Accelerated Fatigue Resistance of Bonded Composite Resin and Lithium Disilicate Screw-Retained Incisor Crowns with Long and Short Titanium Bases

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This study evaluates the fatigue resistance and failure mode of CAD/CAM composite resin and lithium disilicate–bonded screw-retained incisor crowns with long and short titanium bases. Sixty CAD/CAM implant restorations were fabricated using lithium disilicate (IPS e.max CAD, Ivoclar Vivadent) and composite resin (Block HC, Shofu). The central incisor crowns were bonded to a prefabricated titanium base 6 mm tall (groups: Emax6 and Shofu6; n = 15 each) or a modified abutment 4 mm tall (groups: Emax4 and Shofu4; n = 15 each). The intaglio surface of the restorations was conditioned according to the material and bonded to the titanium abutments/bases using dual-cure cement. All assembled crowns were torqued onto implants and subjected to cyclic isometric loading at the incisal edge along the implant axis. Samples were loaded until fracture. Groups were compared using Kaplan-Meier survival analysis (log rank test at P = .05). The number of mean survived cycles differed significantly, with Emax6 and Emax4 at 48,448 and 43,727 cycles, respectively, and Shofu6 and Shofu4 at 44,124 and 37,620 cycles, respectively. Post hoc tests showed similar fatigue resistance for Emax6, Emax4, and Shofu6. Shofu4 was less resistant than all other groups (P < .03). All restorations survived significantly above physiologic load limits. Lithium disilicate screw-retained incisor crowns can be used with long and short titanium bases, while it is recommended to keep a long titanium base for screw-retained composite resin crowns. The composite resin material required the full height of the abutment for optimal strength but may offer enhanced shock absorption and wear-friendliness when considering function and antagonist wear.


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was left open lingually to provide access for screw fastening, combining the versatility of cemented restorations and the simple delivery and retrievability of screw-retained restoration. No custom implant components were required, and the premachined abutments were unaltered. In addition, the access hole for the fastening screw can be considerably smaller (just the size of the screw driver) because the screw can remain with the abutment. Nowadays, CAD/CAM materials and techniques can be used to replicate this approach. Special hollowed blocks with their corresponding titanium bases are available to facilitate the process. However, it is also possible to modify prefabricated stock abutments or even provisional titanium cylinders and use them as a base to be scanned and assembled with a milled restoration through bonding instead of cementation. This modern version of the combined cemented and screw-retained restoration by McGlumphy can be called the CAD/CAM–bonded screw-retained crown (BSRC) (Figs 1 and 2).

This approach differs from the modern CAD/CAM approach using the hollowed blocks and corresponding titanium bases, as BSRC can be fabricated with more economic components such as standard abutments and regular CAD/CAM blocks, not necessarily hollowed ones. It is also more versatile because BSRC can be used with any type of materials or systems, opening the door to more affordable implant systems.

When combined with adhesive techniques, sophisticated histomorphologic and bilaminar-bonded dentin-like and enamel-like materials can be produced and delivered with a screw-retained approach using the BSRC concept. The simplest way to fabricate an anterior BSRC, however, is to combine a monolithic CAD/CAM crown with a standard titanium abutment. If needed, the abutment can be shortened to accommodate linguocervical clearance or to enhance esthetics. Ceramic materials are usually the favored crown material, but lithium disilicate and zirconia are the primary choices.
for this application. However, a limiting factor of zirconia is the chipping of layered porcelain. In recent decades, composite resin CAD/CAM blocks have gained popularity. The marketplace of these high-performance polymers is developing steadily, offering excellent esthetics with various translucencies like their ceramic counterparts. In addition to their wear-friendliness to the antagonistic natural teeth, composite resin blocks are also milled faster and more accurately than ceramic ones (especially thin margins) and will induce less wear to the milling instruments. Polymer-based materials also offer unique mechanical properties, including a tooth-like damping behavior that can compensate for the absence of a periodontal ligament and implant rigidity inherent to implant-supported restorations. Indirect hand-layered composite crowns exhibited a fracture resistance similar to that of PFM crowns, even after fatigue testing on implant abutments. Thus, composite resin and lithium disilicate blocks (the modern CAD/CAD–bonded counterparts) are excellent candidates to be compared and combined with the BSRC as single incisor implant-supported restoration (see Appendix Table 1, available in the online version of this article at quintpub.com/journals).

