The damping effect of five restorative materials used to veneer test crowns rigidly connected to a Brånemark implant and subjected to an impact force was measured. These materials included a gold alloy; a noble metal ceramic alloy; porcelain; a laboratory-processed, light-activated microfilled resin; and a heat- and pressure-polymerized poly(methyl methacrylate) resin. The two resins were found to reduce the impact force by about 50% when compared to porcelain or the alloys. The clinical significance of the results is discussed.


The connection between osseointegrated dental implants and the surrounding bone is direct and relatively stiff. It is theorized that an impact load applied to the prosthesis or implant may cause bone microfractures. An abnormal rate of marginal bone loss may be an indication of overstressing of the implant. Concern has been expressed for the necessity of providing a way to dampen the impact forces that may be exerted on implants.

The literature suggests different ways to introduce a damping element to compensate for the integrated implant. For example, a shock-absorbing device can be incorporated between the restoration and the implant, such as the intramobile element in the IMZ implant. When using an implant system that has a stiff connection between the implant and the prosthetic component, some investigators suggest veneering the metal framework with acrylic resin, regardless of whether the restoration is for a completely or partially edentulous arch. Other clinicians feel that this is unnecessary and suggest fabricating prostheses for the partially edentulous patients with metal or porcelain occlusal surfaces.

The amount of acrylic resin necessary for a conventional implant restoration in a completely edentulous arch provides the patient with a generous layer of material with sufficient cushioning effect to dampen most commonly exerted oral forces. This has been suggested in the laboratory compressive and bending tests conducted by Lili and coworkers. Adell et al. stated that to maintain long-term osseointegration of implants, especially in the maxillae, it is critical to keep the induced stresses as small as possible. These authors believe that occluding surfaces made of porcelain or gold may be deleterious to the viability of the bond between bone and implant. They advocated the use of acrylic resin occlusal surfaces, since clinical observations showed that these seemed to act as shock absorbers and that any minor occlusal irregularities could be eliminated by wear.

Skalak theorized that the peak stress generated by the impact of an object onto a metallic fixed partial denture supported by implants can be decreased by the interposition of an acrylic resin sheath. No experimental data were presented to substantiate such a model.

Brånemark emphasized the importance of careful prosthodontic treatment to promote long-lasting osseointegration and stated that it is essential to institute frequent recalls to maintain proper occlusion. He also suggested using acrylic resin.
teeth on implant-supported restorations. He inferred that this material would replace the resilience normally provided by the periodontium.

Jemt concurred with Brånemark in recommending the use of heat-polymerized acrylic resin, since complete restorations veneered with this material demonstrated an apparent reduction in the rate of fatigue fractures in the anchorage components. He suggested that porcelain-veneered crowns can be used to restore partially edentulous patients provided that the occlusal contacts with the opposing teeth can be designed on autopolymerizing acrylic resin.

More recently, Davis et al examined the issue of shock absorption using finite element analysis. A three-dimensional beam veneered with either heat-polymerized acrylic resin or porcelain was generated. These investigators examined the behavior of the finite element model under the application of a static load and after a slow impact stress. They concluded that acrylic resin is beneficial in reducing the impact stresses.

Finally, Lili et al looked at the deformation of idealized crowns made of acrylic resin, gold, or porcelain connected to an implant and subjected to a slowly increasing load of 100 N. These authors found that acrylic resin deforms significantly more than the other two materials, but the thickness of each veneer was not specified.

Most of the papers reviewed either discuss theoretical models or contain clinical observations and conclusions not supported by any scientific data. To date, there are no laboratory studies that have investigated the shock-absorbing behavior of veneered fixed prostheses for osseointegrated implants. The thickness of veneering material is greatly reduced when restoring a partially edentulous arch. The question is raised whether resin used as a veneering material provides a significant cushioning effect.

The purpose of this in vitro study was to measure the impact force-absorbing behavior of five restorative materials when used to veneer test crowns rigidly connected to a Brånemark implant.

