

Shock Absorption Capacity of Restorative Materials for Dental Implant Prostheses: An In Vitro Study

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Purpose: To measure the vertical occlusal forces transmitted through crowns made of different restorative materials onto simulated peri-implant bone. **Materials and Methods:** The study was conducted using a masticatory robot that is able to reproduce the mandibular movements and forces exerted during mastication. During robot mastication, the forces transmitted onto the simulated peri-implant bone were recorded using nine different restorative materials for the simulated single crown: zirconia, two glass-ceramics, a gold alloy, three composite resins, and two acrylic resins. Three identical sample crowns for each material were used. Each crown was placed under 100 masticatory cycles, occluding with the flat upper surface of the robot to evaluate the vertical forces transmitted. Two-way analysis of variance was used. Alpha was set at .05. **Results:** The statistical evaluation of the force peaks recorded on the vertical z-axis showed mean values of 641.8 N for zirconia; 484.5 N and 344.5 N, respectively, for the two glass-ceramics; 344.8 N for gold alloy; 293.6 N, 236 N, and 187.4 N, respectively, for the three composite resins; and 39.3 N and 28.3 N, respectively, for the two acrylic resins. Significant differences were found between materials ($P < .0001$), except for the comparison between gold alloy and one of the glass-ceramics. **Conclusion:** Composite and above all acrylic resin crowns were more able to absorb shock from occlusal forces than crowns made of zirconia, ceramic material, or gold alloy. *Int J Prosthodont* 2013;26:549–556. doi: 10.11607/ijp.3241

Implant dentistry has become an increasingly effective method for correcting edentulism, either partially or completely. Implant treatments exhibit an overall excellent clinical success rate in the long term.^{1–4} Despite its rare occurrence, the reasons for peri-implant bone loss and implant failure in some patients are not completely understood. Multifactorial aspects (general health, bone quality and quantity, surgical procedure, implant characteristics, parafunctional habits, occlusal overloading, medications, bacterial insult, etc) potentially induce peri-implant bone damage. However, the role of some of these aspects in reaching and maintaining

osseointegration is controversial.⁵ Several authors consider occlusal load a crucial factor affecting the dental implant healing phase and the long-term survival and success of dental implants.^{6–12}

In teeth, a semi-elastic connection between the tooth and bone exists (periodontal tissue), whereas in implants, a direct and relatively rigid connection between the bone and implant is achieved if healing without complications has taken place.^{13,14} Therefore, a direct transmission of forces on the peri-implant bone without any shock-absorbing element is consequent to implant loading.¹⁴ It can usually be achieved by the adaptation capacity of peri-implant bone architecture toward changing load conditions.^{15,16} According to Frost,^{15,16} within the range of a physiologic loading, bone undergoes its physiologic turnover. In mild overloading, below bone's microdamage threshold, modeling drifts can begin adding to and/or reshaping bone. But in the case of a pathologic overload, bone fractures and bone resorption may occur.^{15,16} For these reasons, it appears to be important to control the forces transmitted on the bone-implant interface. However, the amount of load defined as overload has not been quantified because the range of host physiologic adaptability varies. Overload can be considered the amount of force that overextends the host sites adaptation potential.

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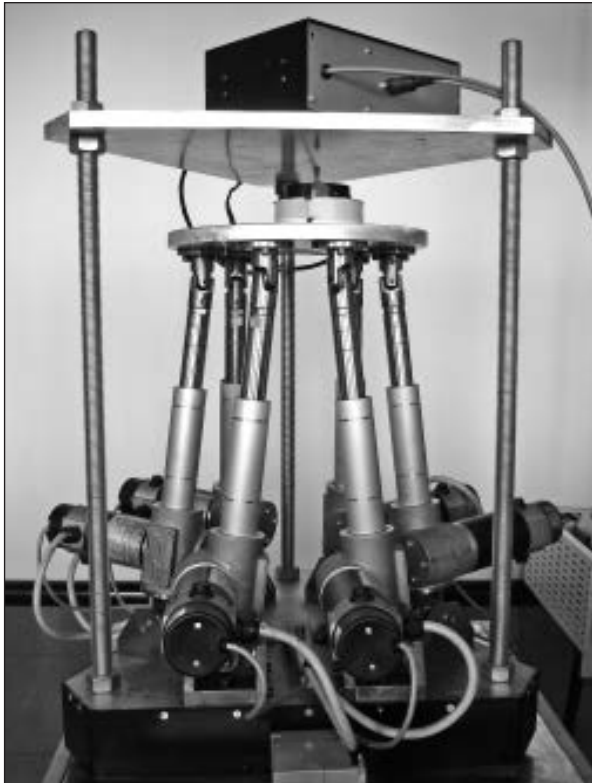
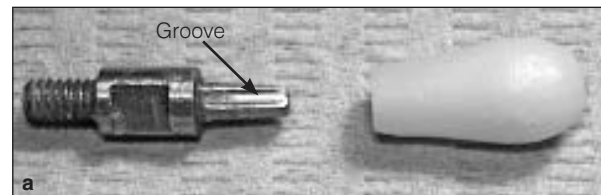


Fig 1 (left) Sensor-equipped masticatory robot.

