ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/351220094

In vitro evaluation of material dependent force damping behavior of implant-supported restorations using different CAD-CAM materials and luting conditions

Article *in* Journal of Prosthetic Dentistry · April 2021

DOI: 10.1016/j.prosdent.2021.03.016

CITATIONS
9

READS
97

2 authors:



Doaa Taha
Ain Shams University-faculty of Dentistry
13 PUBLICATIONS **251** CITATIONS
SEE PROFILE



Ahmed Ezzat Sabet
Ain Shams University
20 PUBLICATIONS **369** CITATIONS
SEE PROFILE

All content following this page was uploaded by Doaa Taha on 03 January 2024.

The user has requested enhancement of the downloaded file.

THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

In vitro evaluation of material dependent force damping behavior of implant-supported restorations using different CAD-CAM materials and luting conditions

Doaa Taha, PhD[a] and Ahmed Sabet, PhD[b]

ABSTRACT

Statement of problem. Although force-damping behavior that matches natural teeth may be unobtainable, an optimal combination of crown material and luting agent might have a beneficial effect on the force absorption capacity of implant-supported restorations. However, the force-absorbing behavior of various restorative materials has not yet been satisfactorily investigated.

Purpose. The purpose of this in vitro study was to evaluate the material dependent force-damping behavior of implant-supported crowns fabricated from different computer-aided design and computer-aided manufacturing (CAD-CAM) materials luted to implant abutments under different conditions.

Material and methods. Titanium inserts (N=84) were screwed to implant analogs, scanned to design zirconia abutments, and divided into 4 groups to receive CAD-CAM fabricated crowns in 4 materials: zirconia, polyetheretherketone (PEEK), polymer-infiltrated ceramics (VITA Enamic), and lithium disilicate (e.max). The crowns were subdivided as per the luting agent: none, interim cement, and adhesive resin cement. Measurements were performed by loading specimens in a universal testing machine with an increasing force and measuring the resulting force with a digital forcemeter, followed by image processing and data acquisition. Two-way multivariate analysis of variance (MANOVA) was used to assess all interactions with multiple pairwise comparisons (α=.05).

Results. The curve progression of the applied and resulting forces varied significantly among the investigated materials, resulting in differently inclined slopes for each material (P<.001). With no cementation, the mean slope values of the resulting force curves ranged from 77.5 ±0.03 degrees for zirconia, followed by 71.8 ±0.03 degrees for lithium disilicate, 56.2 ±0.1 degrees for polymer-infiltrated ceramics, and 51.1 ±0.01 degrees for polyetheretherketone. With interim cementation, the mean slope values ranged from 75.4 ±0.01 degrees for zirconia, followed by 70.05 ±0.02 degrees for lithium disilicate, 56.1 ±0.02 degrees for polymer-infiltrated ceramics, and 52.2 ±0.1 degrees for polyetheretherketone. As with adhesive cementation, curve slopes ranged from 73.2 ±0.02 degrees for zirconia, followed by 70.5 ±0.2 degrees for lithium disilicate, 55.9 ±0.04 degrees for polymer-infiltrated ceramics, and 52.3 ±0.1 degrees for polyetheretherketone. Slope loss was significant after the cementation of zirconia and lithium disilicate crowns but less significant for polymer-infiltrated ceramics and polyetheretherketone.

Conclusions. Force damping is generally material dependent, yet implant-supported crowns fabricated from resilient materials such as polymer-infiltrated ceramics and PEEK show better force absorption than rigid materials such as zirconia and lithium disilicate ceramics. Furthermore, cementation of rigid materials significantly increased slope loss, indicating enhancement in their force-damping behavior, whereas less-rigid materials benefit less from cementation. Further studies are essential to investigate the effect of prosthetic materials on the stress distribution to the peri-implant bone in the crown-abutment-implant complex. (J Prosthet Dent 2021;■:■-■)

Implant-supported prostheses have become a common treatment option in the management of missing teeth because of their demonstrated long-term, functional, biologic, and mechanical clinical prognosis.[1] However, the difference in their biomechanical behavior compared with that of natural teeth is of concern because of the

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

[a]Visiting Researcher, Section Medical Materials Science & Technology, University Hospital Tübingen, Tübingen, Germany; and Lecturer, Department of Fixed Prosthodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.

[b]Associate Professor, Department of Fixed Prosthodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt; and Head of Fixed prosthodontics department, Faculty of Dentistry, British University, Cairo, Egypt.

Clinical Implications

The selection of a favorable combination of crown material and luting agent for implant-supported restorations is recommended to mediate the stress distribution pattern to the peri-implant bone. Combining rigid materials with adhesive cementation might enhance their force damping behavior to resemble more resilient materials with poorer mechanical properties.

direct contact of implants with bone with no periodontal ligament.[2] The direct bone contact deprives implant-supported prostheses of the elastic buffering mechanism present in the natural dentition, resulting in a different response to masticatory forces.[2,3] In addition, biomechanical control of force transmission from the implant to the surrounding bone is necessary to improve the long-term success of the implant-abutment-crown complex.[4,5]

The presence of multiple layers or structures comprising the implant-abutment-crown complex plays an important role in the transmission of the masticatory forces to the implant-bone interface.[6,7] Therefore, the applied force passing through the prosthetic crown, cement layer, screw, and abutments and forces can be absorbed by these intermediate structures before reaching the supporting bone.[8]

