# Influence of Superstructure Materials on Strain Around an Implant Under 2 Loading Conditions: A Technical Investigation

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***Purpose:*** *This investigation was concerned with the effect of 3 superstructure materials on the strain around an implant under static and nonimpact dynamic loading.* ***Materials and Methods:*** *Five highly filled composite resin–veneered crown analogs, 5 autopolymerized acrylic resin–veneered crown analogs, and 5 gold-alloy full cast crown analogs were prepared. The resin veneers were applied to gold-alloy frameworks. These crown analogs were prepared to fit an ITI implant-abutment assembly, which was screwed into a block of acrylic resin to simulate implantation in bone. The crown analogs were successively placed on the abutment, and a lateral load of 100 N was applied to the superstructure by a lever-type testing machine. Strains were recorded under static and dynamic loading by a 2-mm-long strain gauge bonded to the surface of the bone simulant tangential to the implant. The dynamic load simulated masticatory cycles (75 strokes/min).* ***Results:*** *Although the strain values differed significantly between the static and dynamic loading (*$P < .05$*), there was no significant difference among the superstructure materials under either loading condition (*$P > .05$*).* ***Discussion:*** *These findings are in agreement with in vivo measurements, thus suggesting that cyclic rather than impact loading should be used in the investigation of occlusal material behavior under functional loading.* ***Conclusion:*** *Under static and nonimpact dynamic loading, the 3 superstructure materials tested (highly filled composite resin, acrylic resin, and gold alloy) had the same influence on the strain transmitted to a bone simulant that surrounded a single implant.* INT J ORAL MAXILLOFAC IMPLANTS 2004; 19:735–742

**Key words:** *dental implants, dental materials, dynamic loading, static loading, strain gauges*

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Theoretical assumptions suggest that use of acrylic resin for the occlusal surfaces of a prosthesis would protect the connection between implant and bone.[1] Indeed, damping of the peak force transmitted to implants has been reported by in vitro studies using impact forces on resin-veneered superstructures.[2,3] However, no significant differences were found between in vivo strain-gauge measurements of peak force at the abutment level with ceramic occlusal surfaces versus with acrylic resin surfaces.[3] Similarly, no significant differences have been found in the clinical, radiologic, or histometric parameters of the peri-implant tissues (eg, bone loss) supporting acrylic resin–veneered metal and ceramometal fixed prostheses in a dog model.[4] In comparisons of the bone stress under static loading with occlusal materials such as acrylic resin, gold alloy, and porcelain, most finite element analyses have shown no difference between the materials for single crowns and only very small differences for fixed prostheses.[5–7] An in vitro experiment with single crowns of the aforementioned materials under


**Fig 1** Specimen components. *(a)* The resin block, implant, abutment, and crown analog; *(b, c)* the 3 aspects of the crown analogs in groups 1 and 3, respectively. The crown analogs in group 2, not shown, were very similar in appearance to the group 1 crowns.

vertical loads that slowly increased with time also found no significant difference in bone stress between the materials.[8]

Since many prosthodontic complications and technical failures have been reported with acrylic resin occlusal surfaces,[9,10] composite resin has been used as an alternative. A clinical study has found no significant difference in marginal bone height around implants between fixed partial prostheses with composite resin occlusal surfaces and those with porcelain occlusal surfaces.[11] Recently, composites with high inorganic filler content for improved mechanical abilities[12–15] have been available for implant superstructures. However, their influence on bone strain has not been investigated.

Most in vitro studies on the influence of superstructure materials on the strain transmitted through the implant have been conducted under impact forces. However, a 1975 review study on the masticatory function and a recent study have shown that the mandible is decelerated prior to tooth contact,[16,17] in contrast to impact forces. Since it has been suggested that impact forces occur only accidentally during mastication,[18] the shock-absorbing effect of resilient materials that has been reported under this loading in vitro[2,3] might not be relevant during most actual mastication. Therefore, the relationship between prosthesis materials and the force transmitted through the implant system also needs to be investigated under conditions that resemble the intraoral mechanical environment.

