The Utility of Implant-Supported Fixed Dental Prosthesis Material for Implant Micromovement and Peri-implant Bone Microstrain: A Study in Rabbit Tibia

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Purpose: To evaluate and compare the effects of two restorative materials with different stiffness on peri-implant bone microstrain and implant micromovements during occlusal loading in implant-supported single and adjacent splinted crowns. Materials and Methods: Two 3 × 10-mm implants were inserted into the tibia of four rabbits. During the osseointegration process, prosthetic restorations were performed. Before suturing the flap, each implant’s position and direction were obtained by fastening two splinted transfer abutments, onto which implant analogs were placed and fastened; the splinted transfer abutments were subsequently unfastened. Splinted transfer abutment/analog complexes were cast using type IV plaster to obtain eight different working models. Two single mandibular premolar crowns of monolithic zirconia and acrylate polymer composite were generated using CAD/CAM technology, and 16 adjacent splinted crowns (eight of each material) with the same design were also generated. After 6 weeks of implant osseointegration, the animals were sacrificed. Tibial sections with the implants were extracted, and prosthetic restorations (performed during implant osseointegration) were fastened to the implants. Static loading tests were performed with 100-N force application and an inclination of 6 degrees over the central fossa of the premolars. Implant micromovement was measured using an image analysis technique. Bone microstrain was quantified using two strain gauges placed on the crestal bone around the implants. Data were analyzed using two-way analysis of variance. Results: The mean implant micromovement values were lower for monolithic zirconia single and splinted crowns (61.5 ± 26.3 µm and 57.7 ± 8.8 µm, respectively) than for acrylate polymer composite-based single and splinted crowns (78.9 ± 37.3 µm and 59.61 ± 11.5 µm, respectively). No significant differences between the materials were noted. Bone microstrain around the implants was lower for splinted crowns (303.7 ± 281.3 µε for acrylate polymer composite; 312.4 ± 226.8 µε for monolithic zirconia) than for single crowns (539.7 ± 8.8 µε for acrylic polymer composite; 574.6 ± 271.9 µε for monolithic zirconia). Conclusion: Using restorative materials of different stiffness did not significantly affect the micromovement of already-osseointegrated implants supporting single or splinted crowns. Independent of material stiffness, single crowns transfer significantly more microstrain than splinted crowns. Int J Oral Maxillofac Implants 2020;35:1132–1140. doi: 10.11607/jomi.8094

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Due to their high predictability and survival rates, implant-supported restorations are the most common treatment requested by patients and offered by clinicians to replace one or more missing teeth.1 However, the prosthesis-implant-bone complex is subject to multiple influences that should be avoided or minimized by clinicians to prevent restoration or implant failure. Progressive peri-implant bone loss up to levels incompatible with functioning of the implant is an indicator of implant failure. Inflammatory/infectious (peri-implantitis) or biomechanical stimuli (stress/strain derived from occlusal forces), either alone or in combination, may initiate and maintain peri-implant bone loss.2,3 Regardless of the presence of peri-implantitis, clinicians should consider approaches to control and minimize the effects of occlusal forces and stress/strain transferred to the prosthesis-implant-bone complex. In accordance with Frost’s mechanostat,4 this control is necessary to avoid an increase in peri-implant bone microstrain that may induce peri-implant bone loss and increase implant micromovement. The control of bone microstrain and implant micromovement causes crucial decisions related to the number, situation, and characteristics of the implants, bone quality and availability, strength factors, and the design and material of the restoration. In a fixed implant-supported restoration, single or otherwise, prosthetic material is the first component to receive the...
occlusal load. Subsequently, stress/strain and generated micromovement are transmitted to other components of the prosthesis-implant-bone complex when the prosthesis is used. The influence of stress/strain on peri-implant bone loss and the need for the implant to avoid exceeding a certain range of micromovement until osseointegration is complete are widely accepted. However, the optimal prosthetic material for a fixed partial implant-supported prosthesis to reduce transmission of peri-implant bone microstrain and implant micromovement has yet to be determined, so current information on this subject is insufficient.

Although metal-ceramics are the most widely used material in implant-supported fixed dental prostheses, greater esthetic requirements of patients have favored the use of zirconia ceramic, monolithic zirconia, and indirect veneered zirconia restorations, or even polyether ether ketone. Similarly, the good clinical results of immediately loaded implant-supported restorations have encouraged the use of provisional acrylic resin-based or similar materials. The different mechanical properties of these materials do not impede survival of implants or restorations. Clinical studies have demonstrated similar rates of survival and biologic complications between zirconia restorations and metal-ceramics in single crowns.

