Original paper

Strain analysis in posterior implant-supported fixed dental prostheses – cemented compared to screwed: An in vitro study

Sarit Naishlos[1,A,B,D–F], Joseph Nissan[2,A,C–F], Asaf Shely[2,B,D–F], Gil Ben-Izhack[2,A,B,D,F], Liat Chaushu[3,A,B,D,F], Ofir Rosner[2,A,C–F]

[1] Department of Pediatric Dentistry, Tel Aviv University, Israel
[2] Department of Prosthodontics, Tel Aviv University, Israel
[3] Department of Periodontology, Tel Aviv University, Israel

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;
D – writing the article; E – critical revision of the article; F – final approval of the article

Dental and Medical Problems, ISSN 1644-387X (print), ISSN 2300-9020 (online) *Dent Med Probl*. 2026;63(3):685–693

Address for correspondence
Ofir Rosner
E-mail: rosnerop@yahoo.com

Funding sources
None declared

Conflict of interest
None declared

Acknowledgements
The authors wish to express their deepest gratitude to Jared Levy and Jonah Teich for their scientific assistance with theoretical content in the introduction and in the methodology section.

Received on August 10, 2024
Reviewed on September 18, 2024
Accepted on September 20, 2024

Published online on June 30, 2026

Cite as
Naishlos S, Nissan J, Shely A, Ben-Izhack G, Chaushu L, Rosner O. Strain analysis in posterior implant-supported fixed dental prostheses – cemented compared to screwed: An in vitro study. *Dent Med Probl*. 2026;63(3):685–693. doi:10.17219/dmp/193568

DOI
10.17219/dmp/193568

Abstract

Background. Research on the etiology of excessive strain at the implant neck, which may be associated with technical and biological complications, is still lacking.

Objectives. This in vitro study aimed to compare strain development at the implant neck between cement-retained and screw-retained implant-supported fixed restorations, as well as among 3 prosthesis designs, using strain gauge analysis.

Material and methods. Six prosthetic configurations were fabricated and divided according to their retention mechanism: single crowns – cement-retained and screw-retained (SC-c and SC-s, respectively); splinted restorations – cement-retained and screw-retained (SP-c and SP-s, respectively); and simple three-unit bridges – cement-retained and screw-retained (SB-c and SB-s, respectively). Two strain gauges were attached to the implant necks. A vertical load of 200 N was applied simultaneously at 3 identical loading points on each restoration. Strain measurements were analyzed statistically using ANOVA and Scheffé's post hoc contrast analysis.

Results. Cement-retained restorations transferred significantly less cervical strain to the implant neck than screw-retained restorations in all 3 prosthetic configurations tested ($p < 0.001$; SC-c < SC-s; SP-c < SP-s; and SB-c < SB-s). Single crowns transferred significantly less strain to the implant neck than the other restoration designs in both cement-retained and screw-retained groups ($p < 0.001$; SC-c < SP-c and SB-c; SC-s < SP-s and SB-s).

Conclusions. The use of cement-retained implant-supported fixed prostheses results in less strain development at the implant neck when subjected to high occlusal loads as compared to screw-retained prostheses. Splinting the adjacent implant-supported restorations does not necessarily reduce strain at the implant neck.

Keywords: cement retention, screw retention, posterior partial edentulism, strain analysis, three-unit prosthesis

Highlights

- Cement retention reduces buccolingual strain around the implant neck during loading.
- Occlusal loading of 3 single crowns resulted in less strain development around the implant neck as compared to a three-unit bridge and 3 splinted crowns.
- Applying the same occlusal load to 2 implants in a simple bridge, 3 single crowns and 3 splinted crowns did not result in excessive cervical strain in the simple bridge.

Introduction

The consistently favorable long-term survival and success rates of posterior implant-supported fixed prostheses underscore the preference for this highly reliable treatment modality, even when narrow-diameter implants are used.[1,2]

Technical complications and failures continue to drive research into their possible causes, which are generally attributed to biomechanical factors. These imply that the balance between occlusal forces and the durability of the prosthesis, its components, or its interface with the implant has been exceeded.[3–8] This phenomenon is referred to as overload.[5,8]

As occlusal forces increase toward the posterior dentition,[9] more than 70% of occlusal contacts and occlusal forces occur in these regions.[10] Possible overload in the posterior dentition may result even from physiological occlusal forces because of the lower resilience of the implant–bone interface as compared to the tooth–periodontal ligament–bone interface. Stress generated during the masticatory function with implant-supported prostheses is therefore transmitted more directly to the implant and the surrounding bone.[11] Furthermore, the markedly reduced (approx. 8-fold) tactile sensitivity associated with posterior implant-supported fixed prostheses may further contribute to this effect, since neuromuscular biofeedback is absent.[12,13] As previously reported, these 2 additive effects of occlusal loading are concentrated primarily within the cervical region of the loaded implant.[14,15]

Excessive occlusal forces that may lead to overload can occur during parafunctional activities, such as bruxism and clenching.[16] Tooth clenching commonly accompanies bruxism, which affects approx. 28–36% of the adult population.[5,17] During static clenching, the mandible is held against the maxillary dentition in the intercuspal position. In contrast, normal functions involving multiple intercuspal contacts include mastication (at the end of each chewing cycle) and deglutition. During mastication, the occlusal contact lasts for approx. 200 ms, amounting to less than 10 min per day.[18] During swallowing, the mandible is also stabilized in the intercuspal position for an average of approx. ⅔ of a second while generating forces of about 300 N.[18,19] Swallowing occurs around 590 times over a 24-hour period.[20]

During parafunctional activity, individual clenching episodes may last 20–40 s,[21] amounting to nearly 40 min over a single night's sleep and generating considerable loads through multiple simultaneous occlusal contacts.[22] Moreover, although tooth grinding predominates during sleep, clenching is more common during wakefulness, further increasing the cumulative duration of clenching.[23,24] These 3 clinical situations – mastication, swallowing and clenching – all involve multiple contacts in the intercuspal position, yet they are infrequently simulated in laboratory studies.

