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Influence of Fixation Mode and Superstructure Span upon Strain Development of Implant Fixed Partial Dentures

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Abstract

Purpose: Implant-borne fixed partial dentures (FPDs) should fit passively in order to avoid complications ranging from screw loosening to loss of osseointegration. The aim of this study was to measure the strain development of three-unit and five-unit screw- and cement-retained implant-supported FPDs. Additionally, the influence of the parameters *retention mechanism* and *FPD span* were evaluated.
Materials and Methods: Three Straumann implants were anchored in a measurement model based on a real-life patient situation and strain gauges (SGs) were fixed mesially and distally adjacent to the implants and on the pontics of the superstructures. During cement setting and screw fixation of 40 implant FPDs (10 samples from each group: three-unit cementable; five-unit cementable; three-unit screw-retained; five-unit screw-retained), strain development was recorded. For statistical analysis, multivariate two-sample tests were performed with the level of significance set at $p = 0.1$.
Results: The mean strain values for the four FPD groups at the different SG sites ranged from 26.0 to 637.6 μm/m. When comparing the four groups, no significant differences in strain magnitude could be detected. Similarly, a comparison of the two FPD spans revealed no significant difference ($p = 0.18$ for cementable FPDs; $p = 0.22$ for screw-retained FPDs). A comparison of the two fixation modes also revealed no significant difference ($p = 0.67$ for three-unit FPDs; $p = 0.25$ for five-unit FPDs).
Conclusions: FPD span and retention mechanism appear to have only a minor influence on strain development in implant FPDs. As implant-supported restorations have proven to be successful over time, the question arises as to whether an "absolute" passive fit is a prerequisite for successful implant restorations.

Problems ranging from screw loosening to loss of osseointegration are described for misfitting implant superstructures, causing tensile, compressive, and bending forces at the implant–bone interface.[1,2] The hypothesis that passively fitting superstructures are a prerequisite for long-lasting osseointegration of dental implants is based on the fact that the unique quality of the implant–bone anchorage allows limited movement within a 10 μm range only.[1] In addition, various biomechanical studies have shown that even fixed partial dentures (FPDs) used in conjunction with strain gauges (SGs) as a measuring device induced particular amounts of stress, despite having a perfect fit according to their clinical evaluation.[3,4] Further investigations clarified that these strains corresponded to the level of misfit of a superstructure[5-7] caused by the influence of impression and master cast accuracy,[8-11] machining tolerances of the parts provided by the manufacturer,[12,13] and the accuracy of the laboratory processes.[14-16] Even the various methods for clinical fit evaluation, for example, the Sheffield Test, are considered subjective. Indeed, according to Tan,[13] they are only capable of detecting fairly gross levels of misfit.

Having recognized that passively fitting superstructures could not be obtained using the traditional method of screw retention, several clinicians began cementing restorations using techniques from conventional prosthodontics.[17-19] The cement layer, which ought to compensate for any inaccuracies, was seen as the solution to the passive fit problem. Guichet et al,[20] for example, compared the marginal integrity and the stress generation of cement- and screw-retained implant restorations. Whereas screw tightening caused a decrease in marginal gap size, cementing led to larger marginal gaps. A photoelastic examination, however, revealed that the cement-retained FPDs exhibited consistently lower levels of stress than the screw-retained prostheses.

The term *passive fit* has never been defined quantitatively. Nevertheless, from a biomechanical point of view, passive fit should show zero microstrains on all SGs placed either on the restoration or on the supporting implants and bone.[21,22]

Thus, the aim of this study was to measure the strain development of three-unit and five-unit screw- and cement-retained implant-supported FPDs using the SG technique. The influence of the parameters retention mechanism and FPD span were to be evaluated.[21,22]

Materials and methods

A real-life patient situation with three Straumann solid screw implants in the right maxilla (4.1 mm diameter, 12 mm bone sink depth; Straumann AG, Waldenburg, Switzerland), referred to as implants A, B, and C from mesial to distal, served as the basis for the in vitro investigation presented. Solid abutments for cementable restorations had already been mounted on the implants in the process of rehabilitation.