Fig 2 (below) Pin simulating the implant-abutment system with a ceramic sample crown. **(a)** A groove was made on the pin to match a ridge inside the sample crown, so that the crown would sit precisely on the pin without any possibility of rotation or other movement during testing. **(b)** The sample crown has been inserted onto the pin.



Clinical evidence on the impact of overloading on peri-implant bone is not available. Only some case reports¹⁷⁻¹⁹ and animal studies^{9,12,20} are present. In fact, clinical trials evaluating overloading are difficult to design due to ethical reasons. Moreover, it is generally impossible to identify the reason for peri-implant bone loss in clinical cases, distinguishing overloading from other potential sources of bone loss. It is the authors' opinion that a prudent approach to implant prosthodontics should be aimed at avoiding the risk of overloading the implants. In vitro studies²¹⁻²⁵ also demonstrate that off-axial loads increase stress on the bone-implant interface with respect to axial loads and may also be responsible for increased resorption of crestal bone.²⁰

Some authors maintain that the type of material used for the prosthesis supported by the titanium implant could affect occlusal load.^{14,26-32} In particular, in the 1980s, some investigators recommended resilient occlusal materials such as acrylic resin to reduce the forces exerted on implants.^{14,33,34}

However, contrasting results on this topic³⁵⁻³⁸ suggest the need for further investigation. The role of dental materials in occlusal stress transmission onto peri-implant bone seems to be especially relevant over the past few years because of the increasing use of esthetic but rigid materials, such as glass-ceramic

and zirconia. These materials are reported to have excellent mechanical and biologic properties,^{39,40} but their impact on peri-implant bone and on the whole masticatory system has not yet been investigated.

The aim of this study was to investigate in vitro the shock absorption capacity of nine different restorative materials, including both traditional and modern esthetic materials, using a masticatory robot.

Materials and Methods

A masticatory robot able to simulate human chewing in vitro was used (Fig 1), reproducing three-dimensionally the masticatory movements and loads exerted during mastication, as described in a previous paper.²⁶

The movable part of the robot is composed of a Stewart platform and simulates the mandible. The fixed upper part of the robot simulates the maxilla.

A sensor-equipped base is placed on the moving platform and records the degree of force being transmitted through the three axes (x, y, and z).

The sensor-equipped base supports a pin that simulates the implant-abutment system (Fig 2a). The samples to be tested are placed on the pin and stressed in the various directions during the robot's mastication.

Table 1 Elastic Moduli of Tested Materials

Material	Manufacturer	Type of material	Elastic modulus (MPa)
Procera Zirconia	Nobel Biocare	Zirconia	210,000
Empress 2	Ivoclar Vivadent	Glass-ceramic	96,000
Ney-Oro CB	Dentsply	Gold alloy	77,000
Finesse	Dentsply	Glass-ceramic	70,000
Experience	DEI Italia	Composite resin	13,000
Adoro	Ivoclar Vivadent	Composite resin	7,000 ± 500
Signum	Heraeus Kulzer	Composite resin	3,500
Easytemp 2	DEI Italia	Acrylic resin	2,300
AcryPlus V	Ruthinium	Acrylic resin	N/A

N/A = not available.

The materials tested were yttrium cation-doped tetragonal zirconia polycrystals (Procera Zirconia, Nobel Biocare), a lithium disilicate pressable ceramic (Empress 2, Ivoclar Vivadent), a low-fusing leucite-based pressable ceramic (Finesse, Dentsply), a gold alloy (Ney-Oro CB, Dentsply), a microfilled hybrid composite resin (Experience, DEI Italia), a microfilled composite resin (Adoro, Ivoclar Vivadent), a nano-hybrid composite resin (Signum, Heraeus Kulzer), and two acrylic resins (Easytemp 2, DEI Italia and Acry Plus V, Ruthinium) (Table 1).