Prosthetic design may modify stress distribution within the prosthetic complex, as demonstrated by previous laboratory studies.[25–27] One of the key components of prosthetic design is the choice between cement and screw retention. Each retention modality has its own advantages and limitations, and the selection between the two depends largely on clinician preference. Regarding implant and restoration survival, no significant differences between the two retention methods have been reported.[28] The prevailing belief regarding the maintenance of fixed prostheses is that screw-retained restorations are primarily associated with technical complications, whereas cement-retained crowns are more prone to biological complications.[29] The limited retrievability of cement-retained restorations as compared to screw-retained restorations has been a concern; however, current evidence suggests that newer cement-retention designs offer improved retrieval techniques.[30]

Recently, screw-retained restorations have gained popularity due to their inherent advantages, including retrievability, the elimination of cementation procedures, and the widespread adoption of digital workflows that simplify impression procedures.[31,32] However, recent clinical studies have reported increased biological complications, such as crestal bone loss around these restorations, in both short- and long-term follow-up periods.[33,34] This is in addition to the previously reported higher rate of technical complications, primarily related to screw loosening and porcelain chipping.[29,35] In contrast, in vitro studies have reported different findings regarding the crestal bone region surrounding implants, with outcomes associated with parameters such as the welding technique, the framework material and the engagement modality, which may reduce stress development in the crestal bone area.[36]

Since the primary cause of technical complications is occlusal overload, direct stress and strain measurements within implants should be obtained using strain gauge analysis. This approach enables the assessment of the actual strain generated within implants and the surrounding tissues under loading conditions, without relying on intermediate or theoretical modeling.[37]

Considering the above, when exposed to comparable occlusal loads, the stress distribution patterns within implants supporting cement-retained and screw-retained posterior three-unit fixed partial dentures (FPDs) with different prosthetic configurations should be investigated.

The purpose of this study was to compare implant-supported cement-retained restorations with their screw-retained counterparts, using strain gauge analysis across 3 common partial prosthesis designs. The 1st working hypothesis was that there would be differences among the tested configurations with regard to strain registration. The 2nd hypothesis was that the retention mechanism would not influence strain development in the cervical region of the implant.

Material and methods

This in vitro strain gauge study was performed in one of the laboratories of Vishay Precision Group Corporation (Vishay Measurements Group, Raleigh, USA) to compare 3 posterior designs of cement-retained restorations with their screw-retained counterparts under simulated occlusal loading. Owing to its in vitro design, ethical approval was not required.

Test model preparation

A resin block (PLM-4B; Vishay Measurements Group, Raleigh, USA), measuring 15.8 × 35.4 × 32 mm (Cat. No. S-116H) and exhibiting an elastic modulus similar to that of human bone (2.8 GPa), was used. Three screw-shaped, SLA (sand-blasted, large-grit, acid-etched)-coated, internal-hex implants (MIS Seven; M.I.S. Implant Technology, Bar Lev Industrial Area, Israel), each measuring 3.75 mm in diameter and 13 mm in length, were inserted into the block. The implants were fabricated from Grade V titanium (Ti-6Al-4V; density: 4.4 g/cm^3; elastic modulus: 113 GPa). The implant necks protruded 2 mm above the model surface and were positioned 6 mm apart in a straight line. Open-tray impression copings (Grade V titanium: Ti-6Al-4V; density: 4.4 g/cm^3; elastic modulus: 113 GPa) were secured to the implants and splinted with acrylic resin (DuraLay; Reliance Dental Manufacturing Co., Alsip, USA) to enhance stability and impression accuracy. An implant-level impression was made using a polyether-based impression material (Impregum; 3M ESPE, Seefeld, Germany) and a custom-made acrylic resin tray, after which a working cast was poured. Three cement-retained abutments and three conical screw-retained abutments, all fabricated from Grade V titanium (Ti-6Al-4V; density: 4.4 g/cm^3; elastic modulus: 113 GPa), were connected to the implant analogs, using a controlled tightening torque of 20 N·m.

Fabrication of prostheses

Six cast base-metal fixed prostheses, including cement-retained and screw-retained designs, were fabricated from a Co-Cr-Mo alloy (Remanium GM380; Dentaurum, Ispringen, Germany; composition: Co – 64.5%; Cr – 29.0%; Mo – 4.5%; Mn, C and Si – <2%; density: 8.2 g/cm^3; elastic modulus: 220 GPa). All frameworks were fabricated to identical vertical, buccolingual and mesiodistal dimensions, using a silicone index for standardization. Investment, casting, spruing, and framework finishing procedures were standardized and performed in a single dental laboratory, which fabricated all 6 framework configurations. Framework fit was verified using a low-viscosity silicone material by a single operator (O.R.).

