In Vitro Study on Passive Fit in Implant-Supported 5-unit Fixed Partial Dentures

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Purpose: *Fabrication and retention methods have an influence on the passivity of superstructure fit. The objective of the study was to quantify the strain development of various cemented and screw-retained fixed partial dentures (FPDs).* ***Materials and Methods:*** *Forty samples of 4 different types of FPDs (10 of each type) were investigated. Each sample had 3 ITI implant abutments and 2 pontics. The 3 implants were anchored in a straight-line configuration in a measurement model simulating a real-life patient situation. Strain gauges were mounted close to the implants and on the pontics. The developing strains were recorded during cement setting and screw fixation. For statistical analysis, multivariate 2-sample tests were performed, with the level of significance set at P = .1.* ***Results:*** *All FPDs investigated revealed a considerable amount of strain, with no significant difference between cement and screw retention. Furthermore, no significant difference was found between the conventional fabrication modes for screw-retained FPDs. The lowest strains were found in prostheses that were intraorally bonded onto gold cylinders.* ***Discussion:*** *Because bonding of the superstructure in the oral cavity may compensate for impression and laboratory variables, restorations with the best possible passive fit can result from this retention technique. Before this technique can be recommended, the long-term stability of the adhesive layer should be investigated.* ***Conclusions:*** *As an absolute passive fit of superstructures is not possible using conventional clinical and laboratory procedures, and as clinical fit-evaluation methods often do not detect "hidden" inaccuracies, the more sensitive strain-gauge technique should be utilized for an objective accuracy test. Reference strain values from implant-supported prostheses that have served without complications could help define a "biologically acceptable fit."* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:30–37

Key words: *cement retention, implant-bone interface, intraoral bonding, passive fit, screw retention, strain development, superstructure accuracy*

A passively fitting superstructure was first championed by Brånemark and colleagues to meet concerns surrounding the unique quality of bone-implant anchorage.[1] An osseointegrated implant has extremely limited movement—within the range of 10 µm—whereas a natural tooth can move up to 100 µm within its periodontal ligament, thus compensating for a certain degree of inaccuracy in the fitting of a fixed partial denture.[2] This lack of flexibility in the bone-implant interface means that any tensile, compressive, or bending forces introduced into an implant-supported restoration through misfitting superstructures lacking passive fit will almost certainly remain and result in problems ranging from screw loosening to loss of osseointegration.[2]

Several examiners have investigated the biomechanical loading situation of implants during biting actions using fixed partial dentures (FPDs) equipped with strain gauges. They observed that the process of fixing these measurement superstructures itself induced certain amounts of stress, despite their clinically perfect fit.[3,4] In subsequent studies, it was possible to show that these strains corresponded to the

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level of misfit of the superstructure.[5–9] In finite element analysis, it was shown that superstructure misfit also influences the pattern and magnitude of stress distribution in the prosthesis, the implant components, and the surrounding bone.[10]

Different studies have been conducted to investigate the parameters of superstructure accuracy. Impression and master cast accuracy, 2 of the major determinants of fit, have been examined several times, with varying results.[2,11–19] Machining tolerances of the components provided by the manufacturer[20,21] and accuracy of the laboratory processes[22–24] have been identified as additional factors. According to Tan, all visual and tactile methods for clinical fit evaluation, such as the Sheffield test, are capable of detecting only fairly gross levels of misfit.[21]

Realizing that a truly passive fit could not be obtained when using screw-retained superstructures, clinicians began cementing prostheses, applying techniques known from conventional prosthodontics.[25–27] A cement layer could compensate for inaccuracies and was seen as a possible solution to the passive fit problem.

Pietrabissa and associates[28] undertook an in vitro study investigating the ability of various abutment types to compensate for increasing mismatches of fixed prosthetic units. Increasingly mismatched prosthetics provoked proportionally increasing strain levels for the screw-retained prostheses; however, lower strain values were found for cemented prostheses. Guichet and coworkers[29] compared marginal integrity and stress generation while cement-retained and screw-retained implant restorations were being seated. They found that screw tightening caused decreased marginal gap size but high strain values, whereas cementing led to larger marginal gaps but lower strain values.