The present study compared the influence of 3 occlusal materials (a highly filled composite resin, an autopolymerized acrylic resin, and, as a control, a gold alloy) on the bone strain generated by static and nonimpact dynamic loading.

## MATERIALS AND METHODS

Three groups, each consisting of 5 cylindric crown analogs, were prepared. Group 1 contained highly filled composite resin–veneered crown analogs, group 2 contained autopolymerized acrylic resin–veneered crown analogs, and group 3, the control group, contained gold-alloy full cast crown analogs. These crown analogs were prepared to fit an implant-abutment assembly, which was screwed into a block of acrylic resin to simulate implantation in bone (Figs 1a to 1c). To reduce the number of variables, the same implant-abutment assembly and resin block were used for all crown analogs, and all specimens were prepared by the same investigator (AK). The dimensions of the specimens are given in Fig 2. Details of the implant, abutment, and crown analog materials are listed in Table 1.

The drilling and tapping of the acrylic resin block, placement of the implant, and abutment connection followed methods previously described.[19]

### Fabrication of the Crown Analogs

*Groups 1 and 2.* The same method was used for framework fabrication in groups 1 and 2. A plastic burnout pattern (ITI Implant System; Straumann, Waldenburg, Switzerland) was placed on an implant analog (ITI Implant System), and the height was

**Table 1 Details of the Implant, Abutment, and Crown Analog Materials**

| Component | Product name | Manufacturer | Use |
|---|---|---|---|
| Solid-screw implant | ITI Dental Implant System | Straumann, Waldenburg, Switzerland | All groups |
| Solid abutment | ITI Dental Implant System | Straumann | All groups |
| Gold alloy (type IV) | Protor 3 | Cendres & Métaux, Biel-Bienne, Switzerland | Frameworks of groups 1 and 2, crown analogs of group 3 |
| Highly filled composite resin | Estenia (dentin: DA3) | Kuraray, Osaka, Japan | Veneers of group 1 |
| Autopolymerized acrylic resin | Unifast II | GC, Tokyo, Japan | Veneers of group 2 |

adjusted to 7 mm. Molten wax (medium-type green inlay casting wax; GC, Tokyo, Japan) was then added on top of the implant analog. Retention beads (GC) were glued to the wax pattern, using the adhesive provided with the beads. Spruing, investing, burning out, and casting with a type IV gold alloy were conventionally completed (Fig 3). No internal relief was provided. Castings with poor fit or nodules were discarded and remade.

In group 1, after air abrasion with 50-µm aluminum oxide ($Al_2O_3$) particles and application of a metal surface conditioner (Alloy primer; Kuraray, Osaka, Japan) to the framework, opaque conditioner (Cesead II opaque primer; Kuraray) and opaque (Cesead II opaque; Kuraray) were applied, and the latter was light-polymerized for 180 seconds by a visible light–curing unit (UnitXS; Heraeus Kulzer, Wehrheim, Germany). To standardize the dimensions of the veneering material, a 25.4-mm-wide crown-forming jig consisting of 2 resin blocks was used during the application of the dentin body (Fig 4a). After the implant analog was inserted into the lower block, the framework was placed on it. The upper block was then fixed over the lower block by sticky wax. A glass tube with an inner diameter and height of 7 mm was inserted in the upper block to avoid bonding of the veneering material to the plastic jig during the light-curing process. Dentin body (DA3) from the Estenia kit (Kuraray) was then packed into the jig using a plastic instrument. The excess material was carved flush with the jig surface, and the resin was preliminarily light-cured for 30 seconds. The air-barrier paste from the same kit was applied on the top of the resin before a final light polymerization of 300 seconds. The specimens were then removed from the jig and heat-treated at 110°C for 15 minutes in a heat-curing unit (KL-310; Kuraray). After complete polymerization, the air-barrier paste was removed by water spray, and the occlusal surface of the crown analogs was polished by silicone points (Shofu, Kyoto, Japan).