In total, 27 identical sample crowns were made (three for each material). The occlusal surfaces were semispherical in shape (6.5-mm diameter) (Fig 2b). The main axis of the sample was 11-mm long. The sample crowns presented a single contact point at the center of the occlusal surface when occluding with the flat maxilla of the robot. At this point, the thickness of the material tested was 5 mm. Each sample was measured on its main and smaller axes. The material thickness at the contact point was also measured with calipers to verify that all crowns were identical.

The specimens tested were chosen at random and not in a pre-established sequence. Each crown was placed under 100 chewing cycles with the sample crown occluding with the flat fixed maxilla of the robot. The masticatory robot was programmed to follow a trajectory reproducing human chewing, as described in the previous paper.²⁶ The masticator traced this trajectory in all tests described and the movements were executed independently from generated force.

Vertical loads (kg) transmitted at the simulated peri-implant bone were recorded using strain gauges stuck on the sensorized base supporting the simulated implant-abutment system.

With MATLAB 6.1 (MathWorks), the maximum values of the forces recorded for each masticatory cycle were highlighted. These values underwent statistical analysis using SPSS software (version 18.0, IBM). Two-way analysis of variance (ANOVA) was used to compare transmitted stresses between the nine materials tested and across the three sample crowns of each material. All tests were two-tailed. Alpha was set at .05.

Post hoc comparisons were assessed by means of the Scheffe test or, alternatively, by means of the Tamhane test when homogeneity of variances among materials was not satisfied.

Vertical loads were converted and are found throughout the paper in Newtons.

Results

The ANOVA found a significant difference between the forces transmitted using different materials, and the Scheffe post hoc test was applied. Within the materials, an internal comparison showed a significant difference with $P < .0001$. Only the difference in mean maximum force between Ney-Oro and Finesse was not statistically significant ($P > .999$).

Comparisons within sample crowns made for each material did not show significant differences, and one unique mean was reported for each material.

The force transmitted through the simulated implant onto the simulated peri-implant bone by zirconia (mean 641.8 N) was the greatest (Table 2).

The slope of the curve, representing the force transmitted onto the peri-implant level, showed that materials with greater elastic moduli have steeper peaks compared with other materials, that is, the maximum force is reached more rapidly.

Table 2 Comparison of the Maximum Forces (N) Transmitted onto the Simulated Peri-implant Bone

Material	Mean force (SD)	Difference of force vs zirconia (%)	P
Procera Zirconia	641.8 (6.8)		
Empress 2	484.5 (5.5)	-24.51	
Ney-Oro CB	344.8 (5.7)	-46.28	
Finesse	344.5 (3.5)	-46.32	
Experience	293.6 (16.3)	-54.25	< .0001
Adoro	236 (4.2)	-62.23	
Signum	187.4 (6.7)	-70.80	
Easytemp 2	39.3 (2.3)	-93.88	
AcryPlus V	28.3 (4.2)	-95.59	

Discussion

In this investigation, the use of different restorative materials significantly affected stress transmission on the simulated peri-implant bone. In fact, more elastic materials reduced the stress recorded.

The difference in stress transmission between the gold alloy and one of the two glass-ceramics was the only difference not statistically significant, presumably because of their similar Young's moduli (Table 1).

Zirconia and ceramic crowns also showed steeper peaks of force compared with other materials. These were considered effects of the different elastic moduli of the materials tested.

According to Skalak,¹⁴ the viscoelastic behavior of an acrylic resin as occlusal material would be enough to delay the transmission of force and reduce its peak compared with materials with greater elastic moduli.

An *in vitro* study by Gracis et al³² concluded that the harder and stiffer the material, the higher the force transmitted onto the implant and the shorter the rise time. In fact, according to Hooke's law, the higher the modulus of elasticity of a material, the less the material will deform under pressure and the more likely the force will be transferred through the material.⁴¹ Conversely, the more resilient the material, the more easily it will deform under pressure, the longer the rise time, and the smaller the stress.

However, a review of the literature over the last 20 years demonstrated that many articles refute the existence of a shock absorption capacity of resilient dental materials.⁴²⁻⁴⁹

Some of these studies have used Instron machines⁴⁸ and some have used finite element analysis (FEA).^{44,46,47} These studies have several limitations. They do not accurately reproduce the mandibular

kinematics. Instron machines perform intermittent movements in only a single plane. They do not replicate the same masticatory cycle that occurs clinically with mastication.