The prosthetic configurations were divided into 3 groups (Fig. 1):

- 3 separate cement-retained single crowns and 3 separate screw-retained single crowns (SC-c and SC-s, respectively);
- 2 three-unit FPDs with a central pontic supported by the 2 adjacent abutments, fabricated as either cement-retained or screw-retained restorations (SB-c and SB-s, respectively); and
- 3 splinted cement-retained crowns and 3 splinted screw-retained crowns (SP-c and SP-s, respectively).

After the fabrication of all 6 restorations (3 cement-retained: SC-c, SB-c and SP-c; and 3 screw-retained: SC-s, SB-s and SP-s), the corresponding abutments were connected to the implants according to the planned prosthetic configuration, using a tightening torque of 20 N·m. Ten minutes after initial tightening, all abutment screws were retightened at 20 N·m. For the SB configurations, the central abutment was removed to accommodate the pontic design.

Fig. 1. Six implant-supported fixed assemblies – 3 cement-retained on the right and 3 screw-retained on the left

Temporary cement (TempBond NE; Kerr Dental, Brea, USA) was used for all cement-retained restorations. All abutments and screw-retained restorations were installed, and all cement-retained restorations were cemented by a single investigator (G.B.I.). The cement-retained restorations were initially seated with light finger pressure, followed by the application of a pressure of 5 kg/cm^3 for 4 min, using a Lutron FG-20KG device (Lutron Electronics, Coppersburg, USA).

Strain registration

Two strain gauges (EA-06-015EH-120; Vishay Measurements Group) were attached horizontally to the neck of each implant on opposite surfaces (buccal and lingual) before abutment and crown placement. All strain gauges were bonded using a designated adhesive (M-Bond 200; Vishay Measurements Group), as shown in Fig. 2. During load application to the restorations, the changes in electrical resistance recorded by the strain gauges were used to determine the absolute strain values generated within the implant necks. This location was selected, as it has been shown to experience the highest strain concentrations during loading of implant-supported restorations.[14,15]

The strain gauge terminals were connected to a wiring adapter interface via soldered leads (134 DFV; Vishay Measurements Group). The interface was then connected to an electronic data scanner (Strain Gauge Scanner, model 5100; Instruments Division, Vishay Measurements Group), which communicated with a notebook computer through a designated interface card mounted in the docking station.

Load application

The 3 common posterior three-unit restoration designs, in both cement-retained and screw-retained configurations, were evaluated under 3 simultaneous occlusal loading points, and the resulting strain distribution within the implant necks was recorded. This experimental setup was designed to simulate oral conditions, in which full posterior intercuspation occurs during clenching, mastication and deglutition.

A custom-made loading device was fabricated to apply a vertical load of 200 N to each of the 6 restoration assemblies through 3 individual loading pins positioned in the central fossae of the restorations. The loading points were identical for all prosthetic configurations (Fig. 3).

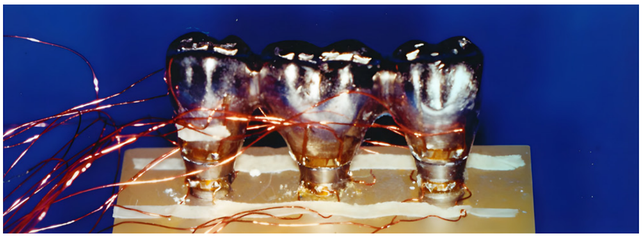

Fig. 2. Strain gauges attached to the experimental model

Fig. 3. Loading device with the test model

Each loading pin was individually adjusted using a tightening screw and 8-µm-thick articulating paper until the paper was ruptured. The loading device was then calibrated to zero, after which the load was gradually increased to 200 N. Each loading cycle lasted 20 s, followed by a 10-second unloading interval. Each prosthetic configuration was tested 3 times. After each testing session and exchange of the prosthetic configuration, the loading pins were recalibrated before the subsequent measurements.

For each loading session, strain measurements were recorded. The deformation detected by the strain gauges was expressed in microstrain (µε) according to the following equation:

$$\varepsilon = \frac{\Delta L}{L} = \frac{\Delta R}{R}$$

where:

ε – strain;

ΔL – change in the strain gauge length [mm];

L – initial strain gauge length [mm];

ΔR – change in the electrical resistance of the strain gauge [Ω]; and

R – initial electrical resistance specified by the manufacturer [Ω].

Although strain measurements may represent either compression or tension, the primary outcome measure was the absolute strain value, calculated as the sum of both components and expressed in microstrain (με) values for statistical analysis. All strain measurements were recorded by a single investigator (A.S.).

Statistical analysis

The groups were compared using one-way parametric analysis of variance (ANOVA). A *p*-value <0.05 was considered statistically significant. Specifically, variance analysis was performed to evaluate differences in strain distribution among the different prosthetic configurations under loading conditions. Additionally, differences among the results obtained from loading the various prosthetic configurations were assessed using Scheffé's contrast analysis. Statistical analyses were performed using IBM SPSS Statistics for Windows, v. 24 (IBM Corp., Armonk, USA).