Watanabe and coworkers[9] compared 4 differently fabricated superstructures for screw-retained implants using strain gauges. Frameworks produced by 1-piece casting, 1-piece cast/ split soldering, and soldering methods were compared with prostheses fabricated according to the IMZ passive-fit system.[9] The IMZ passive-fit method entails eliminating contact spots between superstructures and copings fixed on the implants in the mouth and then joining the counterparts with an adhesive. Watanabe and coworkers showed that the strains developed by passive-fit system restorations were significantly lower than those developed when using other methods. The sequence of screw tightening influenced the stress situation. The best method appeared to be to tighten the middle screw first and then the terminal screws.[9]

To date, no precise method has been determined for assessing the accuracy of fit of an implant superstructure in an objective way. The term "passive fit" suggests absolute lack of strain development, but it has never been defined in biomechanical terms. Furthermore, it is not known how much static stress the implant-bone interface can tolerate and whether passive fit is a prerequisite for long-lasting osseointegration. The goal of this study was to quantify in vitro the strains generated by cement- and screw-retained 5-unit FPDs and possibly shed light on their relative importance in determining the effect of static loading on osseointegration. In addition to the conventional methods of FPD fixation, the innovative method of bonding separately cast prosthesis frames onto prefabricated gold cylinders was investigated.

MATERIALS AND METHODS

As a real-life arrangement of implants was needed to serve as a basis for the in vitro study presented, a 69-year-old male patient with 3 implants in the right maxilla (referred to as implants A, B, and C from mesial to distal) volunteered for the experiment. His implants were ITI solid-screw implants (Straumann, Waldenburg, Switzerland), 4.1 mm diameter, with 12-mm bone sink depth and previously screwed-in 5.5-mm solid abutments. The study was approved by the Erlangen University Ethics Commission.

Fabrication of the Measurement Model

To transfer the implant positions with maximum precision onto a measurement model, plastic coping "crowns" with lateral extensions were placed on the solid abutments and connected in the oral cavity with resin (Palavit G; Heraeus Kulzer, Hanau, Germany) (Fig 1).

Three ITI implants and abutments were repositioned into the individually connected plastic coping "crowns." An epoxy resin block (Araldit; Ciba Geigy, Wehr, Germany) with known mechanical properties (Young's modulus, 3,000 MPa) similar to those of trabecular bone[30] provided the basis for the measurement model. Precisely aligned sites were prepared, into which the implants were anchored using clear Paladur (Heraeus Kulzer), an autopolymerizing acrylic resin (Fig 2).

Impression Making and Fabrication of Master Casts

To precisely simulate the clinical procedure of prosthesis fabrication, impressions were made from the measurement model and master casts were made for each prosthesis. Custom-made impression trays

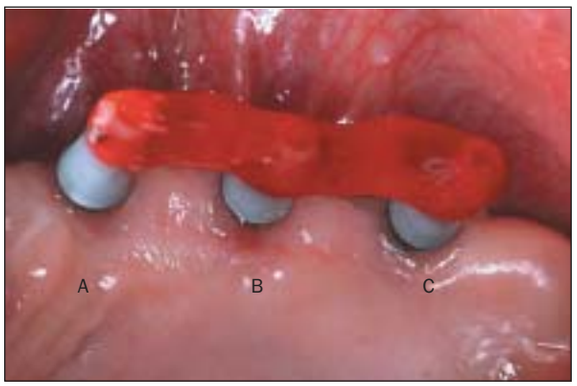


Fig 1 In vivo situation prepared for transfer of the implants (labeled A, B, and C from mesial to distal) onto the measurement model.

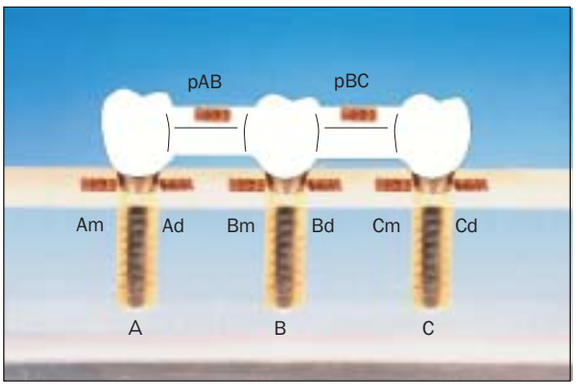


Fig 2 Graphic illustration of the measurement model with implants A, B, and C fixed in epoxy resin using Paladur (Young's modulus, 3,000 MPa). Strain gauges, 1 mesial and 1 distal, are mounted at the implants (Am, Ad, Bm, Bd, Cm, and Cd) and on the pontics (pAB and pBC).