Materials and Methods

The products used in this study and their manufacturers are listed in Table 1. Six experimental groups, each consisting of five cylindrical samples, were tested (Table 2).

### Table 1 Products and Manufacturers

<table>
<thead>
<tr>
<th>Type</th>
<th>Product name</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant components and torque screwdriver</td>
<td>Brånemark Systeme</td>
<td>Nobelpharma USA, Chicago, IL</td>
</tr>
<tr>
<td>Casting Alloys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold alloy</td>
<td>Type III Harmony Line Hard</td>
<td>Williams Dental Co, Buffalo, NY</td>
</tr>
<tr>
<td>Metal ceramic alloy</td>
<td>Will-Ceram Lodestar</td>
<td>Williams Dental Co, Buffalo, NY</td>
</tr>
<tr>
<td>Veneering materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porcelain</td>
<td>VMK-88</td>
<td>Vident, Baldwin Park, CA</td>
</tr>
<tr>
<td>Microfilled resin</td>
<td>Visio-Gem</td>
<td>ESPE/Premier, Norristown, PA</td>
</tr>
<tr>
<td>Poly(methyl methacrylate)</td>
<td>Biolon</td>
<td>Dentsply International, York, PA</td>
</tr>
<tr>
<td>Electronic components</td>
<td></td>
<td>PCB Piezotronics, Depew, NY</td>
</tr>
<tr>
<td>Force Transducer</td>
<td>11402 Digitizing Oscilloscope</td>
<td>Tektronix, Redmond, WA</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>GC Pattern Resin</td>
<td>GC International, Scottsdale, AZ</td>
</tr>
<tr>
<td></td>
<td>Silicoater, Siliflam, Silicoup</td>
<td>Kulzer, Irvine, CA</td>
</tr>
</tbody>
</table>

### Table 2 Experimental groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Material(s)</th>
<th>Framework height</th>
<th>Veneer thickness</th>
<th>Sample height</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Harmony Line Hard gold alloy</td>
<td>6.0</td>
<td>—</td>
<td>6.0</td>
</tr>
<tr>
<td>II</td>
<td>Lodestar ceramic alloy</td>
<td>6.0</td>
<td>—</td>
<td>6.0</td>
</tr>
<tr>
<td>III</td>
<td>Lodestar framework</td>
<td>4.5</td>
<td>1.5</td>
<td>4.5</td>
</tr>
<tr>
<td>IV</td>
<td>Lodestar framework + porcelain veneer</td>
<td>4.5</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td>V</td>
<td>Lodestar framework + Visio-Gem veneer</td>
<td>4.5</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td>VI</td>
<td>Lodestar framework + Biolon veneer</td>
<td>4.5</td>
<td>1.5</td>
<td>6.0</td>
</tr>
</tbody>
</table>

All units are in millimeters. All specimens are 9.0 mm in diameter.
The cylindrical test crowns were constructed using two jigs (Fig 1) and a brass abutment replica embedded in an acrylic resin base with GC Pattern Resin (Figs 2a and 2b). These components allowed standardization of the sample dimensions (Fig 3).

The first jig (a, Fig 1) had a cavity 9 mm in diameter and 6 mm deep, and the second (b, Fig 1) had a cavity with the same diameter but only 4.5 mm deep. Both devices had a hole in the middle of the internal cavity matched to the diameter of the brass analog, and the floor of the internal cylindrical cavity was at the level of the notch in the outer surface of the gold cylinder when positioned on top of the brass analog.