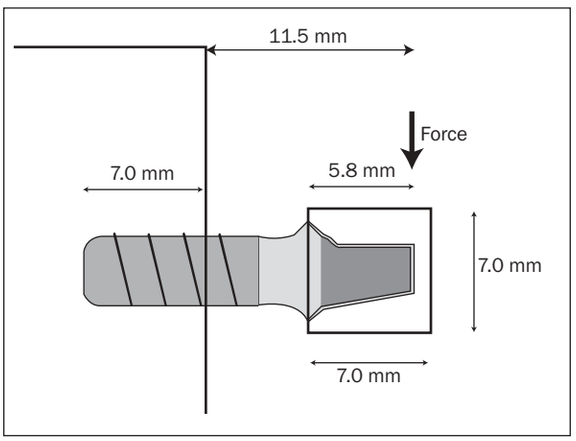


**Fig 2** Schematic representation of the specimen and the force application point, as exemplified in group 1.

In group 2, after preparing the framework as described above, the acrylic resin paste (Unifast II; GC) was prepared using a standard powder-liquid ratio (2 g/mL). The resin was then similarly packed into the same jig (Fig 4a), adjusted flush with its surface, and allowed to cure at room temperature. Finally, the specimens were removed from the jig and polished as those in group 1.

*Group 3.* For the fabrication of the crown analogs in this group, the aforementioned implant analog, plastic burnout pattern, and wax were used together with a crown-forming jig consisting of 2 brass blocks (Fig 4b). The forming jig and the steps of the crown analog fabrication were described in detail in a previous study.[19]

## Measuring Device and Test Conditions

To measure the strain generated around the implant by a lateral force applied to the superstructure, a strain gauge (Type KEP-2-120-C1-65L1M2R;

**Fig 3** Framework of the crown analogs for groups 1 and 2 (3 aspects shown) and the implant analog.



**Fig 4** *(a)* The crown-forming jig and crown analogs from groups 1 and 2 and *(b)* the jig for group 3. The implant analog was placed in the lower block of each jig.

**Fig 5** Specimen mounted in the holder of the lever-type testing machine. The moisture sealing tape had not yet been applied over the strain gauge.

Kyowa, Tokyo, Japan) was bonded to the surface of the resin block using a cyanoacrylate-based strain gauge adhesive (CC-33A; Kyowa) (Fig 5). The gauge was 2 mm long, and its long axis was perpendicular to the force direction, which allowed the measurement of the average circumferential strain over the area covered by the gauge. Since this strain gauge was temperature-compensated for plastic, a dummy gauge was not used for temperature compensation. The force application point is illustrated in Fig 2. Static and then cyclic forces (100 N and 0 to 100 N, respectively) were generated by a lever-type testing machine. The peak load was equivalent to the lateral component of a 200-N vertical force on a 30-degree cuspal inclination to the longitudinal axis of the implant. This peak load was within the range of maximal posterior occlusal forces for fixed prostheses supported by implants (35 to 330 N).[20] Dynamic loading was carried out at 75 strokes/min, which is within the range of the average human chewing frequency.[16] During each cycle, the specimens were loaded for about 0.3 seconds, which approximately corresponds to the duration of tooth contact in 1 chewing cycle.[16,21] An insulating and moisture sealing tape (VM Tape; 3M, Austin, TX) was applied over the strain gauge before starting the measurements. The strain gauge was wired into a Wheatstone bridge that was connected to a strain amplifier (DPM-1K; Kyowa). The amplified strain gauge signals were then recorded on a pen recorder (VP-654B; National, Osaka, Japan), and this output was finally computed into strain.

Before starting the actual measurements, 1 crown analog from each group was placed on the abutment, and the static force was applied for at least 200 seconds and then removed. Strain recordings were performed from the moment of load application to the moment when the recorder pen returned to 0 and the resulted time-strain curve was checked for permanent, residual strain.