To precisely transfer the intraoral relationships, plastic "crown" copings with lateral extensions were fabricated and connected in the oral cavity with a tiny amount of autopolymerizing resin (Palavit G®, Heraeus Kulzer, Hanau, Germany; Fig 1) to serve as a "basic impression."

Three original implants assembled with 5.5 mm solid abutments as existing in the patient's maxilla were repositioned into the "basic impression" (resin connected plastic "crown" copings). To fabricate the measurement model, an epoxy resin block (Araldit®, Ciba Geigy, Wehr, Germany) with mechanical properties (Young's modulus 3000 MPa) similar to those of trabecular bone[23] was used. Precisely aligned sockets into which the implants were anchored using clear Paladur® (Heraeus Kulzer), an autopolymerizing resin, were prepared. Thus, a resin layer of approximately equal thickness was obtained at the whole circumference of the implants. Six SGs (LY11–0.6/120, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) were attached to the model material mesially and distally close to the implants using a special adhesive (Z 70, Hottinger Baldwin Messtechnik GmbH). In addition, one SG was placed on the occlusal surface of each pontic. The sensing elements of all SGs were oriented in the mesiodistal direction (Fig 2). A measurement amplifier (DMC 9012A, Hottinger Baldwin) was used along with BEAM® software (AMS Gesellschaft für angewandte Mess-und Systemtechnik GmbH, Flöha, Germany) to analyze the resulting strains.

For the different measurement series, synOcta abutments and solid abutments were fixed to the implants with a torque of 35 Ncm using the implant manufacturer's ratchet.

To fabricate the FPDs, the commonly used steps in clinical practice were to be followed. For impression taking from the measurement model, custom-made impression trays (Palatray XL®, Heraeus Kulzer) were fabricated. Pick-up technique impressions were made to fabricate the screw-retained FPDs and repositioning technique impressions for the cementable FPDs. A polyether impression material (Impregum®, 3M ESPE, Seefeld, Germany) was used for all impressions. Master casts were fabricated using the manufacturer's implant analogues and Fujirock EP®, a type IV stone (GC Corporation, Tokyo, Japan).

Ten samples of three-unit and five-unit FPDs of both cement and screw retention (3-cem, 5-cem, 3-screw, 5-screw) were serialized for a total of 40 specimens.

The three-unit FPDs rested on implants A and B, and the five-unit FPDs rested on implants A, B, and C.

To fabricate the cementable FPDs, the superstructures were waxed up onto premachined burnout plastic copings and cast in one piece.

For the fabrication of the screw-retained restorations, the wax molds were cast to prefabricated gold cylinders.

Degudent U®, a high precious metal-fused-to-ceramics alloy (DeguDent GmbH, Hanau, Germany) was used for all restorations. To standardize the manufacturing conditions, random sets comprising FPDs of different types were made and cast together.

The SGs around implants A and B and the pontic SG (pAB) were active to investigate the three-unit samples. For the five-unit restorations, the SGs at implant C and the second pontic SG (pBC) were added.

After temporary cement (ImProv®, Nobel Biocare, Cologne, Germany) had been applied into the crown-lumina of the cementable FPDs, all SGs were set to zero, and the FPDs placed on the abutments. An initial defined force of 200 N was applied to the pontics by a universal testing machine (Zwick, Ulm, Germany) for 30 seconds. The force was then reduced to 100 N and sustained for 3 minutes. The FPDs were then relieved, and the cement allowed to set for a further 2 minutes. The final strain readings after a measurement period of 6 minutes were taken for analysis (Fig 3).

In the screw-retained FPD groups, all SGs were set to zero, and the FPDs were subsequently placed on the abutments. The Screw Carrier System (SCS) occlusal screws were tightened onto the synOcta abutments with a torque of 20 Ncm[24] using an electric torque controlling device (Torque controller®, Nobel Biocare). The fixation screws were attached to the implants in the following sequence:

- Three-unit restorations—1st screw: implant-B; 2nd screw: implant A.
- Five-unit restorations—1st screw: implant-B; 2nd screw: implant C; 3rd screw: implant A.