Fabrication of Complete Cast Alloy Samples (Groups I/II)

A 4-mm gold cylinder was screwed onto the brass analog using a 10-mm stainless steel guide pin (Figs 2a and 2b). The selected jig (a, Fig 1) was placed on the acrylic resin block around the gold cylinder, which partially protruded through the hole. Molten wax was flowed in the cavity. After the wax solidified, the guide pin was unscrewed and the wax was carved flush with the top of the jig. The pattern with the gold cylinder was removed, sprued on the side wall, and cast in either Harmony Line Hard or Lode-
star alloy. After casting, the ring was allowed to cool for 5 minutes and then quenched. The sprue was removed, and the top surface of the cast pattern was finished and polished (Fig 3). Each specimen thickness was measured with a micrometer and adjusted to a tolerance of ±0.02 mm using an engineering lathe (Unimat, EMCO, Austria). This created a flat occlusal surface for each sample. Two impact sites, 180° apart, were marked on the side of the test crowns.

**Fabrication of Veneered Samples (Groups III through VI)**

Samples were cast in Lodestar in the same manner as previously described using the jig shown in Fig 1 (b). Once cast, the occlusal surfaces of the five samples were prepared for porcelain application according to the manufacturer’s instructions. Opaque, body, and enamel porcelains were applied and sequentially fired until a 1.5-mm layer was fabricated (Fig 3). Each specimen thickness was measured with a micrometer and adjusted to a tolerance of ±0.02 mm using an engineering lathe. This created a flat occlusal surface for each sample. The porcelain was then finished with a rubber wheel and glazed.

After completion of the impact tests, these samples were placed in hydrofluoric acid to remove the porcelain. The samples were abraded with aluminum oxide, cleaned in distilled water in an ultrasonic bath for 10 minutes, then silicoated in a Silicoater machine. A SiOx-C layer (Siliflam) was flame-sprayed on the specimens for 3 minutes. The silane coupling agent (Silicoup) was immediately painted on the occlusal surfaces, and a 1.5-mm-thick layer of microfilled resin (Visio-Gem) was then applied and cured. Once the Visio-Gem tests had been completed, this resin was burned off and the specimens were cleaned and silicoated again. A 1.5-mm layer of poly(methyl methacrylate) resin (Biolon) was added and polymerized according to the manufacturer’s directions.

All veneered samples were stored in room-temperature distilled water for a minimum of 4 days prior to testing. All specimens were fabricated, checked for size, and tested by the same investigator.
Test Apparatus

The test apparatus (Fig. 4) consisted of an inclined platform with an included groove at the end of which a force transducer (T, Fig. 5) was mounted on an acrylic resin block (B, Fig. 5). A 4-mm titanium abutment (A, Fig. 5) was screwed into the middle of the transducer’s impact cap. The position of these components was not altered during the experiment. The test crowns (C) were connected to the abutment using the same standard gold screw. A torque screwdriver was used to ensure that the same amount of torque was applied to all devices when tightening the screw.

Fig. 5 Details of test apparatus: force transducer (T) mounted on an acrylic resin block (B), 4-mm titanium abutment (A), and test crown (C).

Fig. 6 Definition of the test variables as depicted by a typical force-time record.
Table 3 Test Sequencing

<table>
<thead>
<tr>
<th>Test</th>
<th>Group</th>
<th>Definition</th>
<th>No. impact repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>Gold occlusal</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>Gold occlusal, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>II</td>
<td>Lodestar occlusal</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>II</td>
<td>Lodestar occlusal, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>III</td>
<td>Lodestar framework</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>III</td>
<td>Lodestar framework, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>IV</td>
<td>Lodestar + porcelain, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>IV</td>
<td>Lodestar + porcelain, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>V</td>
<td>Lodestar + Visio-Gem, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>V</td>
<td>Lodestar + Visio-Gem, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>VI</td>
<td>Lodestar + Bion, crown rotated 180°</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>VI</td>
<td>Lodestar + Bion, crown rotated 180°</td>
<td>10</td>
</tr>
</tbody>
</table>

N = 5 for each test.