Clinical and in vitro studies have demonstrated the performance reliability of monolithic zirconia alongside feasible and promising results obtained with veneering materials for implant-supported zirconia-based restorations. Polyether ether ketone-based, polymethyl methacrylate-based, and acrylate polymer composite-based restorations have also demonstrated good results as definitive or provisional materials. Though the results reported in existing literature vary, mechanical properties of the materials, such as elasticity modulus and Poisson’s ratio, may result in differences in the stress/strain and micromovement transmission to the bone-implant interface. Empirically, clinicians have the impression that materials that are more elastic, less stiff, or have a lower elasticity modulus are more likely to deform under occlusal loading by absorbing this force and transferring less stress/strain to the bone-implant complex. In vitro and clinical studies support this view. In contrast, biomechanical evidence has established that very rigid materials with a higher elasticity modulus, such as zirconia, absorb a large amount of energy in their deformation, thus transferring less stress/strain to the rest of the bone-implant complex. Further, the reduced bending that occurs when two or more restorative units are splinted with higher elastic materials favors lower rotation moments and lower stress/strain values at the bone-implant complex compared with less rigid materials. Datte et al compared implant-supported single crowns with different restorative materials (eg, zirconia, chromium-cobalt, lithium disilicate, and hybrid ceramic) and concluded that the increase in elasticity modulus reduces stress concentration in the system with no differences in peri-implant bone. In contrast, Stegaroiu et al did not observe any significant differences in peri-implant bone microstrains in frameworks with a lower elasticity modulus (eg, acrylic resin, composite resin, and gold alloy). Hence, evidence for the influence of different stiffness of prosthetic materials on implant micromovement and on the stress/strain transferred to the peri-implant bone is inconclusive. This issue requires further exploration to provide practitioners with sufficient data to optimize the selection of implant-supported prosthetic restorations made with materials of greater or lower stiffness. The aim of this study was: (1) to evaluate and compare the influence of the framework of a partial fixed dental prosthesis (one single and two splinted crowns) made with different elastic modulus materials (monolithic zirconia and acrylate polymer composite) on implant micromovement and peri-implant bone microstrain during simulated occlusal force; and (2) to evaluate and compare the differences exerted by a single or two adjacent implant-supported splinted crowns composed of the same materials on bone microstrain and implant micromovement. The null hypothesis proposed that single restorations made of a higher elastic modulus material would cause less implant micromovement and bone microstrain in the implant peri-implant bone complex.

**MATERIALS AND METHODS**

**Sample**

The study sample comprised eight tibias from four adult New Zealand male rabbits, approximately 6 months of age and 4 kg in weight. This study was approved by the Ethical Committee of Minimal Invasive Surgical Centre (Spain; ref. 002/18). ARRIVE guidelines were followed in accordance with the EU Directive 2010/63/EU for animal experiments.

Using a routine surgical technique, two 3 × 10-mm VEGA Klockner implants (Klockner, Soadco) were inserted in each tibia, leaving 2 mm of the most coronal area exposed and an intercenter distance of 6 mm. Before suturing the flap, implant positions and parallelism were registered, and two transfer abutments to the implants were fastened and splinted with a light curing flowable composite (GrandioSO Flow, VOCO; Fig 1). Each implant was randomly assigned to each tibia. A single operator (M.D.-P.) performed the surgical procedures. Once the composite was cured, the transfer abutments were removed, and the flap was repositioned and sutured.
While the implant osseointegration process was occurring, both single and two adjacent splinted crowns were manufactured by CAD/CAM technology as follows. The implant analogs were fastened to the transfer abutments. Splinted transfer abutments/implant analog complexes were then cast using type IV plaster (GC Fujirock EP, GC Europe). After the plaster had set, transfer abutments were unfastened to obtain eight plaster models with two implant analogs embedded in each model. Scan bodies were then fastened into the implant analogs and scanned using iScan L2 scan (Imetric). A mandibular premolar implant-supported single crown and two adjacent splinted crowns with the same shape were designed by Exocad (Exocad) and milled in monolithic zirconia (VITA Zahnfabrik) and acrylate polymer composite (VITA Zahnfabrik) by milling with a CORITEC 250i milling machine (Imes-Icore). Two single crowns (one of each material) and 16 adjacent splinted crowns (8 acrylate polymer composite and 8 monolithic zirconia) were generated to be placed with a cement screw-retained method (Fig 2).
After constructing all restorations and at the conclusion of the 6-week osseointegration period, the animals were sacrificed, and the section of the tibia containing two osseointegrated implants was extracted. Implant osseointegration was assessed with resonance frequency analysis using a Penguin RFA device (Integration Diagnostics Swede). A third of the thickness of each tibial section was embedded in a rectangular (3 × 8 × 2 cm) block of type IV plaster (GC Fujirock EP, GC Europe) of the American Dental Association classification. Thus, eight working models were obtained (Fig 3). The tibial sections were then randomly assigned to each model. Engaging (for single crowns) and rotational (for splinted crowns) 3.5-mm-height titanium abutments (Klockner, Soadco) were fastened to the implants at 30 Ncm² with a calibrated torque wrench. Both the single and splinted crowns were subsequently cemented with an auto-adhesive resin cement (Maxcem, Kerr) to their corresponding abutments. Working models with the implants and cement-screw restorations were prepared for the loading test (Fig 2). The abutments were randomly assigned to the implants. Similarly, prostheses were randomly assigned to the abutments.