This in vitro study aims to evaluate the accelerated fatigue resistance of central maxillary incisor BSRCs made of CAD/CAM composite resin or lithium disilicate on two different titanium base designs (tall or short). The first hypothesis states that the BSRCs made of composite resin will resist fatigue similarly to the BSRCs made of lithium disilicate. The second hypothesis states that the fatigue resistance and failure mode of BSRCs will not differ between original abutments (tall; 6 mm) and modified abutments (short; 4 mm).

Materials and Methods

Sixty Morse tapered implants (4.0-mm diameter, 11-mm length; dual-cone Universal III, Implacil De Bortoli) were embedded in a cylindrical acrylic resin base (Palapress, Heraeus Kulzer). Two different abutments were used: the manufacturer’s original abutment (3.4-mm diameter, 6.0-mm height; CM Universal abutment, Implacil De Bortoli) and a modified version of the same abutment (reduced to a height of 4.0 mm using a diamond disc). Sharp angles on the modified abutment were rounded with a polishing wheel.

For original abutments, the implant and abutment were positioned in a clinically relevant fashion on a natural dentition cast to simulate replacement of a right central incisor by a screw-retained restoration, with lingual placement to allow access for screw fastening (Fig 3). For modified abutments, the implant platform was placed 4.0 mm below...
the level of the buccal gingival margin on a natural dentition cast, and the abutment was attached.

For both abutment groups, the dental arch was scanned using the Cerec 4 system (version 4.3, Dentsply Sirona), and a proposal of a maxillary right central incisor was designed. The resulting crown emulated the natural morphology and emergence profile of the contralateral tooth (Fig 4).

A total of 60 abutment specimens were used: 30 with a 6-mm length, and 30 with a 4-mm length. Four groups were created, each comprising 15 abutment specimens. Thirty identical monolithic lithium disilicate (IPS e.max CAD, Ivoclar Vivadent) crowns were used as a control group and compared to thirty monolithic restorations made of hybrid composite resin (HC Block, Shofu). All crowns were milled with the sprue located at the palatal surface. The groups were divided as follows: 15 lithium disilicate crowns were bonded to 6-mm abutments (Emax6 group); 15 lithium disilicate crowns were bonded to 4-mm abutments (Emax4 group); 15 composite resin crowns were bonded to 6-mm abutments (Shofu6 group); and 15 composite resin crowns were bonded to 4-mm abutments (Shofu4 group). Unlike what is seen in the clinical case from Fig 1, customization of the 6-mm abutment was not necessary because enough clearance was available for the restorative material. Keeping the abutment intact was also preferred in order to keep the procedure as simple and standardized as possible. Before the polishing procedures, the sprue was removed, and the access hole for future screw-tightening was created in the palatal surface using a coarse diamond bur (5850.31.018 FG, Brasseler).

The crowns were then assembled to the abutments (Fig 5). The fitting surfaces of the titanium abutments and composite resin crowns were subjected to airborne-particle abrasion with 27-µm silica-modified aluminum oxide (CoJet, 3M ESPE) at 0.2 MPa for 10 seconds at a distance of 10 mm, then cleaned with water spray for 20 seconds. This was followed by immersion in distilled water in an ultrasonic bath for 2.5 minutes, oil-free air-drying
for 5 seconds, two applications of silane (Silane, Ultradent) for 20 seconds each, and drying at 100°C for 1 minute (DI-500 oven, Coltène). Finally, adhesive resin was applied (OptiBond FL bottle 2, Kerr) without polymerization.