Starting at a fixed position at the top of the platform, a 6.2-mm-diameter stainless steel ball weighing 1.06 g was released and allowed to roll down the groove. This groove guided the ball to the occlusal surface of the test crown. The same stainless steel ball was used for all tests. The position of the acrylic resin block on which the test crown was mounted could be altered so that the length of travel of the ball was always the same. A thickness jig was used to position each new test crown surface 7 mm from the bottom of the groove. The occlusal test surface was always kept perpendicular to the groove, and the inclination of the platform was maintained constant.

Prior to starting the testing procedure, the ball was dropped three times and, with the aid of marking paper, the point of impact was visualized to make sure (a) that it was located approximately midway between the outer edge of the crown and the screw hole and (b) that it was coincident for the three runs.

Recording Apparatus

A shielded cable connected the force transducer (T, Fig 5) to a digitizing oscilloscope that recorded the complete force-time record induced (Fig 6). This impulse originated at the point of impact; traveled through the veneering material, the test crown, and the titanium abutment; and was recorded at what would be the abutment/implant interface (Fig 5). The digitizing oscilloscope computed the peak force value and the rise time to this peak force (Fig 6).

The impact force was defined in newtons, and the rise time was defined in microseconds. Before starting the experimental trials, the force transducer was checked for repeatability. The transducer without the titanium abutment was positioned 7 mm from the bottom of the ramp, and the ball was dropped on it 20 consecutive times.

Test Sequencing

Table 3 shows the individual tests conducted along with the number of test replications. A total of 600 impact recordings constituted the entire data collection.

Statistical Analysis

The variables measured (Fig 6) were (1) the magnitude of the maximum impact force and (2) the rise time to this peak force. A one-way analysis of variance (ANOVA) was used to compare each variable separately for the six groups. The Student-Newman-Keuls test was used to determine significant differences between the test groups at the 95% level. In addition, a linear correlation analysis was run on the means of each group to compare the maximum impact force and the rise time.

Results

The results of the impact testing are presented in Tables 4 and 5 and in Figs 7 and 8.
Impact Force

The ANOVA and the Student-Newman-Keuls test showed that the shock-absorbing behavior of the restorative materials in the five experimental groups with samples of the same height (groups I, II, IV, V, and VI) were all significantly different from each other (P ≤ .05) (Table 5). Porcelain was shown to be the stiffest material and Visio-Gem the most resilient. Figure 7 and Table 4 illustrate that the force peaks for the two resins were less than half those for porcelain or for the two alloys without veneering resin. The force recorded for the specimens in group III (Lodestar framework without veneer) was similar to that for group IV (Lodestar framework with porcelain veneer). A comparison of groups II and III (Table 4) showed that an additional 1.5 mm of metal reduces the impact force.

Rise Time to Peak

Figure 8 illustrates the time in microseconds that was necessary to reach the peak of the force-time record for each experimental group. All means were significantly different from each other (P ≤ .05) (Table 5).

Relationship Between Impact Force and Rise Time

A correlation analysis (Table 5) showed that impact force and rise time were inversely related (P ≤ .01; r = 0.98); the higher the impact force, the shorter the time required to reach the peak impact force.

Discussion

The model designed for this study reproduced a type of implant restoration that might commonly be used in the treatment of a partially edentulous patient. No attempt was made to impart on the test crowns an impact force of a magnitude similar to that found in the mouth. Since this is a comparative study, the only requirement was that of using a force that would allow differentiation in the impact-absorption behavior of the different materials selected. A stainless steel ball 6.2 mm in diameter and weighing 1.06 g was adequate for the sensitivity

Table 4 Means and Standard Deviations of the Test Variables

<table>
<thead>
<tr>
<th>Group</th>
<th>Force (N)</th>
<th>Rise time (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>128.88</td>
<td>14.00</td>
</tr>
<tr>
<td>II</td>
<td>142.22</td>
<td>13.62</td>
</tr>
<tr>
<td>III</td>
<td>147.66</td>
<td>12.96</td>
</tr>
<tr>
<td>IV</td>
<td>148.38</td>
<td>15.15</td>
</tr>
<tr>
<td>V</td>
<td>64.28</td>
<td>25.06</td>
</tr>
<tr>
<td>VI</td>
<td>69.22</td>
<td>24.55</td>
</tr>
</tbody>
</table>

*All means were calculated from 100 values for the five test specimens.*

†Values in parentheses are standard deviations.
threshold of the test equipment. The values recorded for the impact forces were well within the linear range of the transducer, as shown by a data sheet provided by the manufacturer.