Material selection is a crucial factor when force absorption of the whole system is considered. Recent advances in ceramics and manufacturing technologies have led to different ceramic-implant-abutment-crown combinations.[9,10] Different computer-aided design and computer-aided manufacturing (CAD-CAM) materials with a wide range of moduli of elasticity and various luting protocols have been marketed. However, data about their long-term, clinical performance are lacking, and in vitro force absorption testing may provide an estimation of their damping effects.[11]

Lithium disilicate, zirconium dioxide, and their derivatives have become popular dental ceramics because of their excellent biologic, mechanical, and optical properties.[12] These materials have high fracture resistance and can therefore withstand higher loads; however, they might transfer the applied stresses to the components of the implant complex because of their high stiffness.[13,14]

Materials with mechanical properties closer to those of natural tooth structure have been developed to enhance the reliability of the restorative system.[9,15] Examples include polymer-infiltrated ceramic materials that combine the properties of ceramic and polymer. They consist of a structure with 2 interpenetrating networks of a dominating ceramic and a reinforcing composite resin.[16-19] Another example is polyetheretherketone (PEEK), which is a semicrystalline linear polycyclic aromatic polymer that has been claimed to be a suitable material for dental applications with stress distribution to surrounding tissues because of its low modulus of elasticity, which is close to human bone.[20,21] Although the mechanical properties of materials with lower moduli of elasticity may not reach those of other ceramics or metals, they have been reported to have promising in vitro results for the force absorption and damping effect of applied loads when used for implant-supported restorations.[22-24]

Although providing force damping behavior comparable with that of natural teeth might not be attainable, a favorable combination of crown material and luting agent should have a positive effect on the strength and force absorption capacity of implant-supported restorations.[25,26] However, studies on the force absorption and stress distribution behavior of restorative materials combined with different luting conditions in implant-supported restorations are lacking, suggesting the need for research concerning the potential affecting factors and testing methodologies.[11,13] The null hypothesis in this study was that the force-damping behavior of implant-supported crowns would not be affected by the crown material or the luting agent.

MATERIAL AND METHODS

Titanium implant analogs (N=84) (Implant JD Evolution plus+; JDentalCare S.R.L.) (Ø4×13 mm) were embedded in autopolymerizing nonshrink epoxy resin material (Kemapoxy 150; CMB International) with a surveyor (A3005 Surveyor Type A; Dentalfarm) to ensure an upright position. Titanium inserts (N=84) (Implant JD Evolution plus+; JDentalCare S.R.L.) (3-mm high with 0.5-mm margin thickness) were used to customize the abutments. Each titanium insert was screwed to an implant analog and scanned with a desktop scanner (D/R2000; 3Shape A/S). The design of the abutments and crowns was carried out with a CAD software program (exocad DentalCAD; exocad GmbH) (Fig. 1). Figure 2 shows the standardized outlines of the fabricated abutments and crowns.[27]

The specimens were divided into 4 groups (n=21) as per the crown material: zirconia (Z), PEEK (P), VITA Enamic (V), and e.max (E). Each group was further subdivided into 3 subgroups (n=7) as per the luting agent: none (N), interim cement (I), and adhesive resin cement (R). The crown materials tested are presented in Table 1.

After confirmation of the design, standard tessellation language (STL) files were transferred to the CAM software program for milling of the abutments and crowns with a 5-axis milling machine (CAM 5-S1 milling

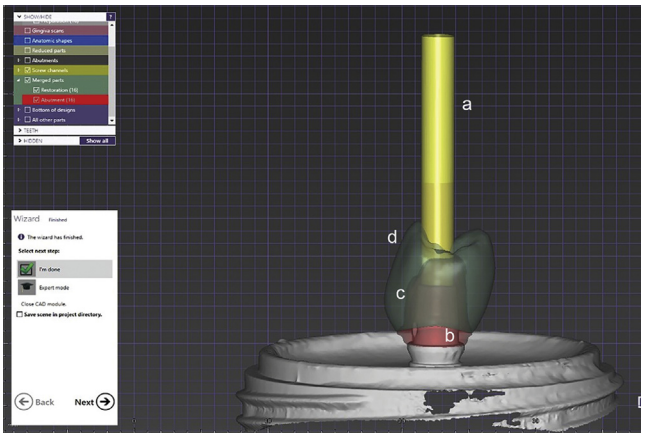


Figure 1. Designing abutment and crown. A, Screw channel. B, Titanium insert. C, Abutment (*red*). D, crown (*green*).

machine; vhf camfacture AG). Zirconia blanks (BruxZir; Prismatik Dentalcraft Inc) were used to fabricate the abutments and crowns of group Z; lithium disilicate blocks (IPS e.max CAD; Ivoclar Vivadent AG) for group E crowns; polymer-infiltrated ceramics blocks (VITA ENAMIC; VITA Zahnfabrik) for group V crowns; and PEEK white blanks (breCAM.BioHPP; Bredent GmbH & Co KG) for group P crowns.

After milling, all abutments and crowns were processed as per the manufacturers' recommendations. The zirconia abutments and crowns were sintered (1350 °C–1500 °C) for approximately 90 minutes in a high-temperature furnace (inFire HTC speed furnace; Dentsply Sirona). The e.max crowns were crystallized in a ceramics furnace (Programat CS4; Ivoclar Vivadent AG) at 840 °C. The VITA Enamic crowns were polished (VITA ENAMIC Polishing Set; VITA Zahnfabrik). For the PEEK crowns, the surfaces to be veneered were airborne-particle abraded with 50-μm Al_2O_3 particles for 15 seconds at a pressure of 0.25 MPa perpendicular to the bonding surface at a 10-mm distance by an airborne-particle abrasion unit (Basic Classic; Renfert). This was followed by the application of a thin, uniform layer of primer (Visio.link primer; bredent GmbH & Co KG) and polymerization for 90 seconds. Veneering resin (Visio.lign; bredent GmbH & Co KG) was applied to PEEK crowns surface and light polymerized for 180 seconds.