Surface treatment of the lithium disilicate structures included etching with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds and rinsing with water for 20 seconds. Post-etching cleaning was done by immersion in distilled water in an ultrasonic bath for 2.5 minutes, followed by oil-free air-drying. The intaglio surfaces were silanated (two applications for 20 seconds each; Silane) and dried at 100°C for 1 minute. Finally, adhesive resin was applied (OptiBond FL bottle 2) without polymerization.

Each titanium abutment was placed temporarily into the implant for easier handling. Polytetrafluoroethylene (PTFE) tape was used to cover the abutment access channel. All restorations were assembled and bonded to the titanium base using dual-cure resin cement (Variolink Esthetic DC, Light+ shade, Ivoclar Vivadent). After removal of all excess resin cement, each surface was light polymerized for 60 seconds at 1,000 mW/cm (Valo, Ultradent). All margins were covered with an air-blocking barrier (K-Y Jelly, Personal Products Company) for an additional 20-second polymerization cycle per surface. Excess adhesive resin was removed with hand instruments. The steps for the assembly of the BSRC are described in Appendix Table 2.

The BSRC was retrieved from the implant for finishing with rubber wheels (Green medium fine rubber wheels, Keystone Industries) to polish the abutment-crown interface. All assembled restorations were then repositioned on the implant, and a 20-Nm torque was applied to the abutment screw according to the manufacturer’s recommendation. The lingual access hole was finally closed with PTFE tape and light-polymerized composite resin (Z100, 3M ESPE). Specimens were stored in distilled water for 24 hours before testing.

An electrodynamic test system (Acumen, MTS Systems) was used for simulating masticatory forces (Fig 6). The chewing cycle was replicated by an isometric contraction (load control) applied along the implant axis through a flat antagonist composite resin surface (Paradigm MZ100, 3M ESPE) at the incisal edge of the specimen. Once positioned in the testing machine, the incisal edge of the crown was adjusted with 600-grit sandpaper until the entire width of the edge was in contact with the antagonist. A new antagonist surface was used for every three specimens. The load chamber was filled with distilled water to submerge the sample during testing. Cyclic loading was applied at a frequency of 5 Hz, starting at 25 N for 1,700 cycles and increasing by 25 N every 50 cycles.
The number of endured cycles and the failure mode of each specimen were recorded. After the test, each sample was evaluated by transillumination (Microlux, AdDent) and an optical microscope (MZ125, Leica Microsystems) at 10:1 magnification. Evaluations were confirmed by two examiners (J.R.I. and M.R.).

The fatigue resistance of the four groups was compared using the number of cycles until failure and Kaplan-Meier survival analysis.

Results

The survival function and mean number of survived cycles are presented in Figs 7 and 8. Mean survived cycles significantly differed between groups. Emax6 and Emax4 survived a mean of 48,448 cycles (mean load: 809 N) and 43,727 cycles (mean load: 734 N), respectively; Shofu6 and Shofu4 survived means of 44,124 cycles (mean load: 739 N) and 37,620 cycles (mean load: 641 N), respectively. Post hoc tests with the P value set at .05 showed similar fatigue resistance for Emax6, Emax4, and Shofu6. Shofu4 appeared less resistant than the other groups (P < .03). Comparisons were performed at a significance level of P ≤ .008 (Bonferroni correction for six comparisons) but only revealed the superiority of Emax6 over Shofu4.

No screw/abutment fractures were observed. There seemed to be plastic deformation of some abutments, especially the 6-mm original abutments (Fig 9). Appendix Table 3 shows the distributions of the various failure types. Lithium disilicate BSRCs fractured in the buccolingual direction for 80% of the specimens, while all composite resin BSRCs fractured in the mesiodistal direction. Emax groups tended to show remains of the luting composite resin on the crown side (leaving a clean titanium abutment on 67% to 73% of the specimen), while Shofu groups exhibited more remaining luting composite resin on the titanium abutments (present in 93% to 100% of specimens) (Fig 10).