Table 1. Strain under load at the implant neck with regard to the 2 retention mechanisms and the 3 restoration types used

Strain gauge	Restoration type	Cement retention	Screw retention	F(p)†
1	SC	162.64 ±69.41 t	886.33 ±121.68 t	400.26*
	SB	1,736.71 ±100.58 t	4,154.47 ±69.95 t	5,841.69*
	SP	1,884.40 ±59.62 t	2,130.55 ±177.08 t	26.03*
F(*p*) contrasts‡		SP > SB > SC 2,216.43*	SB > SP > SC 2,397.84*	–
2	SC	10.27 ±1.62 t	572.66 ±49.98 c	1,897.21*
	SB	47.33 ±1.39 c	505.93 ±6.95 c	62,711.94*
	SP	48.40 ±4.86 c	384.20 ±1.93 c	61,666.52*
F(*p*) contrasts‡		SP,SB > SC 750.42*	SC > SB > SP 161.14*	–
3	SC	48.53 ±2.66 c	9.13 ±2.47 c	1,757.70*
	SB	–	–	–
	SP	31.13 ±59.62 c	32.66 ±2.79 c	3.76
F(*p*) contrasts‡		SP > SC 523.43*	SP > SC 596.21*	–
4	SC	529.20 ±4.21 c	946.33 ±82.35 c	383.78*
	SB	–	–	–
	SP	965.01 ±19.28 c	1,209.86 ±64.89 c	195.70*
F(*p*) contrasts‡		SP > SC 7,321.57*	SP > SC 94.75*	–
5	SC	117.13 ±3.96 c	150.86 ±13.16 c	90.33*
	SB	349.86 ±2.06 c	374.73 ±64.42 c	2.23
	SP	233.60 ±4.01 c	105.86 ±2.74 t	10,341.01*
F(*p*) contrasts‡		SB > SP > SC 16,890.75*	SB > SC > SP 215.53*	–
6	SC	121.00 ±7.20 c	159.53 ±16.16 c	71.13*
	SB	114.40 ±5.59 c	229.13 ±33.91 c	167.12*
	SP	186.00 ±11.77 c	334.00 ±4.69 c	2,044.37*
F(*p*) contrasts‡		SP > SC,SB 317.64*	SP > SB > SC 242.12*	–

Data presented as mean ± standard deviation (*M* ±*SD*).
SC – single crowns; SB – three-unit -bridges; SP – splinted restorations; c – compression; t – tension; † differences between cement- and screw-retained restorations; ‡ differences among the 3 types of restorations; * statistically significant ($p < 0.001$; ANOVA).

Results

Comparing retention mechanisms

The ANOVA was performed separately for each of the 3 restoration types – single crowns (SC), splinted restorations (SP) and the three-unit bridge design (SB) – to ascertain differences between the 2 retention mechanisms used (cement and screw retention). Strain gauge recordings were obtained from all 6 registration points located on the implants. The means (*M*), standard deviations (*SD*), and *F*-values of these recordings are presented in Table 1.

Significant differences were found between cement- and screw-retained restorations in all 3 restoration types, with cemented restorations generating less strain. In the SC configuration, all but one strain gauge exhibited less strain with cemented restorations (strain gauge no. 3). This trend was repeated in the SP assembly, where all strain gauges except for no. 5 exhibited significantly less strain with cemented restorations.

When the strain gauge recordings were combined at the implant level, as presented in Table 2, the overall strain pattern became even more apparent. Each implant exhibited greater strain under screw-retained restorations than under cemented restorations. These differences were well beyond the accepted level of significance for all implants and across all prosthetic configurations ($p < 0.001$). Therefore, the 2nd hypothesis was rejected, as substantially less strain was recorded for cemented restorations than for screw-retained restorations, regardless of the restoration design.

Table 2. Comparison of the strain values on each of the 3 implants according to the retention mechanism and the restoration type

Implant	Restoration type	Cement retention	Screw retention	F(p)†
Right	SC	86.45 ±34.81	729.49 ±52.61	1,558.19*
	SB	892.02 ±50.22	2,330.20 ±36.30	8,078.34*
	SP	966.40 ±30.09	1,257.37 ±88.50	145.32*
F(*p*) contrasts‡		SP > SB > SC 2,309.28*	SB > SP > SC 2,511.63*	–
Middle	SC	288.86 ±3.06	477.73 ±40.82	319.28*
	SB	–	–	–
	SP	498.23 ±9.66	621.26 ±33.43	187.43*
F(*p*) contrasts‡		SP > SC 6,391.77*	SP > SC 110.98*	–
Left	SC	119.07 ±2.87	155.20 ±9.66	192.69*
	SB	323.12 ±3.59	301.93 ±27.94	92.09*
	SP	31.13 ±59.62	32.66 ±2.79	27.79*
F(*p*) contrasts‡		SB > SC > SP 2,244.37*	SB > SC > SP 276.92*	–

Data presented as *M* ±*SD*.
† differences between cement- and screw-retained restorations;
‡ differences among the 3 types of restorations; * statistically significant ($p < 0.001$; ANOVA).

Comparing restoration types

Significant overall differences were observed among the 3 restoration types for both cement- and screw-retained designs ($p < 0.001$). The strain gauge data showed that single restorations generated the least strain as compared to the bridge and splinted crown configurations, regardless of the retention mechanism (Tables 1 and 2). Therefore, the 1st hypothesis was accepted, corroborating the findings of previous studies.[25,27]

Discussion

Parallel laboratory reports using multiple simultaneous occlusal contacts to simulate static clenching, chewing and swallowing are rare.[18,38] As noted in previous scoping reviews,[37,39] most in vitro studies evaluate simulated occlusal loading using a single loading point. Consequently, there are few comparable studies against which to evaluate our findings, apart from related publications from our own research group, owing to our unique methodological design.