The strains occurring were measured for the same duration (6 minutes) as in the measurement series for cement-retained FPDs (Fig 4). A new set of SCS occlusal screws was used for each FPD.

To compare the groups in terms of strain development, multivariate *t*-tests (Hotelling's I-square) were performed (SPSS for Windows, version 10, Chicago, IL) with the level of significance set to $p = 0.05$. The use of multivariate *t*-tests allowed for comparison of the mean values of the SGs at different locations simultaneously by measuring the difference between two SG groups by means of a weighted sum of the mean value differences at the locations considered. The test decides on a significant difference between the SG groups if the majority of location differences are large enough. For comparisons within

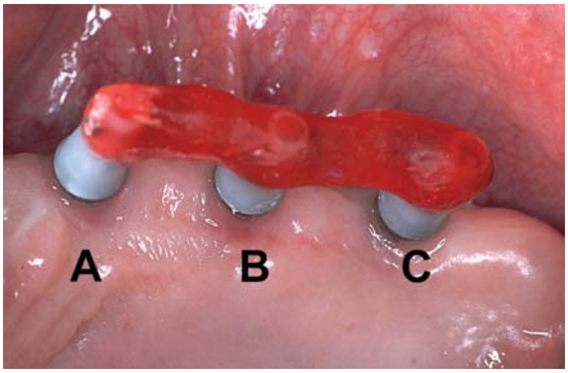

Figure 1 Impression of the three implants in the right maxilla of a patient—used to produce the laboratory model for simulation.

a span group, all active SGs were considered. For comparisons between three- and five-unit restorations, only the SG values active in both groups were evaluated.

Results

The strain development of the four groups as it occurred during the cementing and screw fixation process is depicted in Figure 5. Each column represents an SG.

Besides the statistically proven results of this investigation, it was also observed that all types of FPDs investigated bore a certain level of misfit, which resulted in measurable strains. These fabrication inaccuracies occurred although they could not be detected by usual means of FPD evaluation (visual and tactile testing, fit checker), and the recommended protocol was followed strictly.

To evaluate the influence of retention mechanism upon strain development, the cementable samples (3-cem, 5-cem) were compared with the screw-retained samples (3-screw, 5-screw) within the respective span groups. No statistically significant difference could be found (3-cem vs. 3-screw: $p = 0.67$; 5-cem vs. 5-screw: $p = 0.25$).

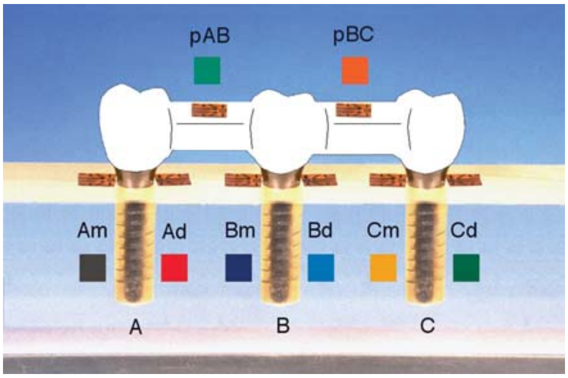

Figure 2 Measurement model with implants A, B, and C fixed in epoxy resin (Young's modulus 3000 MPa) using an autopolymerizing resin. Strain gauges mounted on the model material mesially and distally adjacent to the implants (SG-Am, SG-Ad, SG-Bm, SG-Bd, SG-Cm, SG-Cd) and on the pontics (SG-pAB, SG-pBC).