Discussion

The aim of this in vitro study was to evaluate the accelerated fatigue resistance of incisor BSRCs made of CAD/CAM composite resin or lithium disilicate on two different titanium base designs. The first hypothesis (stating that the BSRCs made of composite resin will resist fatigue similarly to those made of lithium disilicate) can be partially accepted, as both crown materials performed the same on the original 6-mm abutment. The second hypothesis (stating that the fatigue resistance and failure mode of BSRCs will not differ between 6-mm−high and 4-mm−high abutments) can be accepted for the Emax group. Composite resin crowns, however, performed better with the long abutment. This difference did not appear statistically significant when applying a stricter statistical analysis (Bonferroni correction).
The experimental protocol featured a flat composite resin surface as an antagonist to allow more realistic simulation of an anterior tooth occlusal contact through a wear facet included in the incisal edge of the restoration. Localized surface damage and powder-like debris were avoided by the large and uniform contacting surface and submerged conditions. Traditional load-to-failure tests have the advantage of yielding quick results but are also less clinically relevant, as teeth and implants are instead subjected to relatively low forces but a high number of chewing cycles in vivo. Clinical fatigue can be simulated by in vitro tests using low forces and millions of chewing cycles, which represents a time-consuming approach. The present study is a good balance between these experiment types. The progressive increase in load can be considered an “accelerated fatigue test” that covers a wide range of clinically relevant situations (normal and high loads). The test begins within the range of realistic bite forces in the

Fig 7 Kaplan-Meier fatigue resistance survival curves for all four groups considering the number of cycles until failure. Emax groups = lithium disilicate crowns bonded to a 6-mm abutment (Emax6) or a 4-mm abutment (Emax4); Shofu groups = composite resin crowns bonded to a 6-mm abutment (Shofu6) or a 4-mm abutment (Shofu4).

Fig 8 Box-and-whisker diagram presenting the median number of cycles until failure (bold black horizontal line), the minimum and maximum values (vertical “t” lines/whiskers), and the interquartile range (box). Emax groups = lithium disilicate crowns bonded to a 6-mm abutment (Emax6) or a 4-mm abutment (Emax4); Shofu groups = composite resin crowns bonded to a 6-mm abutment (Shofu6) or a 4-mm abutment (Shofu4).

Fig 9 Long titanium base (left) with apparent permanent deformation consecutive to loading/fracture, shown next to a short titanium base (right) apparently intact after loading/fracture.
anterior region (up to 100 N)\textsuperscript{14} and then increases to a range of loads that may be encountered in bruxism, trauma (high extrinsic loads), or intrinsic masticatory accidents (under chewing loads but delivered to small area as a result of a hard foreign body, such as a fork, stone, or seed). The experiment was conducted in extremely standardized conditions: The loads were uniform, the titanium abutments/bases were prefabricated, and the crowns were made with CAD/CAM technology. Many confounding manufacturing variables were therefore avoided by milling the exact crown replica multiple times in different materials. All components were strictly identical.

Both titanium and zirconia abutments/bases could have been used in this study. Titanium components were chosen because of their tighter adaptation to the implant platform (less microgap).\textsuperscript{15} The failure modes of the different groups were dissimilar, as seen in Figs 9 and 10. Further experiments using finite element analysis are underway to understand this phenomenon, but it can be anticipated that the elastic modulus of the crown influenced the stress distribution with values above 80 GPa for Emax vs only 9.6 GPa for Shofu.\textsuperscript{16} The low elastic modulus may have allowed deformation of the crown in a more three-dimensional way, resulting in major “out-of-plane” forces (mesiodistal). However, because of the increased stiffness, ceramic crown fracture remained within the plane of the force and deformation, namely buccolingual. From a clinical perspective, repairing and reassembling the fragments would be easier with a mesiodistal fracture (fracture line hiding interproximally) compared to a buccolingual one (fracture line visible). Another trend revealed by the failure modes is the tendency for the ceramic BSRC to retain more luting composite resin inside the crown. The opposite trend was found for composite resin BSRC, with more luting composite resin remaining on the abutment. Resin-to-titanium bonding can be obtained by micromechanical retention and chemical bonding. Silicoating the titanium surface using the tribochemical approach and a silane (CoJet/Rocatec Systems) was chosen for this experiment because it not only yielded high shear bond strength (15 MPa) but it also achieved acceptable