Table 1 Abbreviations for Different FPD Types

Group	Description
c-rep	Cementable prostheses fabricated on master casts obtained from repositioning technique impresssions
s-pla	Screw-retained prostheses fabricated using burn out plastic copings
s-cas	Screw-retained prostheses cast to gold cylinders
s-bon	Screw-retained prostheses bonded to gold cylinders

(Palatray XL; Heraeus Kulzer) were fabricated that allowed impressions to be made according to either the pick-up technique or the repositioning technique using a polyether impression material (Impregum; ESPE, Seefeld, Germany).

FPD Fabrication

Four groups of FPDs were tested. Each group comprised 10 serialized samples of a commonly used type of FPD (Table 1). A variety of commonly used impression techniques, fabrication methods, and modes of fixation (eg, cement or screw retention) were tested.

Degudent U, a high precious-metal-fused-to-ceramic alloy (DeguDent, Hanau, Germany) was used for all prosthesis groups.

To standardize the manufacturing conditions, random sets comprising prostheses of different types were made and cast together. All prostheses were independently evaluated by 2 experienced clinicians to ensure that they had an acceptable fit. During the laboratory stages, abutments as well as screw carrier system (SCS) fixation screws were tightened using an electric torque-controlling device (Nobel Biocare, Göteborg, Sweden). Both synOcta abutments (Straumann) and solid abutments (Straumann) were tightened to 35 Ncm using the implant manufacturer's ratchet. Following the recommendations of Haack and associates,[31] the SCS screws were tightened to 20 Ncm.

Bonded FPDs

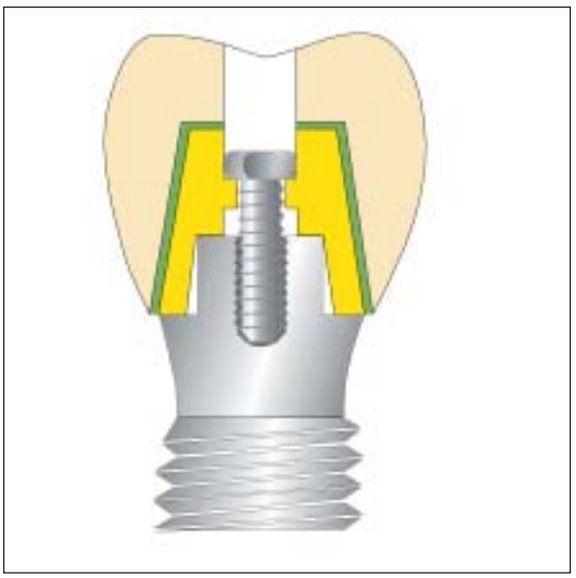
In addition to standard methods of FPD fabrication, an innovative method based on the findings of Watanabe and coworkers[9] also was examined. In the bonded group (s-bon), separately cast prosthesis frames were conditioned with Silicoater MD (Heraeus Kulzer) and bonded to premachined gold cylinders on the measurement model using Degufill (DeguDent) (Fig 3).