The present study confirmed the 1st working hypothesis. Our findings revealed that 3 separate crowns yielded the most favorable strain distribution in both cement- and screw-retained configurations. These results are supported by previous theoretical models.[7,40] A previous finite element analysis (FEA) reached similar conclusions, demonstrating that 3 separate screw-retained crowns generated less strain than a three-unit bridge; at the level of the implant neck, 3 separate crowns produced the least strain, as did the abutment and the prosthetic screw.[41]

Disregarding the differences in our use of screw-retained prostheses and the additional restorative designs evaluated, more comprehensive reports have documented comparable findings. A recent in vitro study examined stress distribution among various cement-retained prosthetic configurations, using strain gauge analysis and the same loading protocol as the present study.[25] Regarding three-unit prostheses, the lowest strain was observed with 3 separate crowns, consistent with our findings. A simple bridge and a three-unit splint also registered significantly higher strain, as observed in the present study.[25] Similar strain gauge results for cement-retained prostheses were reported by Nissan et al. in an in vitro study, which also favored 3 separate units over a three-unit splint.[27] Another strain gauge analysis employed three-point loading on 3 screw-retained prosthetic designs.[42] Unlike the screw-retained assemblies in the present study, a simple 3-unit bridge generated the least strain at both the prosthesis level and the bone crest model as compared to a three-unit cantilever bridge. No strain gauges were placed at the implant neck, and a proximal contact point was present, both of which may have contributed to the differences between those findings and the results reported here.[42]

The 2nd working hypothesis was rejected, as the comparison of the 2 retention modes demonstrated that the cement-retained modality was significantly more favorable, with less cervical strain recorded at the implant level. Guichet et al. reported that cement-retained restorations distributed occlusal loads more evenly to the abutments because of the cushioning effect provided by the cement layer.[43] A comparative in vitro study evaluating the probability of surviving cyclic loading for cement-retained vs. screw-retained three-unit bridges found that cement-retained prostheses had a higher probability of survival than screw-retained prostheses, regardless of the implant–abutment interface.[44] Another study, using FEA, compared the biomechanical performance of the 2 retention designs.[45] The results indicated that screw-retained prostheses exhibited a higher biomechanical risk of failure at the abutment fixation screw, which was more prone to loosening or fracture.[45]

Fracture resistance has also been compared in vitro between cement- and screw-retained prostheses. Two studies demonstrated the superiority of cement retention for both five-unit and three-unit prostheses.[46,47] Gaur, comparing the strain patterns of cement-retained and screw-retained prostheses, found that under vertical loading, cement-retained prostheses generated less strain in the cervical region of the implants.[48] In that study, 2 point loads were applied to the pontics of a five-unit bridge supported by a pier abutment. Complementing our findings, the bridges were supported by 3 implants, each instrumented with 2 strain gauges placed on the mesial and distal aspects, and, as in the present study, exhibited lower overall strain with cement retention.[48]

Strain concentration within the implant neck warrants the analysis of the adjacent bone, which intimately surrounds this region. Two clinical reviews and a leading textbook in periodontology reported evidence linking cement retention with reduced crestal bone loss as compared to screw retention.[29,33,34] The structural superiority of cement-retained prostheses is well accepted.[29,42] Establishing a mechanical etiology that may contribute to peri-implant crestal bone loss is of primary importance for both understanding and managing peri-implantitis. Although this research is laboratory-based, it attempts to provide a theoretical adjunctive mechanism contributing to crestal bone loss.

An experimental setting that directly reflects strain development within the cervical region of a bone-level implant is not feasible through strain gauge analysis, as there is no space for strain gauge placement when implants are submerged within a bone substitute. The resorption of the bone surrounding implants in the crestal region is primarily considered a biofilm-mediated infectious and inflammatory process, sharing considerable similarities with the etiology and clinical characteristics of periodontitis. This premise has been described in several reviews and textbooks.[49–51] According to some authors, occlusal overload is not considered an initiating factor in peri-implantitis.[52,53]

Others have described it as an "alternative hypothesis for the cause of peri-implantitis",[50] implying a limited cause-and-effect relationship between occlusal overload and disease development. Conversely, other researchers maintain that, in addition to microbial involvement in the initiation of peri-implantitis, occlusal overload may contribute to disease progression and the exacerbation of crestal bone loss.[8,54,55] The present laboratory model may, theoretically, reveal additional mechanical factors that contribute to the initiation and possible progression of crestal bone loss in conjunction with bacterial colonization.

Limitations

Limitations of this in vitro research include the assessment of strain only along the buccolingual axis and the acquisition of data from areas in close proximity to the strain gauges, without information from more distant regions. Anteroposterior strains remain unknown, and their inclusion in the total strain dataset might influence the primary outcome parameters.

We may assume that anteroposterior strains are considerably smaller than buccolingual strains, as previously reported[56]; however, this cannot be regarded as evidence until this relationship has been thoroughly examined. The forces applied in our experiment were purely vertical and do not represent the average direction of physiological occlusal forces, which are predominantly three-dimensionally oblique.[57] Our study evaluated the various prosthetic assemblies in a "stand-alone" setting, without interproximal contacts on either side, and therefore does not fully represent clinical stress dissipation in the presence of the adjacent units. The sample size was small, and the insertion torque during the installation of abutments and screw-retained crowns remained constant, and was not compared with higher torque values exceeding 20 N·m.