**Loading Test and Strain and Micromovement Registration**

All loading tests were performed within the first 24 hours after the animals were sacrificed. Before the loading test, a 2-mm strain gauge (gauge factor 2.09% ± 1.0%; resistance 120.4Ω ± 0.4%; Kyowa) was adhered to the crestal bone near each implant on the internal side of each tibia in each working model with cyanoacrylate (CC-33A, Kyowa; Fig 3). Once the working model with the strain gauges was fixed on the loading machine, the restorations were fastened to their respective implants, and the loading tests were started. A total of 16 loading tests were performed for each prosthesis design and material. For single crowns (one sample of each material), the restoration was removed and fastened to another implant after each test according to the randomized assignments previously performed. For adjacent splinted crowns (eight samples of each material), two tests for each material and working model were performed with alternative force applications over the two implants. The loading application sequence was also randomized. All loading tests were performed by simultaneously applying a 100-N load with 6-degree inclination with respect to the occlusal surface of the premolar cusps using a 10-cm-diameter cylindrical steel device. A load of 2.5 kN was applied from a load cell by a Bionix 358 servohydraulic machine (MTS Sensor Technologie) at a speed of 1 mm/min for 30 seconds (Fig 4).

To measure implant displacement, a series of images were obtained at the start (F = 0 N) and end of the test (F = 100 N) using a Questar OM 100 long-distance microscope (Seven Astro-Optics Division) with a resolution of 2 µm, using an 800 × 600 Moticam digital camera (Motic Europe) and the software AnalySIS getIT (Olympus). Coordinate x- and y-axis displacement values...
were recorded for each case, and the resultant displacement between both axes was calculated using ImageJ software (National Institutes of Health), using different reference points from the initial and final images (Fig 5).

Microstrain values were measured with a Model P3 Strain Indicator and Recorder device (Vishay Measurements Group) with the strain gauges programmed and connected to entrance P3. The load was applied, and the results obtained were recorded and stored using P3 software on a laptop. The degree of distortion of the strain gauge was calculated according to the following equation: microstrain $\varepsilon = \frac{\Delta L}{L} (\text{change in length of the strain gauge})/L (\mu m/m) = \frac{\Delta R}{R} (\text{change in electrical resistance of the strain gauge})/R$.

## Statistical Analysis

Sample size was calculated at the power (1-\(\beta\)) of 0.80 and \(\alpha < .05\) and a large, estimated effect of \(f = 0.4\). The obtained sample size for two independent variables and aforementioned selected parameters was 2 \(\times\) 2 \(\times\) 13 = 52. In this study, 2 \(\times\) 2 \(\times\) 16 = 64 samples were used, ensuring sufficient power.

The Shapiro-Wilk test was performed to assess the normality of the variables, which confirmed normality (\(P > .05\)). Two-way analysis of variance (ANOVA) was used to evaluate differences between groups and materials by assessing the influence of each factor in isolation on the dependent variable (additive model) and the influence of combinations of variables (model with interaction). Nonparametric tests (Mann-Whitney and Kruskal-Wallis) were used when the Levene test indicated nonhomogenous variances between groups (\(P < .05\)). Statistical significance was defined as \(P < .05\).

## RESULTS

Table 1 and Figs 6 and 7 show the descriptive statistics and results of statistical analysis. The microstrain variable fulfilled homogeneity of variances (Levene test, \(P = .711\)); thus, two-way ANOVA was used. Micromovement did not meet homogeneity of variances (Levene test, \(P = .001\)); thus, nonparametric tests were used (Mann-Whitney and Kruskall-Wallis tests).