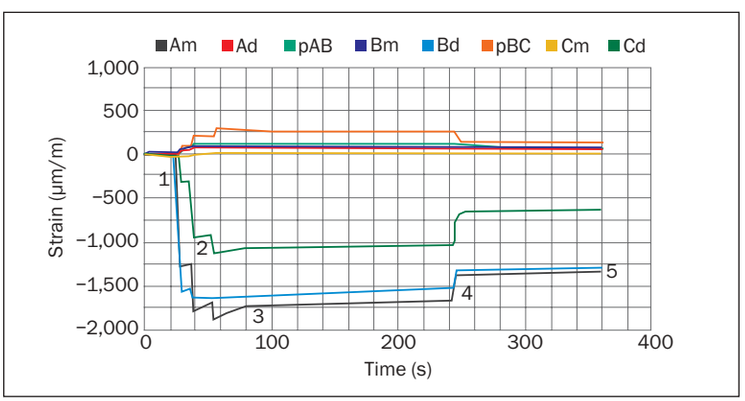
Measurement Equipment and Protocol

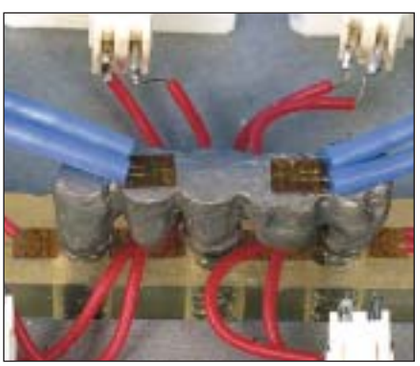
The measurement model was equipped with 6 strain gauges (LY11-0.6/120; 120 W reference resistance; Hottinger Baldwin, Darmstadt, Germany)—a mesial gauge (Am, Bm, and Cm) and a distal gauge (Ad, Bd, and Cd) for each implant. In addition, 1 strain gauge (pAB) was placed on the occlusal surface of the pontic between implants A and B, and 1 strain gauge (pBC) was placed on the occlusal surface of the pontic between implants B and C (Fig 2). A measurement amplifier (DMC 9012A; Hottinger Baldwin) was used together with BEAM software (AMS, Flöha, Germany) to analyze the strains that occurred (Figs 4 and 5).

Cemented FPDs. After temporary cement (ImProv; Nobel Biocare) had been applied to the inner parts of the prosthesis abutments, all strain gauges were set to 0, and the FPDs were placed on the abutments. At the beginning of the cementing procedure, a defined force of 200 N was applied to the pontics by a universal testing machine (Zwick,

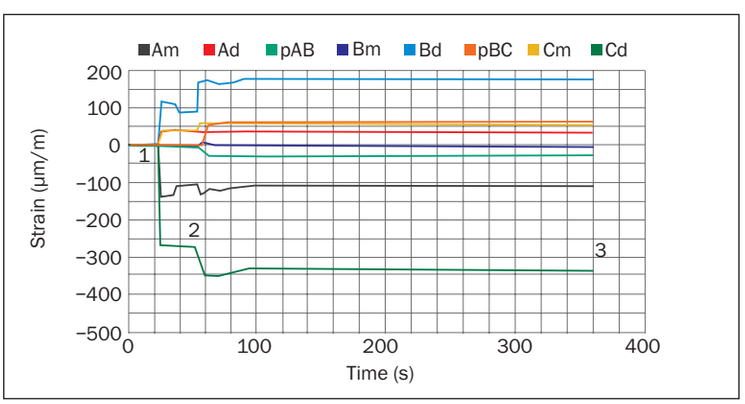
Fig 3 Cross section of bonded FPDs with premachined screw-retained gold cylinders on a synOcta abutment.

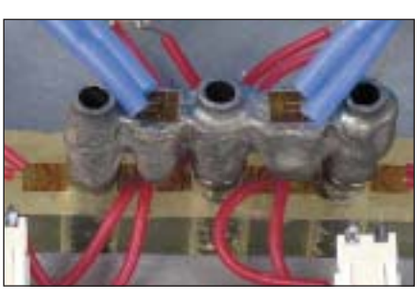






Figs 4a and 4b Measurement of cemented FPDs. *(Left)* Illustration of strain gauge signals during the measurement period. *(1)* Strain gauges set to 0. *(2)* Prosthesis placed on implants, initial load of 200 N applied. *(3)* Force reduced to 100 N and held for 3 minutes. *(4)* Prosthesis relieved. *(5)* Strain values recorded for analysis after 6 minutes. *(Right)* Prosthesis cemented on the measurement model.





Figs 5a and 5b Measurement of screw-retained FPDs. *(Left)* Illustration of strain gauge signals during the measurement period. *(1)* Strain gauges set to 0. *(2)* Prosthesis placed on implants and SCS screws tightened. *(3)* Strain values recorded for analysis after 6 minutes. *(Right)* Prosthesis screwed on the measurement model.

