Strain Development in 3-unit Implant-Supported CAD/CAM Restorations

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Purpose: *Passive fit is difficult to achieve in implant-supported restorations with existing superstructure fabrication techniques. The aim of the study presented was to investigate whether computer-generated fixed partial dentures (FPDs) based on optical impressions lead to less strain development than conventionally fabricated FPDs.* ***Materials and Methods:*** *A measurement model with 2 implants was set up and strain gauges were attached to the model material mesially and distally adjacent to the implants. Two groups of conventional cementable restorations based on repositioning and pick-up impressions, respectively, and 1 group of CAD/CAM-generated FPDs based on optical impressions were fabricated (n = 10). Strain development during FPD fixation was recorded. In order to compare the different FPD groups with one another, a multivariate analysis of variance (MANOVA) was performed at a level of significance of* α *= .05.* ***Results:*** *The mean strain development at the different strain gauge locations ranged from 80.38 µm/m to 437.11 µm/m. The 2 groups of conventionally fabricated FPDs showed no significant difference in terms of strain development (P = .07). The CAD/CAM-fabricated FPDs revealed a significantly lower strain development than those made from pick-up technique impressions (P = .01). No significant difference could be detected between the FPDs manufactured from repositioning technique impressions and the CAD/CAM-generated restorations (P = .19).* ***Conclusion:*** *Within the limitations of the study presented, it can be concluded that restorations fabricated on the basis of optical impressions demonstrate a level of fit which is at least as passive as that of conventional FPDs.* INT J ORAL MAXILLOFAC IMPLANT 2008;23:648–652

Key words: *CAD/CAM, implant-supported restoration, impression accuracy, passive fit*

Relative to natural teeth, osseointegrated implants have very limited mobility within bone. When dental restorations are supported by implants, it is critical that the prosthesis exhibit a passive fit. Failure to achieve this can result in biologic and mechanical complications.[1,2] Although numerous techniques to minimize misfit have been described,[3–8] current clinical and laboratory procedures for framework fabrication fail to routinely achieve passive fit.[9–11]

As every step of the manufacturing process for prostheses contributes to the level of superstructure accuracy, various studies dealing with individual parameters of the fabrication procedure have been conducted. Impression and master cast accuracy,[1,12–20] machining tolerances of the components as provided by the manufacturer,[10,21] and the accuracy of the laboratory processes[22–24] have been identified as major determinants.

In a basic research study on strain development in implant-supported fixed partial dentures (FPDs), it was shown that inaccuracies resulting from impression making and master cast fabrication cause approximately 50% of the stresses evoked by superstructure fixation.[25,26]

The introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) has facilitated the use of superior dental ceramics, while various fabrication techniques have also been developed to enhance the fabrication of consistent and predictable restorations in terms of strength, marginal fit, and esthetics.[27,28] Clinical studies dealing with CAD/CAM restorations focus mainly on single-tooth restorations, but an acceptable degree of precision of fit for clinical use has been reported.[29–31]

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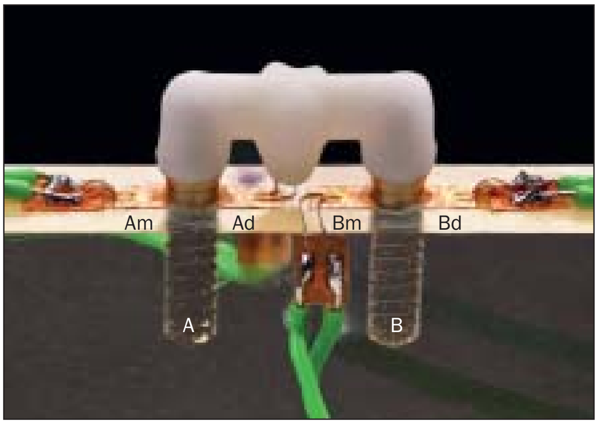

Fig 1 Measurement model during fixation of a CEREC FPD. The strain gauges (Am, Ad, Bm, Bd) are fixed on the model material mesially and distally adjacent to the implants A and B.

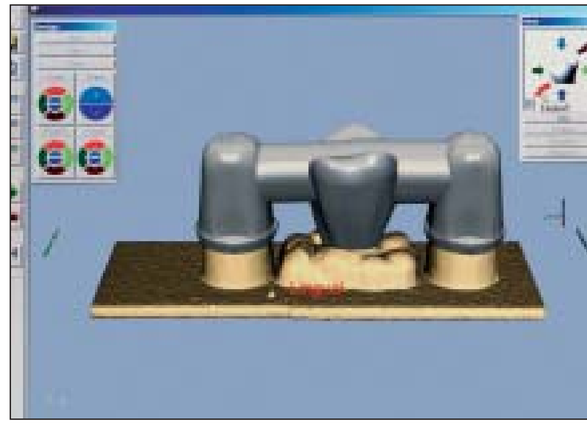

Fig 2 Screenshot displaying a typical FPD frame designed on the basis of an optical impression.