Each abutment was seated to its respective titanium insert and each crown was evaluated for proper fit on the corresponding abutment and titanium inserts. For standardization, all surface treatments were performed by the same operator (Table 2). Autopolymerizing resin cement (Multilink Hybrid Abutment; Ivoclar Vivadent AG) was then applied to the titanium insert after sealing the access opening with Teflon tape. Corresponding zirconia abutments were seated with finger pressure for 5 seconds. Excess cement was immediately removed and left to polymerize for 7 minutes under a loading apparatus with a 49-N load.

Each crown from groups ZN, EN, PN, and VN was measured after seating with no cementation to its corresponding zirconia abutment-titanium insert assembly. Each crown from groups ZI, EI, PI, and VI was connected to its zirconia abutment with interim cement (Charm Temp NE; DENTKIST). Surface treatments of the bonding surfaces of the abutments and crowns from groups ZR, ER, PR, and VR were performed as per each material manufacturer's recommendations as described in Table 2, and the crowns were bonded to the zirconia abutments with self-adhesive resin cement (TOTAL-CEM; ITENA). The bonded crowns were exposed to a brief light polymerization for 2 seconds while left under the static load for 5 minutes and then completely polymerized for 20 seconds on each side after the removal of excess cement. Figure 3 shows the assembly ready for testing.

As a reference, 1 implant analog was tested first without a crown. For measurements, all specimens were loaded in a universal testing machine (Model 3365; Instron Corp) with an increasing force (0 to 200 N) applied on the occlusal surface of the crowns, with the loading piston (Ø12-mm steel ball and velocity=1 mm/minute) centered along the long axis of the specimens. The applied load in the universal testing machine was controlled via a computer software program that recorded the load in N. Because universal testing machines are designed to control only the input load applied on the tested specimen, a digital forcemeter (FGC-B digital force gauges; Shimpo instruments) was used to measure the resulting output forces below the assembly to monitor the impact load and record the specimen response to that load. A special mechanical attachment was designed and manufactured to properly align the forcemeter with the assembly in the universal testing machine. For data acquisition, to draw a synchronized force curve presenting the specimen response recorded by the forcemeter, the data were video recorded instantly by using a mobile phone camera fixed in front of the forcemeter. An image processing technique called 7-segment recognition was then used to recognize the numbers visualized on the forcemeter.[28] The experimental design is shown in Figure 4. To assess the force absorption behavior of the tested specimens, the following data were collected from the previous experimental design; from the software program of the universal testing machine: the curve of applied load [input force] of each specimen against time and the time required by each specimen to reach maximum applied load (200N), and from the forcemeter,