With regard to FEA, which included a virtual simulation, the validity of the mathematical model is difficult to estimate objectively, and the assumptions made in the use of FEA in implant dentistry must be taken into account when interpreting the results. In fact, during the modeling process, several simplifications are necessary (model geometry, material properties, applied boundary conditions, etc) and greatly affect the predictive accuracy of FEA.⁵⁰

An experiment conducted on beagle dogs⁵¹ did not show any clinical, radiographic, or histologic differences between peri-implant tissues surrounding prosthetic restorations made with composite resin versus those made with ceramic materials. However, this study did not control the amount of force exerted onto the implants, and dogs do not replicate human mastication.

In vivo studies^{41,43,49} have measured masticatory forces transmitted through various restorative materials in patients without finding significant differences in the results.

This type of test requires that sensors and connecting wires be applied intraorally, which raises several concerns. For instance, this type of testing may alter the masticatory cycles of the study participants and therefore may distort the results. Moreover, the technique is not conducive to studying humans over long experimental periods, and the masticatory cycles are not identical. In addition, it is not possible to directly measure the forces transmitted onto the bone-implant interface.

Using the masticatory robot, an attempt was made to overcome the limitations associated with previous studies, approximating the three-dimensional nature of masticatory function by an *in vitro* model. The forces were measured by strain gauges attached to the sensorized base to which the simulated dental implant was screwed; therefore, it was considered that the forces were recorded at the simulated peri-implant bone.

Even though non-axial forces seem to be a more relevant factor for bone maintenance compared with axial forces, in the present paper, only data regarding vertical forces have been reported. In fact, previous papers^{26,27} showed that the percentage difference of force using different materials was superimposable on the three axes; data for the three axes were redundant. For this reason, in the present research, the sample crowns were left to occlude with a flat surface and not with the reproduction of the maxilla.

Occluding with a flat surface, forces on the horizontal plane were near zero and only data recorded on the vertical axis were considered for statistical analysis.

The present *in vitro* setup presents several limitations in simulating the clinical situation. Namely, the moving platform and the upper part of the robot, simulating the maxilla, are rigid systems that cannot reproduce the inherent elasticity of human tissues. The elastic properties of implant, abutment, and screws were not properly simulated.

Moreover, no attempt was made to simulate the oral environment in terms of humidity and temperature.

Comparability of the *in vitro* and *in vivo* loading conditions is limited. Therefore, the absolute values of force recorded at the peri-implant bone in the present study cannot be directly correlated to the forces that would be present *in vivo*.

It should also be noted that the masticatory system is provided with protective and self-regulatory mechanisms not simulated in the present *in vitro* setup. In fact, natural teeth are equipped with periodontal mechanoreceptors that signal information about tooth loads and are involved in the control of human jaw actions aiming at preventing accidental excessive occlusal loads.⁵² On the other hand, dental implants lack periodontal receptors. However, a tactile sensibility at the level of dental implants (so-called osseoperception) has been demonstrated and could be responsible for an implant-mediated sensory-motor control.⁵³

Despite the limits of the present *in vitro* setup in simulating the oral implant situation, the attempt was made to eliminate all possible variables involved. The standardized *in vitro* system allowed for fabrication of identical sample crowns that were all submitted to identical loading conditions.

A previous paper²⁶ demonstrated that the masticatory robot is able to reproduce, several times over, identical masticatory cycles. The paper also confirmed the precision of the machine during data collection, therefore validating the reliability of the method. In fact, the small variations found showed that the tests are also repeatable and effective under lengthy testing.

The only variable in the system described was the material from which the crowns were made, which is mandatory for a reliable comparison of different materials. The system was designed to make a comparison between different materials effective and repeatable.

In the present study, a single crown was tested, demonstrating a shock absorption potential for acrylic resin. However, contrasting results could be found using multiunit prostheses.^{41,44,54,55} In fact, stiff prosthetic materials are supposed to distribute the stress more evenly to the abutments and implants. It is the

authors' opinion that, in multiunit prostheses, a stiff substructure (ie, gold alloy) rigidly splinting the implants would be the best option to evenly distribute loads. The shock absorption capacity of more resilient restorative materials could be used at the level of the occlusal surface in association with a stiff substructure.¹⁴

The present paper evaluates the shock absorption capacity of nine restorative materials, including gold alloy and zirconia, which were not tested in previous studies.^{26,27} To the authors' knowledge, there are no published studies evaluating the shock absorption capacity of zirconia. In the last few decades, the growing patient demand for highly esthetic restorations has led to the development of new all-ceramic materials such as zirconia.