The goal of the study was to determine strain generation with computer-generated FPDs in comparison to prostheses fabricated using conventional lost wax techniques.

Table 1 Abbreviations and Descriptions Used for FPD Groups Investigated

c-rep	Cementable FPDs; repositioning impressions; burn-out plastic copings; metal frame
c-pic	Cementable FPDs; pick-up impressions; burn-out plastic copings; metal frame
c-cerec	Cementable FPDs; optical impression; milled from VITA Mark II ceramic blocks

MATERIALS AND METHODS

Experimental Set-up

A model with 2 implants (left implant: A; right implant: B; solid-screw implants, 4.1 mm diameter, 12 mm bone sink depth; Straumann, Basel, Switzerland) with an interimplant distance of 11 mm from center to center served as a basis for the in vitro investigation. The implants were anchored in an epoxy resin block (Araldit; Ciba Geigy, Wehr, Germany) using an autopolymerizing acrylic resin (Paladur; Heraeus Kulzer, Hanau, Germany). RN synOcta cemented abutments (Straumann) were fixed on the implants, and 4 strain gauges were mounted on the model material mesially and distally adjacent to the implants (LY11-0.6/120; 120Ω reference resistance; Hottinger Baldwin Messtechnik, Darmstadt, Germany) with the sensing elements oriented in the mesial-distal direction (SG-Am; SG-Ad; SG-Bm; SG-Bd). A measurement amplifier (Spider 8; Hottinger Baldwin) was used in combination with analyzing software (BEAM for Spider 8; AMS Gesellschaft für angewandte Mess-und Systemtechnik, Flöha, Germany) to record the resulting strains (Fig 1). The final strain values after superstructure fixation were used for analysis.

Superstructure Fabrication

Three groups of 3-unit FPDs each containing 10 samples were manufactured. The abbreviations used and the respective descriptions are introduced in Table 1.

Conventional FPDs. Following standard clinical protocol for the fabrication of conventional FPD groups (c-rep, c-pic), impressions were made from the measurement model according to either repositioning or pick-up technique. For both impression types, custom-made trays (Palatray XL; Heraeus Kulzer, Hanau, Germany) with a polyether impression material (Impregum; 3M ESPE, Seefeld, Germany) were used. Master casts were poured in type IV stone (Fujirock; GC Corporation, Tokyo, Japan), and the FPD frames were waxed using the implant manufacturer's plastic copings. All of the specimens were cast in a dental training material (Phantom-metal; Ag 56%, Cu 22%, Zn 17%, Sn 5%; DeguDent, Hanau, Germany) whose properties closely represent those of commercial dental precious-metal alloys. Visual and tactile evaluation was performed to ensure a clinically acceptable fit of the FPDs both on the master casts and on the measurement model.[25,26] In the event of a misfit, corrective measures were taken.

CAD/CAM-generated FPDs. Two systems for generating CAD/CAM restorations are available for the CEREC system (Sirona, Bensheim, Germany). The chairside unit allows for the construction of single-tooth restorations on the basis of optical impressions made in the oral cavity. The lab-side unit, however, is used to manufacture multi-unit restorations on the basis of scans of stone casts. For the study presented, an experimental version of the CEREC software was

Table 2 Mean Absolute Strain Values Recorded at the Different Strain Gauge Locations and Standard Deviations

FPD group	SG-Am		SG-Ad		SG-Bm		SG-Bd	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
c-rep	187.92	143.33	115.80	74.04	225.70	145.63	277.68	226.70
c-pic	264.10	256.90	252.82	132.18	437.11	239.43	388.50	239.33
c-cerec	80.83	38.62	91.37	46.71	125.25	76.77	149.47	105.86

Table 3 *P* Values Resulting from Multivariate Analysis of Variance (MANOVA)

	c-pic	c-cerec
c-rep	.07	.19
c-pic		.01

α = .05.

developed on the basis of existing software for the chairside and the lab-side systems, which allowed for the construction of 3-unit FPDs based on intraoral optical impressions.

For each FPD, an optical impression was made from the measurement model and a framework was designed (Fig 2). The FPD frames were milled from a leucite based feldspathic porcelain material (VITA Mark II ceramic blanks; VITA, Bad Säckingen, Germany). A visual and tactile inspection on the measurement model was then performed to ensure an acceptable fit.[25,26] Any misfit detected was duly corrected.