The electronic components were reliable and consistent. This was demonstrated in the initial repeatability test of the force transducer and also by the small standard deviations found for each experimental group (Table 4). The impact location on the occlusal surface of the test crowns was constant, as indicated by the contact marks prior to each series of runs and by observation of the deflection of the ball after impact.

The transducer was positioned at the site that would correspond to the abutment/implant interface to analyze only the effects of the restorative materials and the components of the implant pros-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical subsets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact force</td>
<td>[V], [VI], [I], [II], [III, IV]</td>
</tr>
<tr>
<td>Rise time</td>
<td>[III], [II], [I], [IV], [VI], [V]</td>
</tr>
</tbody>
</table>

Correlation analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>r value</th>
<th>Significance of r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force vs rise time</td>
<td>0.98</td>
<td>99%</td>
</tr>
</tbody>
</table>

*Brackets define independent sets P ≤ .05.

thesis. If the transducer had been placed at the base of an osseointegrated implant, other factors that are difficult to standardize for an experimental protocol would influence the results. These include the extent of osseointegration, bone quality, and bone quantity.

The following variables were measured for each test specimen:

1. **Impact force** refers to the magnitude of the maximum peak of the force-time history recorded by the transducer after the force has traveled through the test crown and the titanium abutment. This is the measurement of the degree of shock absorption provided by a material, since a reduction in this force implies an increased cushioning effect.

2. **Rise time** is the time necessary to reach the peak of the first or maximum force-time record. From an analysis of the results, this variable seems to be a function of the relative stiffness of the materials used (the higher the elastic modulus of the material, the faster the impulse will travel through it) and the height of the specimen (the shorter the specimen, the shorter the time recorded).

Because the standard deviations found in the analysis of variance were so small (0.8% to 4.8% of the means), it was felt that a linear regression of the means was sufficient. This linear regression analysis (Table 5) demonstrated that these variables are well correlated with each other. The harder or stiffer the

![Fig 8 Mean rise time recorded for each group.](image-url)
material, the shorter the rise time; conversely, the more resilient the material, the longer the rise time and the smaller the stress. The findings of this paper confirmed the results of Jones et al. in their laboratory impact test.

When comparing groups I and II, it was found that the alloy with the higher elastic modulus (Lodestar, Young's modulus $14.2 \times 10^5$ lb/sq inch, versus Harmony Line Hard, Young's modulus $12.5 \times 10^5$ lb/sq inch) allowed a higher impact force to be recorded. When comparing groups V and VI it was found that the heat-processed poly(methyl methacrylate) resin (Biolon) had a higher force peak than did the light-polymerized microfilled resin (Visio-Gem, 40% filled/weight).

**Clinical Significance**

When trying to extrapolate the results of the present study to the clinical situation, one must be very careful about interpreting these data. As Brunski pointed out, there are at least three important questions that should be asked:

1. Does impact loading of implants occur clinically?
2. At what point does impact loading compromise the bone/implant interface?
3. Is it necessary to provide an implant with a shock absorber, either internal (eg, intramobile element in the IMZ system) or external (resin veneer)?