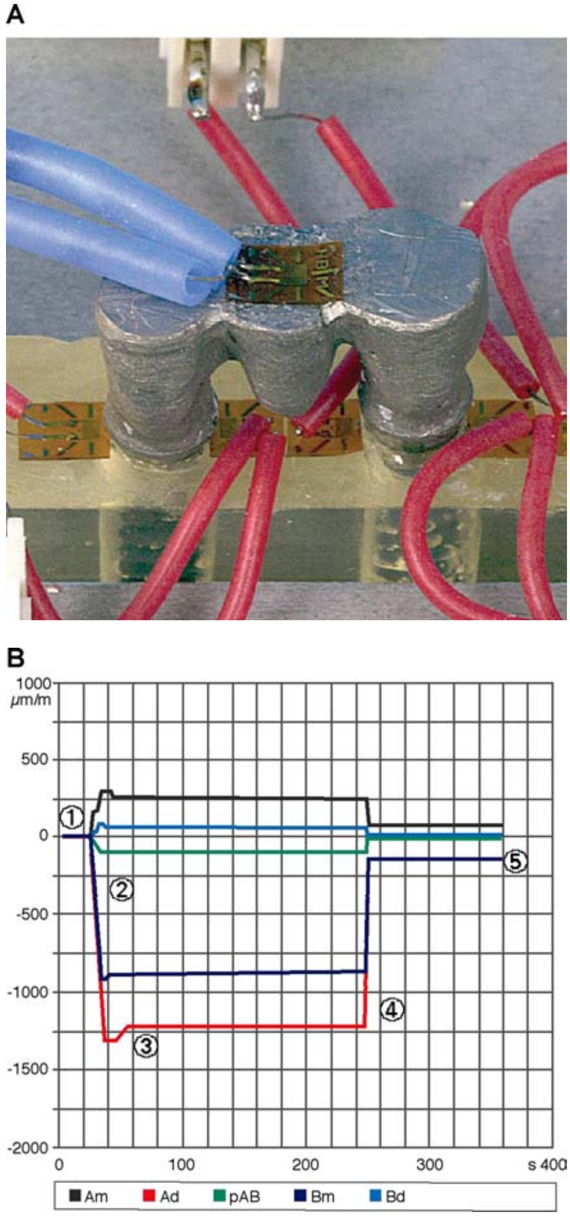

Figure 3 (A) Three-unit FPD cemented on the in vitro model for strain gauge measurements. (B) SG signals during cementation procedure (*x*-axis: time in seconds; *y*-axis: strain in μm/m); (1) SGs set to zero, (2) FPD placed on implants, initial load of 200 N, (3) force reduced to 100 N and maintained for 3 minutes, (4) FPD relieved, and (5) final strain values recorded for analysis (cf. Fig 2 for SG identification).

Similarly, the comparison of restorations with the same retention mechanism but different span revealed no significant difference (3-cem vs. 5-cem: $p = 0.18$; 3-screw vs. 5-screw: $p = 0.22$).

Discussion

As all of the FPDs investigated bore a certain level of misfit, it seems almost impossible to produce in conventional ways