For the actual measurements, 1 crown analog from each group was alternately placed on the abutment and the static force was applied for 75 seconds. Readings were made 60 seconds after the onset of force application, when the output curve had reached a plateau. On completion of the static testing, the dynamic test was performed on the specimens in the same order. After an initial 100-N loading that was continued until the time-strain curve tended to flatten, the cyclic loading of each sample was performed for 75 seconds. Readings were made after about 60 seconds of dynamic loading and corresponded to a peak strain developed under the maximum load.

After the last dynamic measurement and load removal, the strain recordings were continued until the recorder pen returned to 0, to confirm that no fatigue damage was induced during the testing.

### Statistical Analysis

It was hypothesized that under lateral loading, neither the superstructure material nor the loading condition would affect the strain values around the implant. Statistical analysis was performed using a commercial computer program (SigmaStat 2.0.3, SPSS, Chicago, IL). Data for the 3 superstructure materials were compared for each loading condition

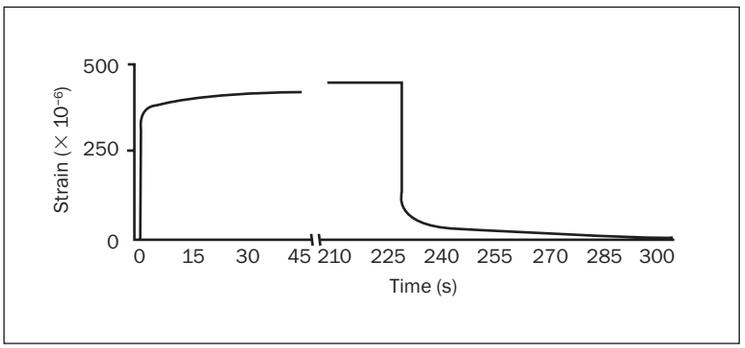


**Fig 6** The time-strain curve of a sample during a pilot trial that confirmed the absence of permanent, residual strain after load removal.

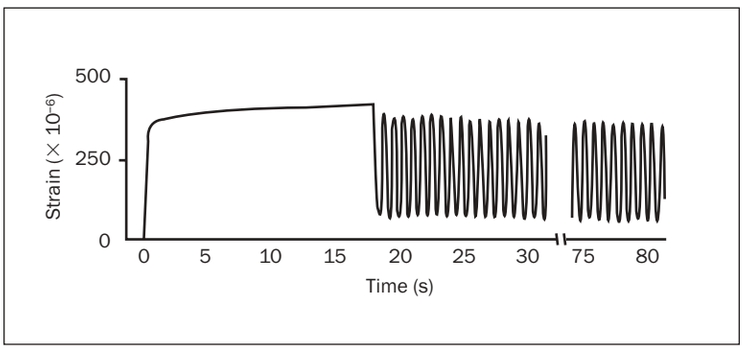


**Fig 7** The time-strain curve of a sample during dynamic loading. The time of strain increase in the dynamic loading was much shorter than the time needed for the strain to reach its peak under static loading.

by means of a 1-way analysis of variance (ANOVA), while strain under static loading and strain under dynamic loading were compared for each material by the 2-tailed *t* test. The level of significance was set at .05 for both analyses.

## RESULTS

The time-strain curve of at least 200 seconds of static load application revealed a fast strain increase in the first seconds of loading, followed by a much slower increase to the maximum value (Fig 6). After load removal, the curve showed a rapid decrease and then a gradual decrease to 0, with an aspect similar to the strain-increasing portion. Thus, it was confirmed that the acrylic resin block has the property of delayed elasticity. Although the resin block behaved like a viscoelastic body rather than a perfect elastic body, no permanent, residual strain was detected. Thus, the actual measurements were performed.

A representative example of the time-strain curves that were recorded under dynamic loading is shown in Fig 7. After the last dynamic measurement and load removal, the time-strain curve confirmed gradual reduction of the strain until disappearance in the bone simulant, and thus the absence of fatigue damage.