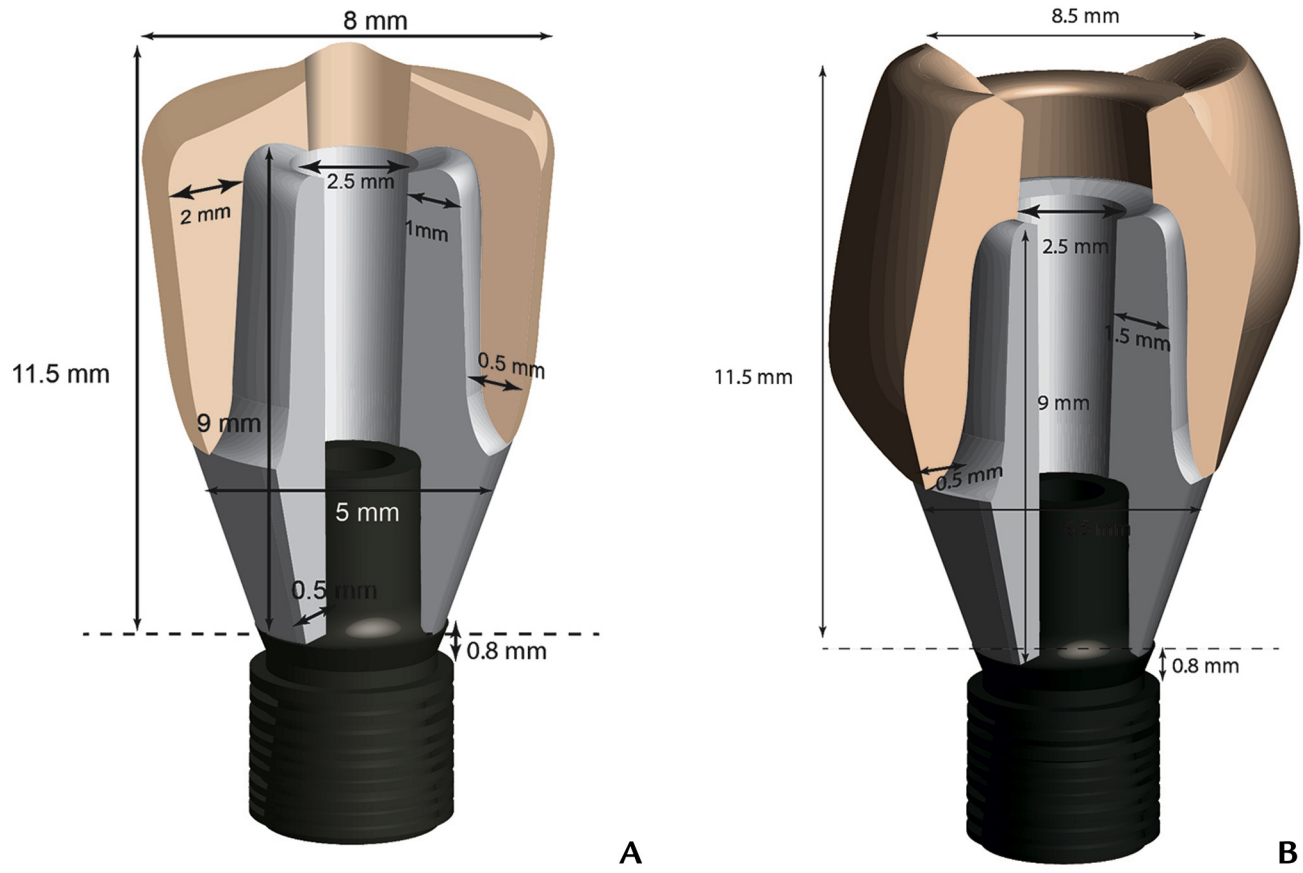


Figure 2. Dimensions of implant abutment and crown. A, Mesiodistal view. B, Buccolingual view.

Table 1. Crown materials tested

Group	Material	Ceramic Type	Manufacturer	Modulus of Elasticity (GPa)
Z	BruxZir zirconia	Zirconium oxide	Prismatik Dentalcraft, Inc	200-210
P	breCAM.BIOHPP	Modified polyetheretherketone	bredent GmbH & Co KG	3.6-4.1
V	VITA Enamic	Polymer infiltrated ceramic	VITA Zahnfabrik	26-30
E	e.max CAD	Lithium disilicate glass ceramic	Ivoclar Vivadent AG	95-100

the curve of the resulting load (output force) measured below the assembly in each specimen against time. Examples of load curves of tested specimens are presented in Figure 5.

The slopes of all curves were calculated automatically by the software program, collected, and analyzed with a statistical software program (IBM SPSS Statistics, v20; IBM Corp). Descriptive statistics were primarily determined for each group. The data normality was assessed by the Kolmogorov-Smirnov and Shapiro-Wilk tests, and the data were assumed to be normally distributed. Two-way multivariate analysis of variance was used to assess the interactions of different materials, and pairwise comparisons using the Tukey post hoc test (α=.05) were used to assess the different luting agents.

RESULTS

Descriptive statistics (mean ±standard deviation) of force absorption behavior of implant-supported crowns represented by the slopes of applied and resulting force curves measured in degrees and the time to reach maximum load measured in seconds for different crown materials and different luting agents are presented in Table 3. The curve progression of the applied and resulting forces varied among the investigated crown materials, resulting in differently inclined slopes for each material, with each luting agent demonstrating statistically significant differences (P<.001). In addition, significant differences were observed in the time required by each material to reach maximum load with each luting agent (P<.001) (Table 3) (Fig. 6).

Table 2. Surface treatments for adhesive cementation of different crowns and components of tested assembly

Component	Surface Treatment
Titanium inserts	Airborne-particle abrasion with 50-μm Al_2O_3 at 0.25 MPa at 10-mm distance, followed by application of primer (Monobond Plus; Ivoclar Vivadent AG) for 60 s
Fitting surface of zirconia abutments	Airborne-particle abrasion with 50-μm Al_2O_3 at 0.1 MPa at 10-mm distance, followed by application of primer for 60 s
Zirconia abutments and zirconia crowns (ZR) group	Airborne-particle abrasion with 50-μm Al_2O_3 at 0.1 MPa at a 10-mm distance, then conditioned with zirconia primer (Z-Prime Plus; BISCO) and left to react for 60 seconds then dried with stream of oil free air.
e.max crowns (ER) group	Etching of bonding surfaces with 9.5% hydrofluoric acid gel (Porcelain etch; Ultradent Products, Inc) for 20 s. Crowns then rinsed thoroughly for another 60 s, dried, silanized (Porcelain Silane; Ultradent Products, Inc), and left to react for 60 s
VITA Enamic crowns (VR) group	Etching of bonding surfaces with 9.5% hydrofluoric acid gel for 60 s. Crowns then rinsed thoroughly for another 60 s, dried, silanized, and left to react for 60 s
PEEK crowns (PR) group	Airborne-particle abrasion with 50-μm Al_2O_3 at 0.2 MPa at a 10-mm distance, ultrasonically cleaned for 5 min in distilled water, and air-dried

PEEK, polyetheretherketone.

The change in the slopes between the applied and resulting force curves varied among the investigated crown materials with different luting agents (Fig. 7). For the zirconia group Z and the e.max group E, the interim and adhesive cementation of crowns significantly increased slope loss ($P<.001$ for both). For the VITA Enamic group V, the interim and adhesive cementation of crowns also showed increased slope loss ($P=.008$, $P<.001$, respectively). As for the PEEK group P, the adhesive cementation of crowns did not significantly affect slope loss ($P=.993$).