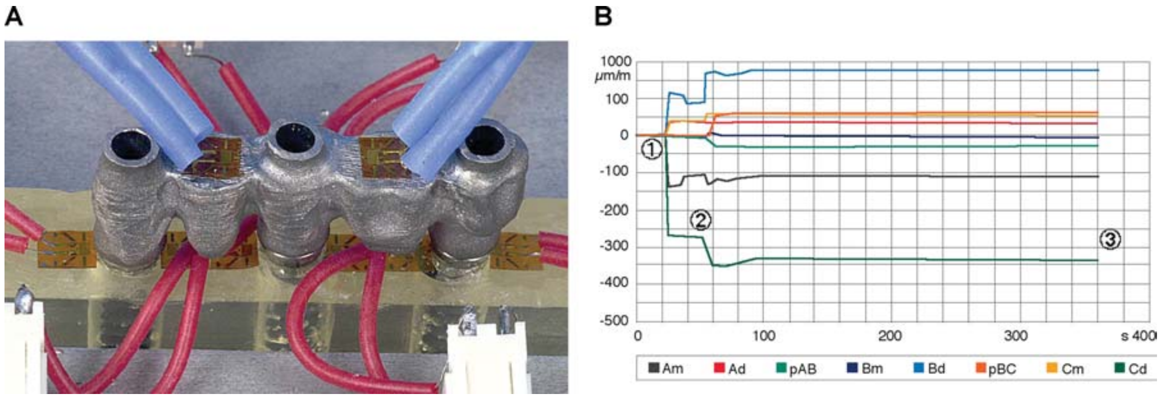

Figure 4 (A) Five-unit screw-retained FPD fixed on the in vitro model for strain gauge measurements. (B) SG signals during screw fixation (*x*-axis: time in seconds; *y*-axis: strain in μm/m); (1) SGs set to zero, (2) FPD placed on the implants and fixation screws tightened, and (3) strain values after 6 minutes recorded for analysis (cf. Fig 2 for SG identification).

implant-supported restorations that exhibit a true passive fit with the SGs showing "zero microstrains."[21,22]

Many authors have discussed whether it would be advantageous to cement implant FPDs or to use screw retention.[17–19] If the influence of the retention mechanisms alone is under discussion, only screw- and cement-retained superstructures of the same impression technique, fabrication method, and span can be compared in order to avoid bias. But as far as implant practice is concerned, certain variables should be taken into consideration. According to the recommendations of the manufacturer, different impression modes are normally used for cemented (repositioning technique) and screw-retained (pick-up technique) FPDs. Furthermore, different laboratory analogues are used with the repositioning technique (cementable FPDs) and pick-up technique (screw-retained FPDs). To fabricate screw-retained FPDs, the original synOcta abutments,

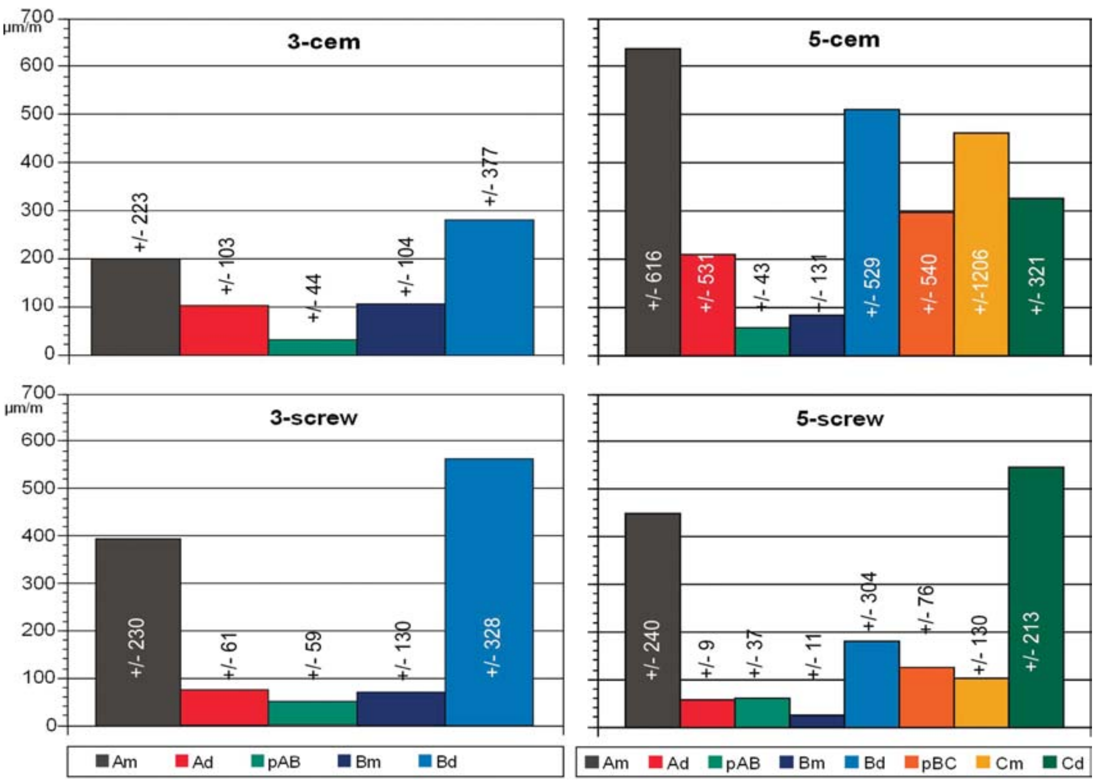

Figure 5 Mean values for the four FPD groups. Each column represents one strain gauge (cf. Fig 2 for SG identification). The standard deviations are added numerically to the columns.

which will later also be inserted into the implants in the patient's mouth, are used. This differs considerably from the fabrication of cemented FPDs where special laboratory analogues are used to wax-up the FPDs.