The median implant micromovement values were 59.21 µm and 59.6 µm in single crowns and splinted crowns, respectively (\(P = .413\)). Median values of acrylate polymer composite and monolithic zirconia materials were 60.6 µm and 58.9 µm, respectively (\(P = .314\)). No interaction effect was observed between the prosthesis and material used (\(P = .552\)). For each material, no significant differences were observed between the micromovement values of the two types of crowns (single and splinted; Fig 6). Further analysis revealed that splinting two adjacent implant-supported crowns reduced implant micromovement compared with single crowns (\(P = .413\)), with a greater effect for acrylate polymer composite restorations. Implant micromovements were lower with monolithic zirconia restorations than with acrylate polymer composite restorations (\(P = .314\)); this decrease in micromovement for monolithic zirconia was greater when single crowns were used.

Mean bone microstrain values were 557.1 ± 266.6 µε and 308.0 ± 251.4 µε in single and splinted restorations,
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respectively \((P = .001)\). Mean values of acrylate polymer composite and monolithic zirconia were 421.7 ± 296.0 \(\mu\varepsilon\) and 443.5 ± 279.9 \(\mu\varepsilon\), respectively \((P = .742)\). No interaction effect was noted between the crown and material \((P = .843)\). For each material, significant differences were observed between the micromovement values of the two types of crown (Fig 7). A significant difference was observed in bone microstrain mean values between acrylate polymer composite single restorations (539.7 ± 8.8 \(\mu\varepsilon\)) and acrylate polymer composite splinted restorations (303.7 ± 281.3 \(\mu\varepsilon\)). In addition, a significant difference was observed in mean values of single and splinted monolithic zirconia crowns (574.6 ± 271.9 \(\mu\varepsilon\) and 312.4 ± 226.8 \(\mu\varepsilon\), respectively). In sum, the effect of splinting two adjacent crowns resulted in a reduction in microstrain values registered for both tested materials of approximately half compared with that for single crowns; this effect was statistically significant for both monolithic zirconia and acrylate polymer composite (Table 1).

**DISCUSSION**

This study evaluated the effect of a static load on the transmission of peri-implant bone microstrain and implant micromovement in osseointegrated implants with cement-screw-retained restorations (single and two adjacent splinted crowns) composed of two materials with different mechanical properties (acrylate

<table>
<thead>
<tr>
<th>Crown Type</th>
<th>Micromovement ((\mu\text{m}))</th>
<th>Microstrain ((\mu\varepsilon))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (SD, Median)</td>
<td>Single (SD, Median)</td>
</tr>
<tr>
<td>Total</td>
<td>64.4 (24.9), 59.4 (32.9)</td>
<td>70.2 (10.1), 59.1 (9.6)</td>
</tr>
<tr>
<td>Acrylate polymer composite</td>
<td>69.3 (28.9), 60.6 (37.3)</td>
<td>78.9 (11.5), 68.8 (11.5)</td>
</tr>
<tr>
<td>Monolithic zirconia</td>
<td>59.6 (19.4), 58.9 (26.3)</td>
<td>61.5 (8.8), 58.8 (8.8)</td>
</tr>
</tbody>
</table>

\(^a\) \(P\) values corresponding to the nonparametric approach. Total row = comparison between crowns (M-W, Mann-Whitney); total column = comparison between materials (M-W); lower right corner = crown and material interaction (K-W, Kruskal-Wallis).
polymer composite and monolithic zirconia) in rabbit tibias. To date, this is the first study measuring implant micromovement and bone microstrain in osseointegrated implants. All tests were performed under a 100-N occlusal load, which is considered the normal chewing force and frequently cited in in vitro studies. 27,28

The data obtained revealed that two adjacent splinted crowns transferred significantly lower microstrain levels to the peri-implant crestal bone compared with single crowns, regardless of the prosthesis material used. Mean registered microstrain values for splinted crowns fell within the physiologic range, where bone modeling and remodeling processes occur with a balance between bone apposition and bone resorption, in accordance with Frost mechano-stat theory. 4 Although microstrain values were higher for single crowns, they still fell within the physiologic range. Wherever possible, clinicians should increase the total occlusal surface by splinting adjacent implant-supported restorations to control the occlusal load to avoid increasing bone microstrain with single crowns and possible peak forces in other cases where the total load exerted could exceed 100 N, such as at molar areas. However, splinting adjacent implants remains controversial. Previous in vitro studies using different methods and 3D imaging have indicated that there were no significant differences between splinted and nonsplinted restorations with regard to bone microstrain, 29–31 although splinted restorations generated a more uniform strain distribution. 31 Similar results were observed in a photoelastic model study. 32 In contrast to the results observed here, Nissan et al 33 reported that single unsplinted restorations transferred significantly less strain to implants and supporting structures and greater strain to crown margins compared with adjacent splinted restorations. In contrast, finite element and strain gauge studies have indicated that splinted implant-supported restorations exhibited better distribution and lower transferred stress values to the peri-implant bone. 34–41 However, clinical studies have not reported statistically significant differences in marginal bone loss between single and splinted restorations, with mechanical problems being restricted to single restorations. 42