DISCUSSION

The data obtained supported the rejection of the null hypothesis, as there were statistically significant differences in the force-damping behavior of implant-supported crowns for different crown materials and luting agents. The modulus of elasticity describes the relative stiffness or rigidity of a material and therefore is considered a crucial factor in determining how a material behaves when subjected to stress.[17] In the present study, the curve progression of the applied and resulting forces varied among the investigated crown materials with different moduli of elasticity, resulting in differently inclined slopes for each material. In all the tested luting agents, materials with higher moduli of elasticity such as zirconia and e.max crowns (200-210, 95-100 GPa, respectively) showed steeper slopes of the applied and resulting force curves, while materials with lower moduli of elasticity such as VITA Enamic and PEEK crowns (26-30, 3.6-4.1 GPa, respectively) showed less steep slopes of the applied and resulting force curves. In addition, zirconia and e.max crowns reached the maximum forces more rapidly, whereas VITA Enamic and PEEK crowns required more time.

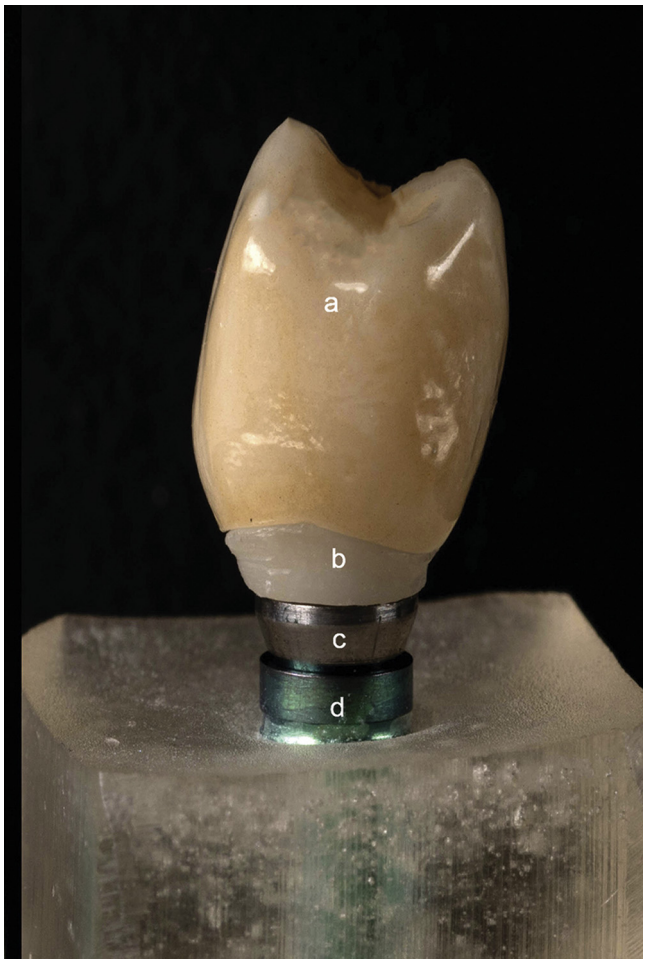


Figure 3. Assembly before testing. A, zirconia crown. B, zirconia custom abutment. C, titanium insert. D, implant analog.

These findings indicate that the more rigid the material the less will be its damping effect on the load transmission to the abutment. This could be explained by Hooke's law,[5] which states that the higher the modulus of elasticity, the lower the deformation in the material and the more likely the forces will be transferred through the crown material directly to the implant. The lower the modulus of elasticity, the higher the deformation in the crown material itself, reducing the forces that will be transferred eventually to the implant. The pattern of the stress distribution behavior of different tested materials in the present study was consistent with that of other in vitro studies.[11,15,24,29]

Possible limitations of the present study included the use of vertical loading, which does not closely simulate the masticatory forces produced in the oral environment. However, measuring only forces on the vertical axis with



Figure 4. A, Experimental design in schematic side view. B, Testing equipment front view.

this force absorption testing methodology might provide a consistent comparison among the tested materials under reproducible conditions and avoiding the inevitable effect of the load direction on stress levels. This suggestion is supported by the results of Yilmaz et al,[26] who concluded that the recently introduced resin-based crown materials behaved similarly to glass ceramics and zirconia when subjected to occlusal loads, resulting in similar amounts of strain on the implant surrounding structures. The authors attributed this finding to the study design where implants were loaded with an angled cyclic loading simulating the functional loading of a dental implant, resulting in increased stresses, regardless of the tested material.[26]

Similarly, lack of consistency in the results from different studies could be attributed not only to different experimental study designs but also to different testing methodologies of the damping behavior of materials

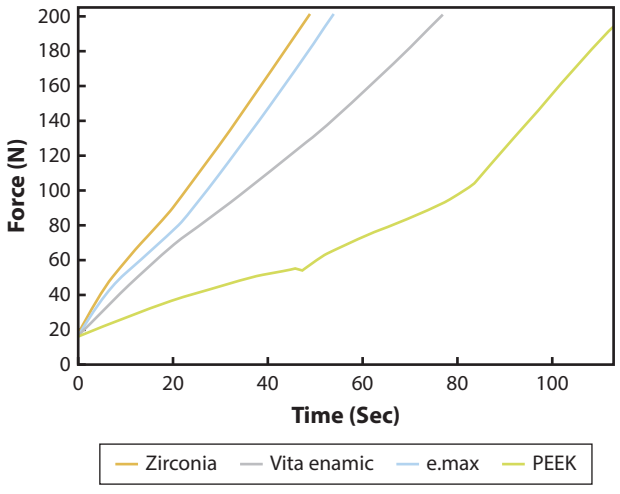


Figure 5. Representative load curves of tested specimens as generated from software program. PEEK, polyetheretherketone.