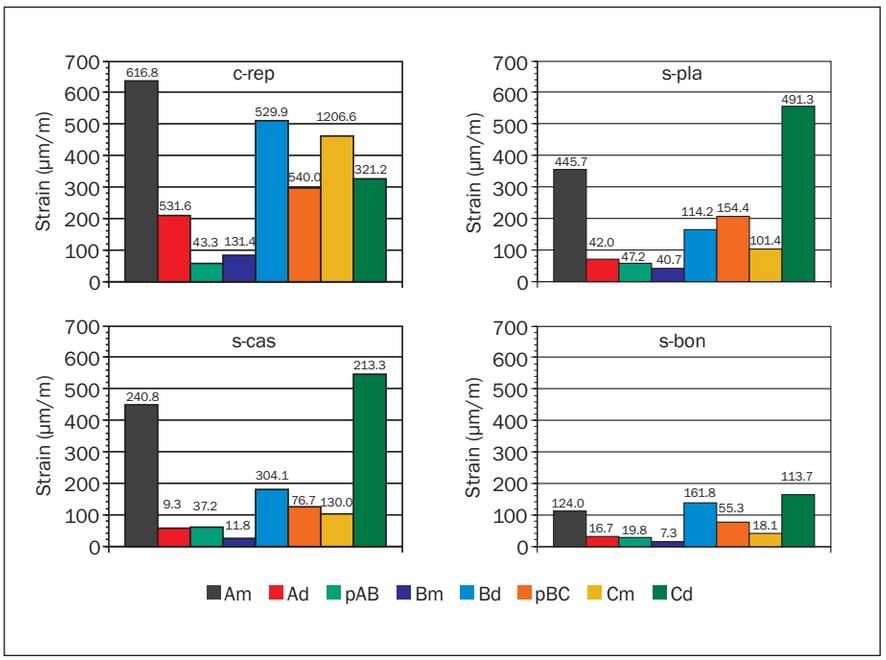


Fig 6 Mean values for each strain gauge for the 4 FPD groups. Values for standard deviation are printed on each bar.

Table 2 *P* Values for All Statistical Comparisons Conducted

	c-rep	s-pla	s-cas	s-bon
c-rep		.76	.25	.16
s-pla			.96	.18
s-cas				.08*

*Statistically significant.
Multivariate 2-sample tests.

Ulm, Germany). After 30 seconds, the force was reduced to 100 N and applied for 3 minutes. Then the force was removed and the cement was allowed to set for another 2 minutes. The final strain values were recorded after 6 minutes (Figs 4a and 4b).

Screw-Retained FPDs. All of the strain gauges were set to 0, and the prostheses were placed on the abutments. Using the electric torque-controlling device,[31] the SCS occlusal fixation screws were tightened onto the synOcta abutments with a torque of 20 Ncm in the following sequence[9]: *(1)* the occlusal screw on implant B, *(2)* the occlusal screw on implant C, and *(3)* the occlusal screw on implant A. Strains were measured after 6 minutes. A new set of SCS occlusal screws was used for each prosthesis (Figs 5a and 5b).

Statistical Analysis

To compare the strain development of the various prosthesis groups, multivariate 2-sample tests were performed. As the sample size was limited to 10 samples per prosthesis group, the level of significance was set at $P = .1$.

RESULTS

Figure 6 shows the mean strain development for each of the 4 groups calculated from the absolute values of the measurement results. When the cement-retained prostheses (c-rep) were compared with the screw-retained samples fabricated in the conventional way (s-pla, s-cas), no statistically significant differences were observed (c-rep vs s-pla, $P = .76$; c-rep vs s-cas, $P = .25$) (Table 2). There also was not a statistically significant difference between screw-retained prostheses fabricated using burn-out plastic copings (s-pla) and those fabricated by casting to gold cylinders (s-cas) (s-pla vs s-cas, $P = .96$). The screw-retained prostheses bonded to gold cylinders on the measurement model (s-bon) showed lower strain levels than any other group. Nevertheless, only the difference between the s-bon group and the s-cas group was statistically significant ($P = .08$).

DISCUSSION

Passive fit has been described as a treatment objective when fabricating implant-supported restorations. In

this study, all types of FPDs investigated showed measurable levels of strain. Thus it can be concluded that the FPDs investigated had a certain degree of misfit despite being fabricated by a master technician and evaluated to be clinically acceptable.

Influence of Retention Mechanism

The question of whether to cement implant-supported FPDs or to use screw retention has been addressed by several authors,[25–27] but there is still a lack of experimental evidence indicating which one to prefer in clinical practice. If the influence of the retention mechanisms alone were to be considered, only screw- and cement-retained prostheses fabricated from the same impression technique and the same span could be compared to avoid bias. But as far as practice is concerned, some variables should be taken into consideration. According to manufacturers' recommendations, different impression methods are normally used for these 2 retention mechanisms—repositioning technique for cement-retained FPDs and open-tray technique for screw-retained FPDs. Furthermore, different laboratory analogues are used with each technique. For the fabrication of screw-retained prostheses using the ITI implant system, the original synOcta abutments, which later will be connected to the implants in the patient's mouth, are used. This differs considerably from the fabrication of cemented FPDs, in which special laboratory analogues are used to wax and cast FPDs. According to Ma and colleagues[20] and Tan,[21] the tolerance of Nobel Biocare components between laboratory analogues and implant abutments is also a determinant of prosthesis accuracy.