For future research, a more clinically relevant setting should be considered, including the presence of neighboring teeth with interproximal contacts, thereby influencing strain magnitude through the integrity of the dental arch. Higher insertion torque values should also be examined to evaluate their impact on the same primary outcome parameters. The use of contemporary materials, such as all-ceramic prostheses and abutments fabricated from high-performance polymers, should be considered due to their reported potential influence in reducing peri-implant bone strain.[58]

Conclusions

Within the limitations of this in vitro study and based on its results, cementing posterior implant-supported prostheses may be considered as a modality for reducing strain at the implant neck in comparison with screw-retained restorations. Prosthetic design influences stress distribution within posterior three-unit implant-supported restorations, with 3 separate crowns demonstrating the lowest inherent strain.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets supporting the findings of the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Use of AI and AI-assisted technologies

Not applicable.

ORCID iDs

Sarit Naishlos https://orcid.org/0000-0002-2920-7000
Joseph Nissan https://orcid.org/0000-0001-7290-4357
Asaf Shely https://orcid.org/0000-0003-3436-4411
Gil Ben-Izhack https://orcid.org/0000-0001-5482-0264
Liat Chaushu https://orcid.org/0000-0002-5755-7526
Ofir Rosner https://orcid.org/0009-0006-3693-3648

References

1. Pjetursson BE, Sailer I, Merino-Higuera E, Spies BC, Burkhardt F, Karasan D. Systematic review evaluating the influence of the prosthetic material and prosthetic design on the clinical outcomes of implant-supported multi-unit fixed dental prosthesis in the posterior area. *Clin Oral Implant Res*. 2023;34(S26):86–103. doi:10.1111/clr.14103
2. Alshiddi IF. Survival rate and clinico-radiographic parameters around narrow-diameter dental implants for fixed dental prostheses in the posterior regions: A systematic review. *Dent Med Probl*. 2023;60(2):345–353. doi:10.17219/dmp/140757
3. Chochlidakis K, Fraser D, Lampraki E, et al. Prostheses survival rates and prosthetic complications of implant-supported fixed dental prostheses in partially edentulous patients. *J Prosthodont*. 2020:29(6):479–488. doi:10.1111/jopr.13185
4. Yi YJ, Lee JY, Kim YK. Comparative clinical study of three-unit fixed partial prostheses supported by two or three implants. *Int J Oral Maxillofac Implants*. 2013;28(4);1110–1115. doi:10.11607/jomi.2940
5. Sadowsky SJ. Occlusal overload with dental implants: A review. *Int J Implant Dent*. 2019:5(1):29. doi:10.1186/s40729-019-0180-8
6. Rangert B, Krogh PH, Langer B, Van Roekel N. Bending overload and implant fracture: A retrospective clinical analysis. *Int J Oral Maxillofac Implants*. 1995;10(3):326–334. PMID:7615329.
7. Skalak R. Biomechanical considerations in osseointegrated prostheses. *J Prosthet Dent*. 1983;49(6):843–848. doi:10.1016/0022-3913(83)90361-x
8. Naveau A, Shinmyouzu K, Moore C, Avivi-Arber L, Jokerst J, Koka S. Etiology and measurement of peri-implant crestal bone loss (CBL). *J Clin Med*. 2019;8(2):166–186. doi:10.3390/jcm8020166
9. Ferrario VF, Sforza C, Serrao G, Dellavia C Tartaglia GM. Single tooth bite forces in healthy young adults. *J Oral Rehab*. 2004;31(1):18–22. doi:10.1046/j.0305-182x.2003.01179.x
10. Turkistani KA, Alkayya MA, Abbasy MA, et al. Comparison of occlusal bite force distribution in subjects with different occlusal characteristics. *Cranio*. 2023;41(3):204–211. doi:10.1080/08869634.2020.1830662