The means and standard deviations of the strains for each loading condition and the results of the 1-way ANOVA are shown in Table 2. There was no significant difference among the 3 groups under either static or dynamic loading ($P > .05$). Thus, the null hypothesis for the superstructure materials was accepted. The *t* test (Table 3) revealed significantly lower strains under dynamic loading than under static loading in each experimental group ($P < .05$); thus, the null hypothesis for the loading conditions was rejected.

## DISCUSSION

In this study, no cement was used for the restoration retention, to allow the placement of all crown analogs on the same implant-abutment unit. If cementation of the superstructure had been carried out, different abutment-implant units would have been necessary for each crown analog. However, in a pilot trial with the same experimental design, screwing individual implants into resin blocks led to different locations of the thread crest in relation to the block surface, and thus to the strain gauge. This noticeably influenced the gauge recordings, because higher strains were found around the thread crests than in the thread nadirs.[22,23] Therefore, in this

**Table 2 Mean Strains in Microstrains (SD) and the Results of the 1-way ANOVA**

| | n | Static loading | Dynamic loading |
|---|---|---|---|
| Group 1 | 5 | 442.6 (7.226) | 360.6 (15.70) |
| Group 2 | 5 | 443.3 (11.30) | 377.3 (36.01) |
| Group 3 | 5 | 429.3 (37.59) | 379.3 (21.13) |
| *df* (between groups) | | 2 | 2 |
| *df* (residual) | | 12 | 12 |
| *F* | | 0.587 | 0.792 |
| *P* | | .571 | .475 |

**Table 3 The *t* Test for Static Versus Dynamic Loading**

| Group | *P* | *t* | *df* |
|---|---|---|---|
| Group 1 | < .001 | –10.606 | 8 |
| Group 2 | .004 | –3.910 | 8 |
| Group 3 | .032 | –2.592 | 8 |

study, the same implant-abutment unit and resin block were used for all tested groups. Moreover, the crown analogs proved a reliable fit; there was no dislodgement during testing.

In this study, the embedded depth of the implant in the resin block was 7 mm; thus 3 mm of bone resorption were simulated. This situation allowed higher implant bending under the lateral load, which led to a magnification of the strain (as an absolute value) in the bone simulant. However, this phenomenon had no influence on the results of this comparative study.

Estenia is reportedly twice as stiff as conventional laboratory-processed composite resins,[13] but much more resilient than gold alloy[24] or porcelain.[25] With a Young's modulus of about 2.4 GPa,[24] acrylic resin was the most resilient superstructure material. However, these differences in stiffness were not of importance to the strain in a bone simulant that surrounded a single implant under static or relatively slow dynamic loads, such as those used in this study to simulate mastication. The results of the present study support the findings of 2 other studies on the bone stress/strain around single implants: a static finite element analysis[7] and an in vitro study under loads that slowly increased with time.[8]

Ceramic, currently the material of choice in implant-supported veneered restorations,[26] was not tested in this study. However, under the loading conditions used, its effect on the strain around an implant is considered to be similar to that of gold alloys (the control group), because of similar Young's moduli.[24,25] Thus, the present results under simulated masticatory cycles were in accordance with in vivo measurements showing no significant difference in the abutment stress of single implants for acrylic resin and ceramic.[3] Similarly, in a dog model, no significant difference was found in peri-implant bone loss or direct bone contact with implants supporting acrylic resin–veneered metal and ceramometal fixed prostheses.[4] A clinical study reported better esthetics, far fewer prosthetic complications, and no statistically significant difference in marginal bone loss when porcelain veneer was used instead of resin.[11] In contrast, in vitro studies using impact forces have shown that different prosthesis materials have different influences on the force transferred to an implant. For example, acrylic resin veneer significantly damped the applied shocks compared to ceramic veneer[2,3] or gold alloy.[2] Thus, rather than impact forces, which are not typical for mastication,[16–18] the dynamic loading design of this study, which simulated masticatory cycles, may be a more appropriate method for in vitro testing of mechanical behavior of prosthesis materials.