Table 3. Mean ±standard deviation values of applied and resulting force curves slopes (degrees) and time to reach maximum load (seconds) for different crown materials with different luting agents

	No Cementation			Interim Cementation			Adhesive Resin Cementation		
Material	**A (degrees)**	**R (degrees)**	**Time (s)**	**A (degrees)**	**R (degrees)**	**Time (s)**	**A (degrees)**	**R (degrees)**	**Time (s)**
Z	77.5 ±0.02^{a}	77.5 ±0.03^{a}	34.4 ±0.1^{a}	79.3±0.03^{a}	75.4 ±0.01^{a}	40.8 ±1.8^{a}	78.3 ±0.02^{a}	73.2 ±0.02^{a}	49.8 ±1.1^{a}
P	51.3 ±0.03^{d}	51.1 ±0.01^{d}	71.4 ±2.2^{d}	52.6 ±0.03^{d}	52.2 ±0.1^{d}	73 ±1.4^{c}	52.5 ±0.04^{d}	52.3 ±0.1^{d}	75.8 ±1.3^{d}
V	56.2 ±0.1^{c}	56.2 ±0.1^{c}	56.6 ±0.9^{c}	56.2 ±0.03^{c}	56.1 ±0.02^{c}	54.2 ±1.8^{b}	56.3 ±0.1^{c}	55.9 ±0.04^{c}	62.4 ±0.9^{c}
E	71.8 ±0.04^{b}	71.8 ±0.03^{b}	38.7 ±0.5^{b}	72.03 ±0.03^{b}	70.05 ±0.02^{b}	42.7 ±0.5^{a}	72.08 ±0.3^{b}	70.5 ±0.2^{b}	57 ±1.4^{b}

A, applied force; E, e.max; P, PEEK, R, resulting force; V, VITA Enamic; Z, zirconia. *Different superscript letters indicate significance in each column assessed by Tukey Post Hoc test (α=.05).

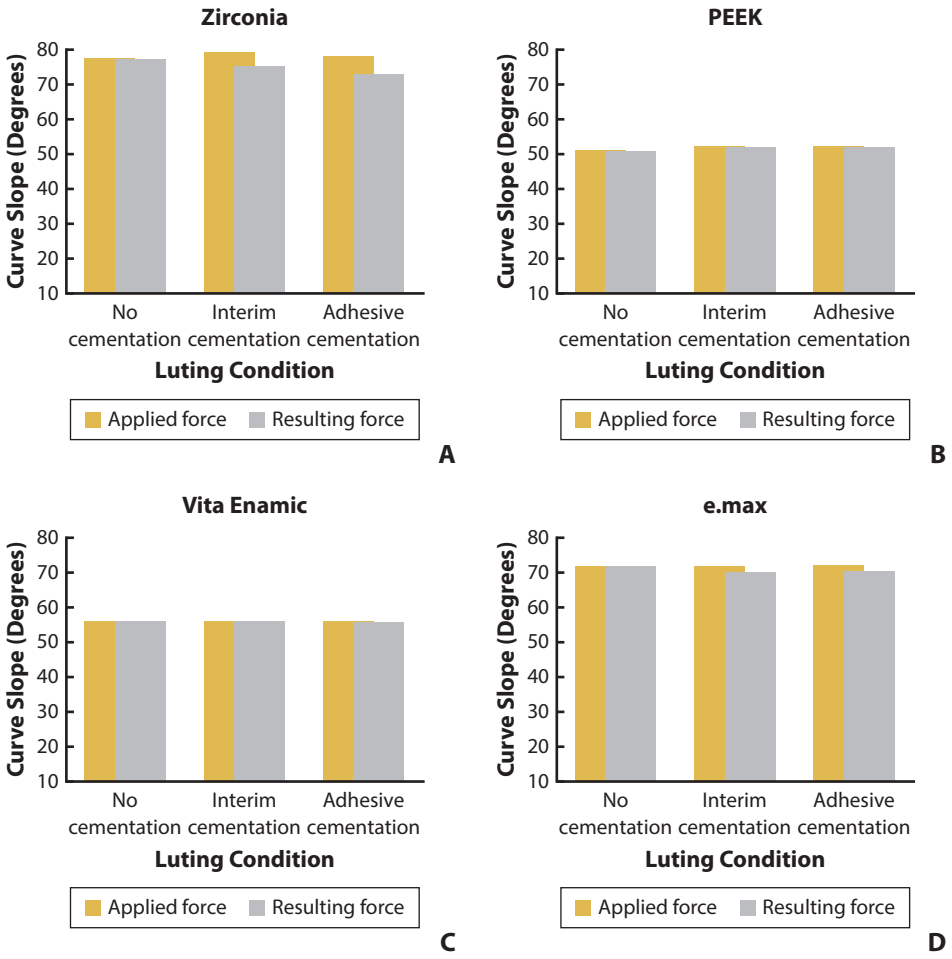


Figure 6. Mean values of applied and resulting force curve slopes for different crown materials with different luting agents. A, zirconia; B, PEEK; C, VITA Enamic; D, e.max. PEEK, polyetheretherketone.

depending on the available armamentarium and the representing factor that will be measured. Examples include percussion probes that measure the energy loss coefficient,[25] strain gauges that measure compressive and tensile strains generated around the implants, and finite element analysis and 3-dimensional digital image correlation that calculate compressive and tensile strains around the implant complex structure.[26] In the present study, the use of a digital forcemeter (gauge) was preferred to compare the amount of dissipated "absorbed" force by different crown materials with different luting agents in a digital pattern with the same unit of applied force in the testing machine (N).

