

In the cement-retained group (Fig 5, C1–C5) one of the FPDs exhibited moderate levels of stress (1 fringe order) located coronally and interproximally (Fig 5, C5). Others in the cement-retained group exhibited lower levels of stress (less than ½ fringe order) also oriented coronally and interproximally. There was no apical localization of stress in this group.

In the screw-retained group, variations in the location and intensity of stress were observed (Fig 5, S1–S5). Some among this group exhibited apical fringe patterns (½ fringe for S3, 1½ fringe for S5). Samples S2 (½ fringe order) and S4 (1 fringe order) produced coronal and interproximal concentrations of stress.

Overall comparison between the cement-retained and screw-retained groups revealed that the cement-retained FPDs more consistently exhibited lower levels of stress (80% of the FPDs).

DISCUSSION

This study compared the relationship of marginal discrepancies and the passivity of fit of screw- and cement-retained implant FPD designs. Microscopic evaluation of marginal opening was used to analyze casting accuracy and to determine whether differences existed between the designs prior to stress analysis. The cast interfaces used in cement-retained restorations differed from the machined interfaces used in the screw-retained designs. Results showed that no statistical differences in marginal adaptation existed between the groups prior to screw tightening or cementation. Screw tightening caused a significant closure in the mean marginal openings for the screw-retained FPDs (65% change, significant at $P < .05$). The results of this study compared favorably with prior studies evaluating marginal adaptation.[30,31]

It has been hypothesized that an intervening cement layer may fill in framework interfacial discrepancies and assist in the equitable distribution of load throughout the bone-implant-restorative system.[32,33] Photoelastic analysis allowed a side-by-side comparison of designs that were ranked in order of increasing stress (Fig 5). This method shows variations that exist among a group. The screw-retained FPDs produced variations in the location and intensity of stress (Fig 5, S1–S5). Although the screw-retained group showed evidence of high and somewhat unpredictable variation in the location and intensity of stress, it was noted that 1 of the 5 screw-retained FPDs exhibited very low stress (Fig 5, S1). This demonstrated that it was possible to have a very low-stress screw-retained restoration, but it occurred only 20% of the time. The cement-retained FPDs exhibited low levels of stress, with similarity in the location and intensity of stress (Fig 5, C1–C5).

The highest stress was seen in the screw-retained group (Fig 5, S5). It was observed that both the highest and lowest stress restorations (Fig 5, S1 and S5) in the study were among the screw-retained FPDs with the smallest predelivery marginal openings. No correlation existed between mean marginal openings and the ranking of stress concentration for the screw-retained group. An inverse relationship was seen between the marginal openings and the stress ranking associated with the cement-retained FPDs. Because of the sample size, it is difficult to draw conclusions regarding the relationships of stress and mean marginal openings. Marginal opening is but one of many possible variables which may influence stress transfer.[34] Additional factors such as internal adaptation and cement viscosity were not evaluated.