Consequently, the use of acrylic resin as a superstructure material, though previously recommended to ensure shock protection of the implant-bone interface,[1] does not seem to ease the strain in the bone around implants under simulated masticatory cycles and static loading. Considering its disadvantages, such as easy wear and fracture and poor esthetics,[9,27,28] other materials seem more suitable for implant-supported veneered prostheses. Although less wear-resistant than porcelain, the highly filled composite resin investigated in this study has been reported to withstand wear better than other composite resins.[12] Its wear resistance was found to be statistically the same as that of a type III gold alloy.[14] Its translucency and color stability after water immersion[29] as well as flexural strength and hardness[13] have also been reported to be significantly superior to those of other composite resins. In an in vitro study in which Estenia and a conventional feldspathic porcelain were used as veneering materials on gold frameworks for implant-supported prostheses, no significant difference in the possibility of failure under compressive loading was found.[15] Thus, if a resin is clinically preferred as a veneering material for implant-supported prostheses, this highly filled composite resin might be a reliable choice.

In other in vitro studies on the shock-absorbing properties of prosthesis materials, the implants were fixed in a metallic support.[2,3] However, the elastic moduli of metals are at least 7 and 50 times higher than those of cortical and cancellous bone, respectively. Thus, a metallic support may be too rigid to appropriately simulate bone, leading to reciprocal

interference with deformation of the superstructure and bone simulant, which can cause over- or underestimation of stress/strain in these components. In the present experiment, an acrylic resin block was chosen as a bone simulant. With an elastic modulus[24] of about one sixth that of human cortical bone,[24,30] it is admittedly not the perfect cortical bone simulant, but it has the advantage of possessing a stiffness similar to that of the human cancellous bone.[31] Since previous studies[6,32] have shown that stresses around implants concentrate primarily in the cortical bone, the precise experimental reproduction of both cortical and cancellous bone stiffness is desirable in investigations on strain/stress distributions. However, the search for the maximum strain of the entire bone is beyond the scope of the present analysis, in which the strains at a certain location on the bone surface were compared between the experimental groups.

During mastication, implant-supported prostheses in the mandible approach and contact their maxillary antagonists (teeth, implant-supported prostheses, or removable dentures). If the maxilla is supposed to be fixed and the presence of periodontal ligaments or alveolar mucosa in the maxilla, the soft tissues in the temporomandibular articulations, bone viscoelasticity, and so on are not taken into consideration, a displacement-prescribed model can be an appropriate approximation of the masticatory system. However, the presence of these structures will allow, in most of the cases, a certain relief of the internal forces produced during mastication and thus a force-prescribed experimental model, like that used in this study, can satisfactorily simulate most masticatory conditions. However, this experimental model is not suitable to analyze extreme occlusal conditions, such as bruxism or prolonged clenching, for which further investigations by a displacement-prescribed model are needed.

The significantly lower strain found with dynamic loading could be explained by the delayed elasticity of the bone simulant, ie, the strain increase phase ceased before equilibrium was reached when the load turned to the falling phase (Fig 7). From Fig 7, it is obvious that the time of strain increase in the dynamic loading was much shorter than the time needed for the strain to reach the maximum value under static loading, and thus the maximum strain will decrease with frequency increase in the nonimpact loading range. Consequently, the maximum strain recorded under the dynamic load was significantly lower than that under the static load. Despite this quantitative difference, the results for the 3 superstructure materials showed the same tendencies under both loading conditions (ie, there was no difference in the strain around the implant). Thus, in a comparative study of prosthetic material behavior under usual masticatory conditions, a static analysis could be of interest, and would not require sophisticated equipment.

## CONCLUSIONS

Two resins (highly filled composite resin and acrylic resin) and a gold alloy used as superstructure materials had the same influence on the strain transmitted to a bone simulant that surrounded a single implant under both static and nonimpact dynamic loading. Thus, in the habitual intraoral mechanical environment, the choice of these occlusal/veneering materials might be made based on criteria other than a hypothetical protective role for the bone.

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