11. Sahin S¸ Cehreli MC, Yalçin E. The influence of functional forces on the biomechanics of implant-supported prostheses – a review. *J Dent*. 2002;30(7–8):271–282. doi:10.1016/s0300-5712(02)00065-9
12. Hämmerle CH, Wagner D, Brägger U, et al. Threshold of tactile sensitivity perceived with dental endosseous implants and natural teeth. *Clin Oral Implants Res*. 1995;6(2):83–90. doi:10.1034/j.1600-0501.1995.060203.x
13. Richter EJ. In vivo vertical forces on implants. *Int J Oral Maxillofac Implants*. 1995;10(1):99–108. PMID:7615323.
14. Misch CE, Suzuki JB, Misch-Dietsh FM, Bidez MW. A positive correlation between occlusal trauma and peri-implant bone loss: Literature support. *Implant Dent*. 2005;14(2):108–116. doi:10.1097/01.id.0000165033.34294.db
15. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: A three-dimensional finite element analysis. *J Prosthet Dent*. 2008;100(6):422–431. doi:10.1016/S0022-3913(08)60259-0
16. Alkan A, Bulut E, Arici S, Sato S. Evaluation of treatments in patients with nocturnal bruxism on bite force and occlusal contact area: A preliminary report. *Eur J Dent*. 2008;2(4):276–282. doi:10.1055/s-0039-1697392
17. Wetselaar P, Vermaire EJ, Lobbezoo F, Schuller AA. The prevalence of awake bruxism and sleep bruxism in the Dutch adult population. *J Oral Rehabil*. 2019;46(7):617–623. doi:10.1111/joor.12787
18. Okeson JP, ed. *Management of Temporomandibular Disorders and Occlusion*. 8th ed. St. Louis, MI: Mosby/Elsevier; 2020:31–35.
19. Pameijer JH, Brion M, Glickman I, Roeber FW. Intraoral occlusal telemetry. IV. Tooth contact during swallowing. *J Prosthet Dent*. 1970;24(4):396–400. doi:10.1016/0022-3913(70)90080-6
20. Flanagan JB. The 24-hour swallowing in man. *J Dent Res*. 1963;42:1072.
21. Kydd WL, Daly C. Duration of nocturnal tooth contacts during bruxing. *J Prosthet Dent*. 1985;53(5):717–721. doi:10.1016/0022-3913(85)90031-9
22. Trenouth MJ. The relationship between bruxism and temporomandibular joint dysfunction as shown by computer analysis of nocturnal tooth contact patterns. *J Oral Rehabil*. 1979;6(1):81–87. doi:10.1111/j.1365-2842.1979.tb00408.x
23. Rompré PH, Daigle-Landry D, Guitard F, Montplaisir JY, Lavigne GJ. Identification of a sleep bruxism subgroup with a higher risk of pain. *J Dent Res*. 2007;86(9):837–842. doi:10.1177/154405910708600906
24. Carra MC, Huynh N, Morton P, et al. Prevalence and risk factors of sleep bruxism and wake-time tooth clenching in a 7- to 17-yr-old population. *Eur J Oral Sci*. 2011;119(5):386–394. doi:10.1111/j.1600-0722.2011.00846.x
25. Ghelfan O, Nissan J, Shely A, et al. Analysis of strain distribution in common clinical designs of posterior implant-supported fixed partial restorations: Comparison between six configurations. *J Funct Biomater*. 2024;15(2):47. doi:10.3390/jfb15020047
26. Kim WD, Jacobson Z, Nathanson D. In vitro stress analyses of dental implants supporting screw-retained and cement-retained prostheses. *Implant Dent*. 1999;8(2):141–151. PMID:10635156
27. Nissan J, Ghelfan O, Gross M, Chaushu G. Analysis of load transfer and stress distribution by splinted and unsplinted implant-supported fixed cemented restorations. *J Oral Rehab*. 2010;37(9):658–662. doi:10.1111/j.1365-2842.2010.02096.x
28. Wittneben JG, Millen C, Brägger U. Clinical performance of screw- versus cement-retained fixed implant-supported reconstructions – a systematic review. *Int J Oral Maxillofac Implants*. 2014;29(Suppl):84–98. doi:10.11607/jomi.2014suppl.g2.1
29. Schoenbaum TR, Klokkevold PR. Prosthetic considerations: Partially edentulous. In: Newman MG, Klokkevold PR, Elangovan S, Kapilla Hernandez YL; Caranzza FA, Takei H, eds. *Newman and Carranza's Clinical Periodontology and Implantology*. 14th ed. St. Louis, MI: Saunders/Elsevier; 2023;890–904.
30. Kamar Affendi NH, Ahmad R, Tong Wah L, Abdul Hamid NF, Abdul Hakim AY. Screw-retrievable cement-retained implant restorations: A scoping review of fracture strength and clinical performance. *Dent Med Probl*. 2024;61(2):257–268. doi:10.17219/dmp/155811
31. Derksen W, Tahmaseb A, Wismeijer D. Randomized clinical trial comparing clinical adjustment times of CAD/CAM screw-retained posterior crowns on Ti-base abutments created with digital or conventional impressions. One-year follow-up. *Clin Oral Implants Res*. 2021;32(8):962–970. doi:10.1111/clr.13790
32. Derksen W, Wismeijer D. Three-year follow-up of a randomized clinical trial on screw-retained monolithic zirconia restorations on Ti-Base abutments based on digital or conventional impression techniques. *Int J Prosthodont*. 2023;36(4):410–415. doi:10.11607/ijp.7891
33. Araujo Lemos CA, De Souza Batista VE, De Faria Almeida DA, Santiago Júnior JF, Verri FR, Pellizzer EP. Evaluation of cement-retained versus screw-retained implant-supported restorations for marginal bone loss: A systematic review and meta-analysis. *J Prosthet Dent*. 2016;115(4):419–427. doi:10.1016/j.prosdent.2015.08.026
34. Strauss FJ, Hämmerle CH, Thoma DS. Short communication: Cemented implant reconstructions are associated with less marginal bone loss than screw-retained reconstructions at 3 and 5 years of loading. *Clin Oral Implants Res*. 2021;32(5):651–656. doi:10.1111/clr.13737
35. Nissan J, Narobai D, Gross O, Ghelfan O, Chaushu G. Long-term outcome of cemented versus screw-retained implant-supported partial restorations. *Int J Oral Maxillofac Implants*. 2011;26(5):1102–1107. PMID:22010095.
36. Tonin BSH, Peixoto RF, Fu J, De Mattos MdGC, Macedo AP. Influence of the frameworks of implant-supported prostheses and implant connections on stress distribution. *Dent Med Probl*. 2023;60(4):551–557. doi:10.17219/dmp/153060
37. Pesqueira AA, Goiato MC, Filho HG, et al. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants. *J Oral Implantol*. 2014;40(2):217–228. doi:10.1563/AAID-JOI-D-11-00066
38. Obara R, Komiyama O, Iida T, De Laat A, Kawara M. Influence of the thickness of silicone registration material as a means for occlusal contact examination – an explorative study with different tooth clenching intensities. *J Oral Rehab*. 2013;40(11):834–843. doi:10.1111/joor.12088
39. Marín-Miranda M, Wintergerst AM, Moreno-Vargas YA, Juárez-López ML, Tavera-Ruiz C. Photoelasticity for stress concentration analysis in dentistry and medicine. *Materials (Basel)*. 2022;15(19):6819. doi:10.3390/ma15196819
40. Brunski JB, Puleo DA, Nanci A. Biomaterials and biomechanics of oral and maxillofacial implants: Current status and future developmnets. *Int J Oral Maxillofac Implants*. 2000;15(1):15–46. PMID:10697938.
41. Silveira MPM, Campaner LM, Bottino MA, Nishioka RS, Borges ALS, Tribst JPM. Influence of the dental implant number and load direction on stress distribution in a 3-unit implant-supported fixed dental prosthesis. *Dent Med Probl*. 2021;58(1):69–74. doi:10.17219/dmp/130847
42. Ahmed MAM, Hamdy AM, Fattah GA, Effadl AKA. Prosthetic design and restorative material effect on the biomechanical behaviour of dental implants: Strain gauge analysis. *Braz Dent Sci*. 2022;25(3):e3380. doi:10.4322/bds.2022.e3380
43. Guichet DL, Caputo AA, Choi H, Sorensen JA. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. *Int J Oral Maxillofac Implants*. 2000;15(2):239–246. PMID:10795456.
44. Anchieta RB, Machado LS, Hirata R, Bonfante EA, Coelho PG. Platform-switching for cemented versus screwed fixed dental prostheses: Reliability and failure modes: An in vitro study. *Clin Implant Dent Relat Res*. 2016;18(4):830–839. doi:10.1111/cid.12363
45. Silva GC, Cornacchia TM, De Magalhães CS, Bueno AC Moreira AN. Biomechanical evaluation of screw- and cement-retained implant-supported prostheses: A nonlinear finite element analysis. *J Prosthet Dent*. 2014;112 (6):1479–1488. doi:10.1016/j.prosdent.2014.06.010
46. Karl M, Graef F, Taylor TD, Heckmann SM. In vitro effect of load cycling on metal-ceramic cement- and screw-retained implant restorations. *J Prosthet Dent*. 2007;97(3):137–140. doi:10.1016/j.prosdent.2007.01.001
47. Mallmann F, Rosa L, Borba M, Della Bona A. Effect of screw-access hole and mechanical cycling on fracture load of 3-unit implant-supported fixed dental prostheses. *J Prosthet Dent*. 2018;119(1):124–131. doi:10.1016/j.prosdent.2017.01.016
48. Gaur S. Analysis of stress distribution in cement-retained and screw-retained five-unit fixed prostheses supported by three implants: An in vitro study. Rajiv Gandhi University of Health Sciences, Bengaluru, India. ProQuest Dissertations & Theses; 2016.
49. Salvi GE, Cosgarea R, Sculean A. Prevalence and mechanisms of peri-implant diseases. *J Dent Res*. 2017;96(1):31–37. doi:10.1177/0022034516667484