This study does not provide supporting evidence for the use of restorative materials of lower elastic modulus and lower stiffness to promote implant survival. According to the results of the present study, the use of restorative materials with very different stiffness did not significantly influence the microstrain transferred to the peri-implant bone. Although not strictly comparable, this finding agrees with the conclusions of a recent systematic review and meta-analysis 19 and with findings from previous strain gauge studies that did not observe any differences in microstrain values using different elastic modulus restorative materials. 21,26,43

Similarly, the findings of the present study concur with other finite element studies that registered lower bone stress/strain values with materials of a low elastic modulus. 22 The results of the present study contradict those from in vitro studies that have reported lower peri-implant bone stress/strain values using materials with a higher elastic modulus, including zirconia. 24,25,44

To clarify these discrepancies, randomized clinical studies are needed to confirm these findings and develop specific clinical procedures to ensure higher implant survival rates.

Implant micromovement values observed in this study exhibited a similar pattern to microstrain values with respect to the favorability of splinted crowns compared with single crowns; however, no significant differences were noted between acrylic polymer composite or monolithic zirconia restorations. In an osseointegrated implant, as used in this study, micromovement may be underpinned by peri-implant bone elastic deformation under a load that simulates the magnitude and direction of a normal chewing force. Although there was a direct relationship between both studied materials (indicated by higher micromovement concurrent with higher microstrain), the threshold above which micromovement may be associated could not be determined with a certain peri-implant bone plastic deformation value. Regardless of the framework material used, the mean implant micromovement values in this study were higher than intrusion and similar to buccolingual physiologic micromovement values of natural teeth, estimated at 28 and 68 µm, respectively, in premolar areas. 45 The lack of differences between acrylic polymer composite and monolithic zirconia in implant micromovement and bone microstrain values may lead clinicians to select modulus materials with higher elasticity than those typically used to make provisional restorations for immediately loaded implants or definitive restorations, with limited risk for the osseointegration of the implants.

This study has several limitations. The 100-N applied force was not high and could be exceeded during normal chewing and in parafunctional habits. Higher applied forces in the loading test may have resulted in significant differences in implant micromovement values among different prosthesis designs and materials. All loading tests in the nonsplinted group were performed on a monolithic zirconia or acrylic polymer composite single crown, which required screwing and unscrewing motions for each implant (16 trials for each material). This could have affected the mechanical properties of the material. To minimize this bias, it would be necessary to increase the sample size with identical crowns and conduct single trials for each one. However, the sample size used in this study was sufficient given the large effect size (f = 0.4). Thus, if
between-group differences were small, the statistical analysis would not have detected these differences as being significant. This reflects an inherent limitation in the detection capacity of the tests.

Although loading tests, micromovement, and microstrain value measurements were performed simultaneously and in the shortest time (24 hours), sectioned tibias were not conserved in a moist physiologic medium. This was a potential limitation, as the mechanical properties of the samples could have been affected. Although these changes may have changed microstrain and micromovement net values, both materials were tested on bone with the same properties and under the same conditions. A further limitation was the use of strain gauges measuring in a single direction and not with a rosette configuration for measuring in multiple directions. The difference between elastic moduli of both tested materials, without using prosthetic materials of intermediate stiffness, is another limitation.

CONCLUSIONS

Based on the results and taking into account the inherent limitations in studies of this kind, the following conclusions can be drawn: (1) the use of restorative materials of very different stiffness (acrylate polymer composite and monolithic zirconia) in single crowns or in two adjacent splinted crowns did not significantly affect the presence of implant micromovement, with splinted crown implants exhibiting lower micromovement values compared with a single crown for both restorative materials; and (2) regardless of the restorative material used (acrylate polymer composite or monolithic zirconia), the microstrain transferred to the peri-implant bone was significantly related to splinting of the crowns. Two adjacent splinted crowns, either acrylate polymer composite or monolithic zirconia, transferred almost 50% less microstrain to the peri-implant bone compared with a single crown.

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