Zirconia minimizes the dark color transmitted through peri-implant tissues associated with metal components. Moreover, zirconia restorations yield higher fracture loads than alumina or lithium disilicate.^{56,57}

Both the increasing industrial pressure and growing enthusiasm for attractive esthetic outcomes have led to the widespread use of all-ceramic restorations and zirconia, even though their impact on the masticatory system has not been sufficiently tested. The esthetic characteristics, as well as the biocompatibility, and the most common shortcomings of all-ceramic restorations (brittleness, chipping of the veneering ceramic, fracture strength) have been thoroughly investigated for zirconia.^{40,58} Zirconia is also considered to have excellent mechanical properties,⁵⁹ but, so far, the biomechanical consequences of such a rigid and stiff material in the masticatory system have not been investigated by the scientific literature. In fact, zirconia's elastic modulus and coefficient of abrasion are much higher than those of natural teeth.

Only a few studies⁶⁰⁻⁶² report assessments of periodontal or peri-implant tissues around teeth or implants supporting zirconia restorations after functional loading. To the authors' knowledge, no clinical studies report possible consequences at the level of the antagonist arch or any gnathological consideration. Moreover, to date, the observational period for the majority of trials on zirconia restorations is quite short.⁵⁷

Two systematic reviews on all-ceramic dental materials and zirconia also underlined the fact that none of the cited clinical trials took bruxism into account. More often, such a parafunction figured into the exclusion criteria. Consequently, the authors suggested that, since parafunctions were not considered in any clinical investigation, they should be regarded as a potential limitation for zirconia-based

restorations.^{39,63} One reason for this suggestion could be the increased risk of chipping and fracture of zirconia-based restorations in parafunctional patients, but evidence is lacking on possible harmful effects on the masticatory system using zirconia restorations when a parafunction is present.

Larsson et al⁶⁴ noticed that significantly more porcelain veneer fractures are reported for implant-supported zirconia fixed dental prostheses when compared with tooth-supported restorations. One explanation for this finding could be the role played by the periodontal ligament, which allows for shock absorption, sensory function, and tooth movement. This hypothesis also suggests that the possible harmful effects of zirconia restorations on the masticatory system would be made worse when dealing with implant-supported restorations in comparison to tooth-supported restorations. In fact, a shock-absorbing element is lacking in implant restorations and higher loads can occur with implant-associated proprioception loss.⁵²

The choice of the restorative material to be used in implant restorations should be made in light of newly introduced concepts of osseosufficiency and osseoseparation⁵: as long as the host, the implant, and the clinical procedures induce and allow for maintaining osseointegration, an osseosufficiency state is present. But some patient-related or nonpatient-related factors could induce osseoseparation, compromising the obtainment or maintenance of osseointegration. As reported earlier, evidence is lacking on the role of overloading in peri-implant bone loss. However, bone has been demonstrated to be sensitive to loading conditions.⁶⁵ This suggests that to control the occlusal loads in implant prosthodontics as much as possible, clinicians should aim to reduce load entity and extra-axial loads. Based on the present in vitro results, if the aim is reducing load entity, zirconia is not the proper restorative material to be used. These findings need to be supported by clinical trials to investigate their clinical relevance

Conclusion

Within the limitations of this in vitro study, several conclusions can be drawn. Zirconia, glass-ceramic, and gold alloy transmitted higher stresses to the simulated peri-implant bone. In contrast, composite resin materials were able to significantly reduce the values of force recorded compared to stiffer materials. In fact, the use of composite resins and acrylic resins reduced occlusal stress by up to -70.80% and -95.59%, respectively, compared with zirconia.

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Literature Abstract

Identification of risk factors for fracture of veneering materials and screw loosening of implant-supported fixed partial dentures in partially edentulous cases

The purpose of this retrospective study was to determine the risk factors for fracture of veneering materials and screw loosening of implant-supported fixed partial dentures. A total of 182 patients had 219 suprastructures inserted. One hundred twenty patients (149 facing suprastructures) were included in a subgroup to investigate the risk factors of fracture of veneering materials, and 81 patients (92 suprastructures) were included in a subgroup to analyze the risk factors for abutment screw loosening. A Cox proportional hazards regression model was performed to identify the risk factors related to technical complications, and eight factors were regarded as candidate risk factors. It was suggested that a screw-retained suprastructure was a significant risk factor for fracture of veneering materials, and connection of suprastructures with natural teeth was a significant risk factor for screw loosening. Further investigations involving dynamic factors, such as occlusal force and bruxism, should be considered as predictors that may be helpful in studying the risk factors of fracture of veneering materials and screw loosening.

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