Keeping these facts in mind and comparing the cement-retained prostheses with the 2 groups of conventionally made screw-retained prostheses (s-pla, s-cas), no significant difference in strain development could be observed. These results indicate that similar fabrication accuracies can be achieved with FPDs having screw and cement retention. Also, there seems to be no difference between the different retention mechanisms in transferring or compensating for inaccuracies of prosthesis fabrication. Therefore, it may be concluded that the magnitude of strain development depends mainly on the accuracy of the fabrication process—the impression technique, master cast accuracy, component tolerance, casting tolerance, and the skills of the dental technician. According to Taylor and coworkers,[32] the strain development of a screw-retained FPD is determined by 2 factors, the misfit of the restoration and the clamping force of the screw, whereas in cement retention, only the level of FPD misfit affects strain development. Due to the experimental design of the present study, it was not possible to confirm Taylor and colleagues' findings.

Influence of Methods for Fabricating Screw-Retained Prostheses

Another point of interest is the influence of different fabrication methods on the accuracy of the prosthesis. Generally, 2 conventional methods of fabricating screw-retained prostheses are available: *(1)* using burn-out plastic copings and *(2)* casting wax patterns to prefabricated gold cylinders. As the FPDs fabricated using plastic copings did not reveal a significantly higher strain development than those cast to prefabricated gold cylinders, it can be concluded that there was no difference between the 2 fabrication methods employed in this study. This apparently does not concur with the recommendations of Carr and associates,[24] who analyzed the preload of fixation screws in single-crown restorations when tightening various gold cylinders to an abutment attached to a strain gauge. They concluded that prefabricated gold cylinders are superior to plastic cylinders.

Bonded FPDs

The bonded FPDs showed less strain development than any other prosthesis group. One reason may be the fact that the prefabricated gold cylinders used were not exposed to possibly detrimental processes such as casting on, devesting, and polishing, as was the case in all other fabrication methods. Inaccuracies that occur during the casting of the superstructure are removed when "trying out" the prosthesis framework (ie, verifying that it can be placed over the gold cylinders fixed on the implants in the mouth without any contact with the superstructure).[9] The matching surfaces are then joined in the oral cavity using a composite adhesive. As these 2 steps, fitting the FPD frame and the bonding process, are carried out in the oral cavity on the original parts, the inaccuracies caused by impression making, master casts, waxing, and casting in 1 piece are presumed to be eliminated.

Critique of Setup

As a strain gauge is capable of detecting strains in only a limited sector of the peri-implant area, tensile or compressive forces are recorded more or less at random. Therefore, absolute strain values were used for evaluation, as they appear to allow comparisons between strain magnitudes resulting from different modes of FPD fabrication and retention.

As in vivo measurements are planned for verification of the in vitro strain values obtained, the measurement model and strain gauge locations were

developed from an actual patient situation. Consequently, the distances between the implants were somewhat different and the implant axes were slightly tilted, which influenced the magnitude and direction of the strains recorded. Strain gauges on each pontic were necessary to allow extrapolations about the strain situation occurring around the implants in vivo. In a subsequent analysis, finite-element calculations will be used to investigate the stresses around the implants as a consequence of superstructure fixation.

CONCLUSIONS

There was evidence from this investigation that not only cemented and screw-retained FPDs but also those prostheses fabricated by bonding separately cast frameworks onto prefabricated components show measurable strains. Thus the conclusion might be drawn that there are shortcomings in superstructure and abutment interface accuracy and that no genuine passive fit was achieved. Even though static loading as a result of inaccurately fitting superstructures may not lead immediately to implant loss or superstructure failure, as good long-term clinical results for both cemented- and screw-retained prostheses indicate, it should be kept in mind that over the years a number of risk factors may become significant.

It must be assumed that passively fitting restorations reduce the risk of biologic as well as mechanical failures. As bonding the superstructure at least compensates for the inaccuracies resulting from impression making and laboratory procedures, it more closely approximated a passively fitting restoration in this investigation. In spite of showing quite promising results, reports on the long-term stability of the adhesive layer should be awaited before recommending this technique for widespread use.

With this study design, it was shown that clinical fit evaluation methods are not capable of detecting "hidden" inaccuracies in implant restorations. Using the more sensitive strain gauge technique, it would be possible to introduce an objective accuracy test for FPDs, giving the clinician the tools needed to measure and thus avoid detrimental misfit.[32]

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