Regarding the effect of luting agents, the results showed that cementation of materials with higher moduli of elasticity such as zirconia and lithium disilicate crowns significantly increased slope loss, indicating enhancement in their force damping behavior, whereas materials with lower moduli of elasticity benefitted less from cementation or adhesion. This could be explained by the fact that part of the energy could be absorbed by the intermediate structures such as the resilient resin

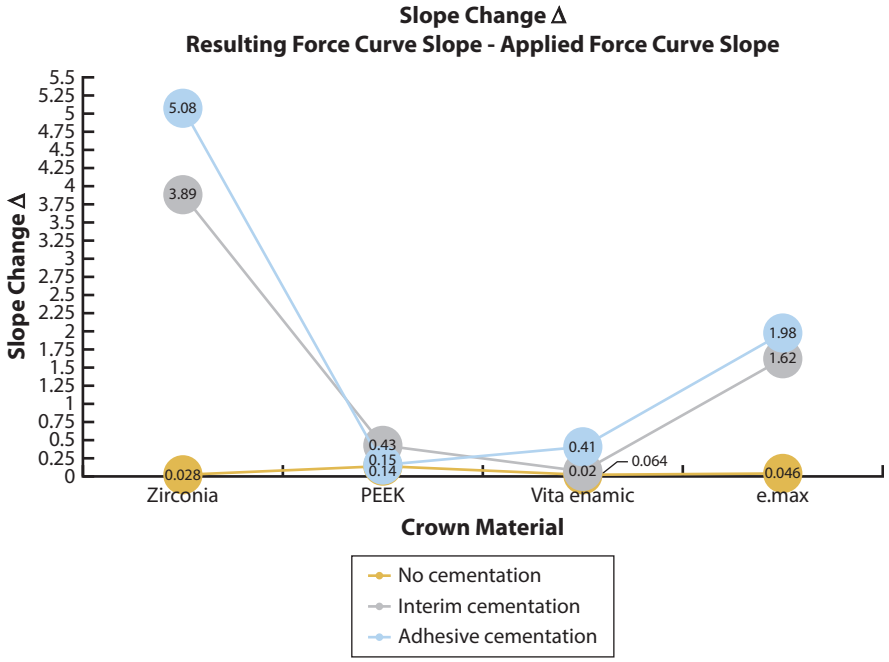


Figure 7. Mean values of slope change Δ (resulting force curve slope - applied force curve slope) for different crown materials with different luting agents. PEEK, polyetheretherketone.

cements (modulus of elasticity 7.7 and 0.2 GPa for resin cement and interim cement, respectively).[30] However, this thin force-absorbing layer will only have an apparent damping effect when the superstructure is of high rigidity, for example, zirconia and lithium disilicate crowns, but when the crown materials and the cement have similar resiliency and behave in the same way, the effect will be negligible, especially with stiff substructure such as zirconia abutments. Nevertheless, adhesive cementation of resin-based crowns will improve their mechanical performance.

Any minor damping effect could help reduce micromovements between the different components of the implant complex, thus minimizing the risk of mechanical complications.[7,11,25] Although this fact might favor the use of the less rigid resin-based materials for implant-supported restorations, their lower mechanical properties might limit their application, especially in the posterior region.[31] Further experimental and clinical studies with multivariate analysis are essential to investigate the effect of different prosthetic materials in the crown-abutment-implant complex on the stress distribution pattern to the peri-implant bone.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Force damping was found to be generally material dependent, yet implant-supported crowns fabricated from resilient materials with low moduli of elasticity such as polymer infiltrated ceramics and PEEK showed better force absorbing behavior than rigid materials such as zirconia and lithium disilicate ceramics.
2. Cementation of rigid crown materials significantly increased slope loss, indicating enhancement in their force damping behavior, whereas less-rigid crown materials benefitted less from cementation or adhesion.

REFERENCES

1. Abou-Obaid AI, Al-Otaibi HN, Akeel RF. Effect of single off-axis implant placement on abutment screw stability under lateral loading. Int J Oral Maxillofac Implants 2016;31:520-6.
2. Pesqueira AA, Goiato MC, Monteiro DR, Santos DM, Haddad MF, Pellizzer EP. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants. J Oral Implantol 2014;40:217-28.
3. Ishigaki S, Nakano T, Yamada S, Nakamura T, Takashima F. Biomechanical stress in bone surrounding an implant under simulated chewing. Clin Oral Implants Res 2003;14:97-102.
4. Koyano K, Esaki D. Occlusion on oral implants: Current clinical guidelines. J Oral Rehabil 2015;42:153-61.
5. Duyck J, Vandamme K. The effect of loading on peri-implant bone: A critical review of the literature. J Oral Rehabil 2014;41:783-94.
6. Sevimay M, Usumez A, Eskitascıoglu G. The influence of various occlusal materials on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite-element study. J Biomed Mater Res B Appl Biomater 2005;73:140-7.
7. Hermann JS, Schoolfield JD, Schenk RK, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged implants in the canine mandible. J Periodontol 2001;72:1372-83.
8. Wang TM, Leu LJ, Wang JS, Lin LD. Effects of prosthesis materials and prosthesis splinting on peri-implant bone stress around implants in poor-quality bone: a numeric analysis. Int J Oral Maxillofac Implants 2002;17:231-7.
9. Taha D, Nour M, Zohdy M, El-Etreby A, Hamdy A, Salah T. The effect of different wax pattern fabrication techniques on the marginal fit of customized lithium disilicate implant abutments. J Prosthodont 2019;28:1018-23.