According to Ma et al[12] and Tan[13] the tolerances between laboratory analogue and implant abutment are also a determinant of superstructure accuracy. Additionally, different auxiliary components for FPD fabrication, for example, burnout plastic copings for cementable FPDs and gold cylinders for screw-retained restorations, are offered by implant manufacturers.

In this study, a comparison of cementable three- and five-unit restorations with their screw-retained counterparts showed no significant differences. These results indicate that with FPDs of both retention types, similar levels of fabrication accuracy are obtained. In addition to this, there seems to be no difference between the retention mechanisms in transferring or compensating inaccuracies of superstructure fabrication. We can therefore conclude that the magnitude of strain development depends mainly on the accuracy achieved in the fabrication process, which encompasses impression technique, master cast accuracy, component tolerance, casting tolerance, and the skills of the dental technician.

As in the study at hand, no statistically significant influence of the FPD span upon strain development in an implant-borne restoration could be detected; it appears that FPD span may not be a major parameter.

Considerations for further investigations

Retrospectively, two major aspects dealing with the set-up of the investigation should be addressed for improved study designs.

Although well-defined geometrical dimensions of the in vitro model bear several advantages with respect to further mathematical considerations, maximum effort should be applied to create more sophisticated models representing the properties of jawbones more realistically.

In this study, the SGs were placed on the surface of the model material, as maximum stress concentration was expected in these areas correlating with the location of bony defects in clinical practice; however, for gaining deeper insight into the stress distribution at the implant–bone interface, it might be advantageous to place the SGs in the model material around the implant surfaces.

Limitations of the study

Some caveats have to be taken into account when interpreting the results of this investigation.

This is an in vitro study based on a homogenous model with known mechanical properties instead of bone. This not only allowed proper strain measurements, but also 100% implant-model material contact. In vivo, additional variables like bone density, implant stability, and bone-to-implant contact would have to be considered.

Although the interimplant relationships were derived from an existing in vivo situation, the model more or less represents a straight line configuration of the implants, which seems to be a simplified situation compared to a curved distribution with a longer segment splinted.

The measurement device used shows some limitations too. It is not possible to place the sensing element of an SG in intimate contact with an implant to allow for the strain situation directly at the implant-bone interface to be evaluated. Additionally, an SG averages the strains measured over the gauge length, possibly leading to lower readings than would be obtained in reality. A finite element analysis is currently under way to gain deeper insight into the stress situation at the implant–bone interface.

Temperature changes are in general a cause for concern in SG measurements. Although this investigation was carried out under ambient conditions, it has to be kept in mind that the strain readings might have been influenced by the inevitable temperature changes of ± 2 K.

As an SG is only capable of detecting strains in a very limited area, it is more or less at random whether tensile or compressive forces are recorded. Therefore, the absolute SG values served to calculate mean strain values for each SG site.

The choice of cement is a major parameter for strain development. As a general comparison of screw-retained and -cemented FPDs should be conducted in the study presented, it was decided to use a temporary luting agent, as this seems to represent clinical practice in the best possible way.

Conclusions

This study has shown that the conventionally fabricated implant restorations do not have a passive fit. Retention mechanism and FPD span seem only to have a minor influence on strain development of an implant FPD.

As implant-supported FPDs have been used successfully over time, the question arises as to whether passive fit is a prerequisite for long-lasting osseointegration. As long as no reference values that would indicate a high degree of strain are available, the intention should be to favor those restorations with as low strain development as possible.

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