![Fig 10](a) Emax BSRC with a typical buccolingual fracture and a clean titanium base surface. (b) Shofu BSRC with a typical mesiodistal fracture and luting composite remnants on the titanium base.
It seems, however, that the high shear bond strength of the resin to Emax (> 20 MPa) far exceeded that of the resin to titanium and resulted in the luting cement remaining inside the crown after fracture. The opposite trend characterized the Shofu crowns, with luting composite resin remaining on the titanium abutment. This difference might explain the slight superiority of Emax BSRCs over Shofu BSRCs when it comes to accelerated fatigue strength. It remains surprising, however, that both materials performed similarly in spite of a large difference in their nominal flexural strength. In fact, there was no difference in strength between BSRCs made of Emax6 and Shofu6. This does not correlate with classic “bench” testing values such as flexural strength. Emax as a material alone is two times stronger than Shofu (flexural strengths of 380 MPa and 191 MPa, respectively). This emphasizes the fact that basic bench testing is not appropriate and that dental materials should always be tested in a clinically relevant fashion, simulating the geometry and integration of the restoration on the tooth and implant. A special criteria called the work of fracture (Wf) may explain this discrepancy. The Wf represents the energy used during the fracture process wherein a new surface is generated and considers the elastic modulus of the material.

The original (6-mm) abutments often performed better than short ones, especially when using composite resin BSRCs. For Emax, both abutments yielded similar results. In the specific situation of a maxillary central incisor, a short abutment may present a slight esthetic advantage (less need for masking the dark titanium near the center of the tooth). However, most masking of the abutment seemed to be resolved by the combination of low-translucency CAD/CAM blocks (usually designated LT; available from both brands used in the present study) with an opaque composite resin for the assembly. Variolink Esthetic DC is available in the shade “Light+,” which provides efficient masking of the titanium. Further research is underway to evaluate the color variations that may be induced by modifying elements of the assembly (crown material, composite resin, abutment height). A shorter abutment base is also useful in the posterior regions, where the interocclusal vertical space is sometimes inadequate for regular abutments. Therefore, the results of the present study should motivate the research on this application for posterior segments.

From a clinical perspective, both composite resin and lithium disilicate can be recommended for BSRCs because they fractured at an average load significantly above the maximum bite force of the anterior dentition in men (569 N). Due to its low elastic modulus, however, the composite resin BSRC is more likely to absorb...
the stress, which is described as “damping behavior.” This property, in turn, protects the abutment itself and the restoration-abutment adhesive interface, and it may also limit microgap openings at the implant-abutment interface. Further research is being conducted to reveal the potential damage or deformation of the implant as a function of the elastic modulus of the crown material.

Several practical elements can be emphasized when using BSRCs. Despite the presence of anti-rotation grooves, it may be challenging to assemble the crown and its titanium base in the exact position that will ensure appropriate occlusion and interdental contact points. In fact, the crown milling includes internal spacing, which may affect anti-rotational properties. This can be easily resolved by assembling the abutment and the crown intraorally in the ideal position, then retrieving the assembled BSRC. Removing excess luting composite resin and finishing it extraorally (Fig 11).

Deeper implant placement is required to avoid a labial ridge-lap design of the BSRC. Implant platform depth must always be related to the amount of buccolingual shift between the implant platform and the labial profile of the crown. Because specimens were designed based on clinically relevant geometry (given by a natural-dentition cast), this study is a foundation to further explore numerous variables related to BSRCs, including the extended range of the titanium base height, materials, three-dimensional implant positioning, and more.

Conclusions

This study investigated CAD/CAM–bonded screw-retained incisor crowns. All restorations, either made of lithium disilicate or composite resin, survived loads significantly above physiologic limits in the anterior dentition (> 600 N). Emax crowns can be combined with long (6-mm) and short (4-mm) titanium bases, but it is recommended to use a long titanium base with Shofu Block HC crowns. BSRCs do not require hollowed CAD/CAM blocks and constitute a versatile solution, as any type of material and implant system can be combined, allowing more affordable components to be used.