ARTICLE IN PRESS

10. Mehl C, Gaßling V, Schultz-Langerhans S, Açil Y, Bähr T, Wiltfang J, et al. Influence of four different abutment materials and the adhesive joint of two-piece abutments on cervical implant bone and soft tissue. Int J Oral Maxillofac Implants 2016;31:1264-72.
11. Rosentritt M, Schneider-Feyrer S, Behr M, Preis V. In vitro shock absorption tests on implant-supported crowns: influence of crown materials and luting agents. Int J Oral Maxillofac Implants 2018;33:116-22.
12. Kontonasaki E, Giasimakopoulos P, Rigos AE. Strength and aging resistance of monolithic zirconia: an update to current knowledge. Jpn Dent Sci Rev 2020;56:1-23.
13. de Kok P, Kleverlaan CJ, de Jager N, Kuijs R, Feilzer AJ. Mechanical performance of implant-supported posterior crowns. J Prosthet Dent 2015;114:59-66.
14. Bijjargi S, Chowdhary R. Stress dissipation in the bone through various crown materials of dental implant restoration: A 2-D finite element analysis. J Invest Clin Dent 2013;4:172-7.
15. Gracis S, Thompson VP, Ferencz JL, Silva NR, Bonfante EA. A new classification system for all-ceramic and ceramic-like restorative materials. Int J Prosthodont 2015;28:227-35.
16. Dirxen C, Blunck U, Preissner S. Clinical performance of a new biomimetic double network material. Open Dent J 2013;7:118-22.
17. Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dent Mater 2014;30:564-9.
18. He LH, Swain M. A novel polymer infiltrated ceramic dental material. Dent Mater 2011;27:527-34.
19. Taha D, Spintzyk S, Schille C, Sabet A, Wahsh M, Salah T, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res 2018;62:293-7.
20. Skirbutis G. A review of PEEK polymer's properties and its use in prosthodontics. Stomatologija 2017;19:19-23.
21. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. J Prosthodont Res 2016;60:12-9.
22. Conserva E, Menini M, Tealdo T, Bevilacqua M, Ravera G, Pera F, et al. The use of a masticatory robot to analyze the shock absorption capacity of different restorative materials for prosthetic implants: A preliminary report. Int J Prosthodont 2009;22:53-5.
23. Komine F, Taguchi K, Fushiki R, Kamio S, Iwasaki T, Matsumura H. In vitro comparison of fracture load of implant-supported, zirconia-based, porcelain- and composite-layered restorations after artificial aging. Dent Mater J 2014;33:607-13.
24. Duan Y, Griggs JA. Effect of elasticity on stress distribution in CAD/CAM dental crowns: Glass ceramic vs. polymer-matrix composite. J Dent 2015;43:742-9.
25. Magne P, Silva M, Oderich E, Boff LL, E nciso R. Damping behavior of implant-supported restorations. Clin Oral Implants Res 2013;24:143-8.
26. Yilmaz B, Alsaery A, Altintas SH, Schimmel M. Comparison of strains for new generation CAD-CAM implant-supported crowns under loading. Clin Implant Dent Relat Res 2020;22:397-402.
27. Fuentes FR, Borie E, Bustos ML, Tomas MD. First premolar morphometry: a study in 54 cases. Int J Morph 2011;29:234-9.
28. Shenoy VN, Aalami OO. Utilizing smartphone-based machine learning in medical monitor data collection: seven segment digit recognition. In AMIA Annual Symposium Proceedings. ACI open 2017;2017:1564-70.
29. Bonfante EA, Suzuki M, Lorenzoni FC, Sena LA, Hirata R, Bonfante G, et al. Probability of survival of implant-supported metal ceramic and CAD/CAM resin nanoceramic crowns. Dent Mater 2015;31:168-77.
30. Kaleli N, Sarac D, Külünk S, Öztürk Ö. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone. J Prosthet Dent 2018;119:437-45.
31. Santing HJ, Kleverlaan CJ, Werner A, Feilzer AJ, Raghoebar GM, Meijer HJ. Occlusal wear of provisional implant-supported restorations. Clin Implant Dent Relat Res 2015;17:179-85.

Corresponding author:
Dr Doaa Taha
Department of Fixed Prosthodontics
Faculty of Dentistry, Ain Shams University
Khalifa El-Maamon st, Cairo, 11566
EGYPT
Email: doaataha@asfd.asu.edu.eg

Acknowledgments
The authors thank Dr Ghosoun Mohammed for her contribution in the technical work, and Dr Ahmed Elbanna for his contribution in the study design.

CRediT authorship contribution statement

Doaa Taha: Conceptualization, Methodology, Validation, Formal analysis, Writing - original draft. **Ahmed Sabet:** Investigation, Resources, Writing - review & editing, Supervision.

Copyright © 2021 by the Editorial Council for *The Journal of Prosthetic Dentistry*.
https://doi.org/10.1016/j.prosdent.2021.03.016

View publication stats