Currently, there are no clinical data that can answer the first question. However, if impact loading does occur, there are indications that the response generated may trigger the proprioception mechanisms in the surrounding bone or periosteum, thus "protecting" the interface. According to Sekine et al., the tactile threshold in osseointegrated implants is higher when a static load is applied than when a dynamic load is imparted (more than 100 g versus less than 35 g, respectively). The former is also much higher than the tactile threshold registered in natural teeth. Therefore, the authors speculate that patients may respond more readily to a percussion type of loading because of the vibration transmitting mechanisms of the bone or periosteum. This has also been suggested by the clinical experience of Langer and Sullivan.

The biologic implication of using a veneering material which provides increased absorption of an impact force is that it will potentially transmit less stress to the implant. Several authors assume that this reduction in stress is beneficial to the longevity of the implant, but there are no conclusive scientific data to support this view. Some of the additional topics that should be addressed by future research endeavors are (1) the influence that bone quality may have on force absorption potential and (2) the magnitude of force reduction that may be necessary to ensure the viability of the bone/implant interface.

Despite the fact that, in the present study, resin was shown to reduce the impact force, other considerations with regard to the physical properties of this material should be kept in mind prior to selecting it over porcelain or gold for veneering the occlusal surface of an implant restoration. Composite and acrylic resins have been shown to wear more than enamel, gold, or porcelain. This could lead to loss of vertical dimension, loss of centric occlusal contacts, supereruption of opposing teeth, and development of occlusal interferences. Therefore, the dentition opposing the implant restoration should play a role in the choice of materials. Other considerations concern the tensile strength, hardness, and color stability of the resin materials and, possibly, the parafunctional habits of the patient should be considered. Davis et al. suggested that, if the patient is a clencher or a grinder, porcelain may be more beneficial than resin, since it stiffens the framework and thus reduces the stresses transmitted to the screws.

**Conclusions**

The following conclusions were drawn from this study:

1. A 1.5-mm layer of Visio-Gem (group V) or Biolon (group VI) reduced the impact force by 57% and 53%, respectively, when compared to an equivalent thickness of porcelain (group IV).
2. Comparing the impact forces between the Lodestar frameworks (group III) and the samples veneered with Visio-Gem and Biolon (groups V and VI, respectively) clearly indicated that the shock-absorbing capability is dependent entirely on the resin veneers.
3. The mean impact forces recorded for the Visio-Gem and Biolon test crowns (groups V and VI) were 50% and 53%, respectively, of the mean value recorded for Harmony Line Hard gold alloy (group I).
4. The mean impact forces recorded for the Visio-Gem and Biolon test crowns (groups V and VI) were 45% and 49%, respectively, of the mean value recorded for Lodestar metal ceramic alloy (group II).
5. The impact force recorded was higher for the alloy with the higher elastic modulus (Lodestar,
group II, Young’s modulus 14.2 \times 10^6 \text{ lb/sq inch}, versus Harmony Line Hard, group I, Young’s modulus 12.5 \times 10^6 \text{ lb/sq inch}).

Acknowledgments

The authors are grateful to the following manufacturers for generously providing the materials used in this study: Nobelpharma USA, Williams Dental Co, Dentsply International, and ESPE/Premier.

References


Literature Abstract

Variation der Terminalen Scharnierachsenposition bei Verschiedenen Registriermethoden (A Comparison of the Position of the Transverse Rotational Axis Obtained by Different Methods)

A modified SAM Axiograph, with an air-operated stylus marker, was used to compare three different methods of locating the transverse rotational axis (TRA) of the mandible. The accuracy of the pneumatic stylus is similar to that of electronic apparatus introduced after observations had been completed. One hundred eighteen subjects participated. With Lauritzen’s chin-point guidance technique, 68% of TRA markings were located 0.3 mm inferior, and usually posterior, to that obtained by Dawson’s method of bilateral guidance of the body of the mandible. Using McGrane’s intraoral central bearing point with light chin guidance, 64% of TRA markings were 0.4 mm superior to the Lauritzen point and posterior to it. These results were not affected by demographic parameters, such as age and sex, or occlusal factors. The authors regard the TRA as a field, rather than a straight line.