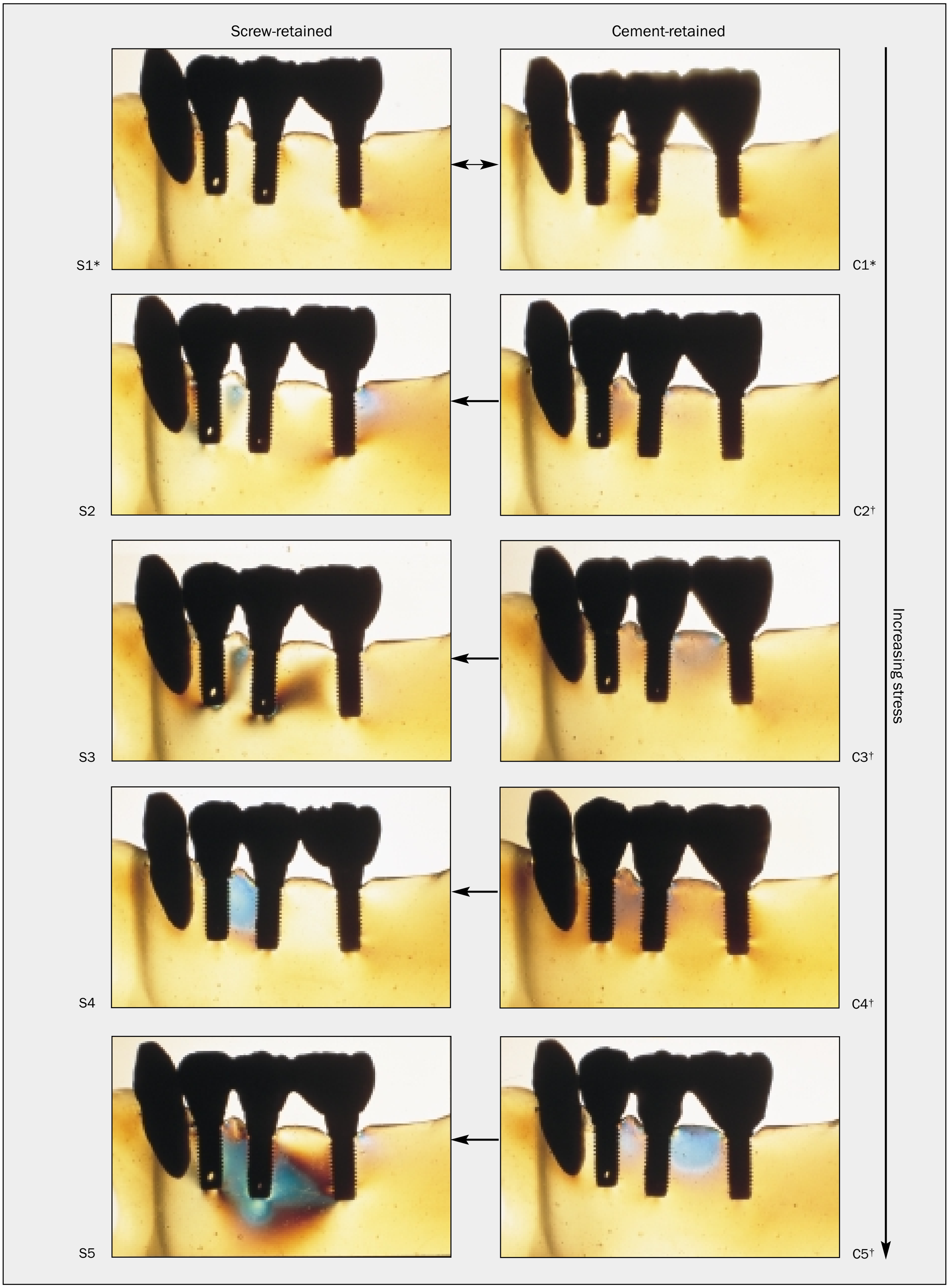

Fig 5 Photoelastic results ranked in order of increasing stress. *Indicates no preference; †indicates lower stress in side-by-side comparison.

Both implant restorative philosophies have advantages and disadvantages. Advocates of cement-retained designs claim to optimize gingival emergence, occlusion, and esthetics and to assist in the restoration of misaligned implants. Surgical advantages include the determination of implant location based on the maximal use of available bone and the esthetic emergence of the proposed restoration rather than on the prosthetic position of the cingulum or occlusal screw access channel. Prosthetic advantages include elimination of the screw access channel, which enables the development of natural occlusal form without undermining porcelain cuspal support. When cingulum screw channels are used, implants are often located palatal to the anatomic center of the alveolar ridge crest and the available bone mass.[35] In some instances, this results in compromised implant placement, with restorations requiring anterior antilevering and ridge lapping, with associated compromised hygienic access.

Cement-retained designs also present disadvantages. The retrievability of cement-retained restorations has been questioned. Dependence upon a cementing medium for retention of the restoration presents inherent risks. The use of temporary cement invites premature loosening. Temporary cementation can inadvertently result in an inability to remove the restoration. Definitive cementation complicates the ability to remove the restoration for servicing if required. Screw-retained restorations do not possess the same problems inherent to cementation, but they present screw loosening as a known potential side effect. In light of the advantages and disadvantages of both restorative designs, this present investigation compared the effect of load transfer in cement-retained and screw-retained implant FPD prostheses. Results showed that in 80% of comparisons the cement-retained FPDs exhibited a more equitable stress distribution than did their screw-retained counterparts. Cement-retained designs may therefore be biomechanically preferable to screw-retained designs when considering the stress generated at placement.

The fit of 1-piece castings continues to raise controversy when the achievement of passive fit is considered. Accessible methods to improve and evaluate fit are needed. The effects of soldering, as compared to 1-piece castings in screw- and cement-retained implant restorative designs, merits further analysis. Additionally, future research may be directed toward the evaluation of electrical discharge machining on the fit of various abutment/FPD design combinations.

CONCLUSIONS

This investigation compared passivity of fit and stress generation upon the placement of screw-retained or cement-retained implant restorations on a photoelastic model. The results led to the following conclusions:

1. Marginal openings for the screw-retained and the cement-retained groups were not significantly different prior to placement. Following placement, marginal openings of screw-retained FPDs were significantly smaller than cement-retained FPDs.
2. Differences existed in stress generation upon screw fastening or cementation. The screw-retained designs exhibited variability in the intensity and location of stress, with instances of high apical stress concentrations. The cement-retained FPDs produced similar, low-level stresses, with a tendency toward coronal stress localization.
3. The significantly decreased marginal opening from screw tightening was associated with higher stress in the screw-retained restorations. The increase in marginal opening seen with cementation was associated with less stress generation in the bone model with the cement-retained group.

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