Acknowledgments

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The authors declare no conflicts of interest.

References


Appendix Table 1 Mechanical Properties of the Materials Tested (Manufacturer Data)

<table>
<thead>
<tr>
<th></th>
<th>Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent)</th>
<th>Hybrid composite (HC Block, Shofu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural strength</td>
<td>380 MPa</td>
<td>191 MPa</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>52.8 GPa</td>
<td>7.6 GPa</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>95 GPa</td>
<td>8.79 GPa</td>
</tr>
<tr>
<td>Composition</td>
<td>Silicon dioxide, lithium oxide, potassium pentoxide, zirconium dioxide, zinc oxide, aluminum oxide, magnesium oxide, pigments</td>
<td>Silica powder, zirconium silicate, micro-fumed silica, UDMA, TEGDMA, pigments, and others</td>
</tr>
</tbody>
</table>

UDMA = urethane dimethacrylate; TEGDMA = triethylene glycol dimethacrylate.

Appendix Table 2 Summary of the Assembly Procedures

<table>
<thead>
<tr>
<th>BSRC crown material</th>
<th>Titanium base</th>
<th>Crown fitting surface</th>
<th>Assembly</th>
<th>Finishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite resin</td>
<td>Airborne-particle abraded with CoJet at 0.2 MPa for 10 sec at a distance of 10 mm. Cleaned with water spray for 20 sec. Immersed in distilled water for 2.5 min. Oil-free drying, silane application for 20 sec (twice), and then dried at 100°C for 1 min.</td>
<td>Wetted the crown and abutment surfaces with adhesive resin. Applied dual light cure resin cement to the crowns, then each surface was light polymerized for 60 sec. All margins were covered with an air block barrier for an additional 20 sec of light polymerization.</td>
<td>Excess adhesive resin was removed with hand instruments. Medium fine rubber wheels were used to polish the abutment crown interface. All BSRCs were repositioned on the implant, and 20 N of torque was applied to the screw. The lingual access hole was covered with PTFE tape and light-polymerized composite resin.</td>
<td></td>
</tr>
<tr>
<td>Lithium disilicate</td>
<td>Acid-etched for 20 sec and cleaned with water spray for 20 sec. Immersed in distilled water for 2.5 min, followed by oil-free drying. Silane application for 20 sec (twice), and then dried at 100°C for 1 min.</td>
<td></td>
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</tr>
</tbody>
</table>

BSRC = CAD/CAM–bonded screw-retained crown; PTFE = polytetrafluoroethylene.

Appendix Table 3 Failure Modes: Fracture Rates and Presence of Remaining Composite Resin

<table>
<thead>
<tr>
<th>Group</th>
<th>Fracture orientation</th>
<th>Remaining luting composite resin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mesiodistal</td>
<td>Buccolingual</td>
</tr>
<tr>
<td></td>
<td>Crown only (abutment clean)</td>
<td>Atabument only (crown clean)</td>
</tr>
<tr>
<td>Emax6</td>
<td>0% (0/0)</td>
<td>80% (12/15)</td>
</tr>
<tr>
<td>Emax4</td>
<td>6.7% (1/15)</td>
<td>80% (12/15)</td>
</tr>
<tr>
<td>Shofu6</td>
<td>100% (15/15)</td>
<td>0% (0/0)</td>
</tr>
<tr>
<td>Shofu4</td>
<td>86.6% (13/15)</td>
<td>6.7% (1/15)</td>
</tr>
</tbody>
</table>

Emax groups = lithium disilicate crowns bonded to a 6-mm abutment (Emax6) or a 4-mm abutment (Emax4); Shofu groups = composite resin crowns bonded to a 6-mm abutment (Shofu6) or a 4-mm abutment (Shofu4). Values are presented as percentages (number of occurrences/total group number).