Measurement Procedure

After temporary cement (ImProv; Alvelogro, Union, WA) had been applied to the abutment cylinders, all of the strain gauges were set to zero and the specimens placed on the implants. A defined force of 100 N was applied to the FPD pontic for 5 minutes using a universal testing machine (Zwick 1425, Ulm, Germany). The FPD was then relieved, and the cement was allowed to set for a further 1 minute before the final strain values were recorded after a total of 6 minutes.

Statistical Analysis

As a strain gauge is only capable of detecting strains in a limited sector of the peri-implant area, it is more or less at random whether tensile or compressive forces are recorded. For this reason, the absolute strain values served for evaluation, as they appeared to allow comparisons of strain magnitude as resulting from the fixation of different FPD types. For the comparisons of the FPD groups with one another, a multivariate analysis of variance (MANOVA) with the fixed factor "FPD type" and the dependent variables "strain gauges" was performed at a level of significance of $\alpha = .05$ (SPSS 14.0; SPSS, Chicago, IL).

RESULTS

None of the FPDs revealed a true passive fit, where the sensors showed zero microstrain. Mean strain development at the different strain gauge locations ranged from 80.38 µm/m to 437.11 µm/m (Table 2). The results of the MANOVA based on the absolute values of the strain gauge readings are given in Table 3. The comparison between the 2 types of conventionally fabricated FPDs (c-rep, c-pic) revealed no significant difference in terms of strain development ($P = .07$). While the CAD/CAM-fabricated FPDs revealed a significantly lower strain development than the specimens fabricated from pick-up technique impressions (c-pic versus c-cerec: $P = .01$), no significant difference could be detected in the comparison of the samples manufactured from repositioning technique impressions (c-rep versus c-cerec: $P = .19$).

DISCUSSION

Previous studies[25,26] have shown that passive fit cannot be achieved with existing techniques of superstructure fabrication. Consequently, FPDs will always bear a certain level of misfit, resulting in measurable amounts of strain. This was also true of this study.

In line with published data,[25] no significant differences in strain development could be found between FPDs fabricated from impressions made using the pick-up and repositioning techniques.

The numerous investigations dealing with impression accuracy[1,12–20] demonstrate that this specific step in the fabrication process of a restoration has a major influence on the accuracy of the restoration. The aim of this study was therefore to manufacture FPDs without using conventional impression-making techniques and master cast fabrication. In contrast to several other CAD/CAM systems, the CEREC system is the only available method that allows for CAD/CAM fabrication of a restoration without these 2 steps. The comparisons of the computer-generated FPDs with the 2 types of conventional FPDs revealed a significantly lower level of strain development in the milled FPDs in 1 case.

Limitations of the Study

Several factors may have influenced the results of the study and should be taken into account when interpreting the findings presented.

Optimum lighting conditions where no shadows are cast on essential structures are a prerequisite for useful optical impressions. Therefore, the implants in the measurement model were positioned in parallel with no subgingival margins. Furthermore, thanks to the in vitro set-up, it was possible to optimize camera adjustment and illumination.

Due to the limited lens size of the digital camera, an interimplant distance of only 11 mm from center to center was chosen. Nevertheless, it was necessary to perform 2 optical impressions for each FPD, each showing a single implant, and for the resulting images to be matched on the computer. This may have caused additional inaccuracies. A possible way to overcome such inaccuracies would be to use a larger lens.

As the intention was to compare the strain development in FPDs with different impression techniques and fabrication methods and evaluate the possibilities of CAD/CAM techniques in implant dentistry, a material that is already used in conventional restorations and that does not have to undergo secondary treatment after milling had to be chosen for the CAD/CAM restorations. This is why the decision was made to use VITA Mark II ceramic blocks, which are not suitable for the fabrication of FPDs used in real clinical situations due to mechanical limitations.

Although the properties of the dental training material used to fabricate the conventional FPD groups closely resemble those of a high precious alloy, the eventual higher contraction cooling of this nonprecious material may have influenced the accuracy achieved in these restorations.

As the level of accuracy of an implant-supported restoration, which determines bone loading caused by superstructure fixation, cannot be derived from measurements of marginal gap sizes,[10] these were not evaluated in the study presented. In conventional fixed prosthetic reconstructions, however, this aspect would also have to be taken into account.

CONCLUSION

Within the limitations of this study, it appears that fabricating superstructures on the basis of optical impressions directly from the patient situation allows for restorations to be produced which are at least as passive as conventional FPD types. However, further research and the development of optical impression techniques that go beyond the experimental stage used in this investigation are needed before clinical use can be recommended.

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