50. Salvi GE, Stähli A, Imber JC, Sculean A, Roccuzzo A. Physiopathology of peri-implant diseases. *Clin Implant Dent Relat Res*. 2023;25(4):629–639. doi:10.1111/cid.13167
51. Lang NP, Berglundh T, Giannobile WV, Sanz M, eds. *Lindhe's Clinical Periodontology and Implant Dentistry*. 7th ed. Hoboken, NJ: Wiley–Blackwell; 2021:318–323.
52. Lee SJ, Alamri O, Cao H, Wang Y, Gallucci GO, Lee JD. Occlusion as a predisposing factor for peri-implant disease: A review article. *Clin Implant Dent Relat Res*. 2023;25(4):734–742. doi:10.1111/cid.13152
53. Duyck J, Vandamme K. The effect of loading on peri-implant bone: A critical review of the literature. *J Oral Rehabil*. 2014;41(10):783–794. doi:10.1111/joor.12195
54. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants. (II). Etiopathogenesis. *Eur J Oral Sci*. 1998;106(3):721–764. doi:10.1046/j.0909-8836..t01-6-.x
55. Di Fiore A, Montagner M, Sivolella S, Stellini E, Yilmaz B, Brunello G. Peri-implant bone loss and overload: A systematic review focusing on occlusal analysis through digital and analogic methods. *J Clin Med*. 2022;11(16):4812. doi:10.3390/jcm11164812
56. Tribst JP, De Oliveira Dal Piva AM, Riquieri H, Nishioka RS, Bottino MA, Rodrigues VA. Monolithic zirconia crown does not increase the peri-implant strain under axial load. *J Int Oral Health*. 2019;11(1):50–53. doi:10.4103/jioh.jioh_307_18
57. Stegaroiu R, Sato T, Kusakari H, Miyakawa O. Influence of restoration type on stress distribution in bone around implants: A three-dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 1998;13(1):82–90. PMID:9509784.
58. El-Mahdy M, Aboelfadl A, Ahmed F, El-Banna A, Wahsh M. Strain gauge analysis and fracture resistance of implant-supported PEKK hybrid abutments restored with two crown materials: An in vitro study. *Dent Med Probl*. 2023;60(3):497–503. doi:10.17219/dmp/170311