Fracture Strength of Implant Screw-Retained All-Ceramic Crowns with the Use of the Angulated Screw Channel: A Pilot Study

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To correct for angulation discrepancies in the maxilla, implant companies have designed angulated screw channel (ASC) abutments. The design of these abutments allows for the restorative screw channel to be placed up to 25 degrees off the center axis of the implant. Minimal independent research has been published to evaluate the fatigue resistance of this implant-abutment connection. This study evaluated the fracture strength of a newly designed zirconia crown with a 25-degree angulated screw channel (n = 5) vs a straight channel (n = 5). Each specimen was subjected to an off-axis compression load from an MTS cyclic loading machine with a custom-designed indenter simulating a natural dentition. All the 25-degree angulated screw channel specimens failed, with four of the five (80%) catastrophically failing. Four of the five straight-channel specimens failed, with two of the five (40%) catastrophically failing. Results revealed the potential abutment fracture from internal stresses at the screw-zirconia and metallic-zirconia interfaces. Further research is needed to test the use of all-ceramic crowns with the use of the angulated screw channel.


Systematic reviews demonstrate that the survival rate of single-implant-supported restorations (89.4%) exceeds conventional tooth-borne fixed partial dentures (89.1%).¹,² Due to peri-implantitis concerns and the desire for retrievability, screw-retained implant restorations are preferred. Cemented implant restorations can create excess cement, which has been associated with signs of peri-implant disease in most cases (81%).³,⁴ Moreover, peri-implant soft tissues respond more favorably to screw-retained crowns when compared to cement-retained crowns.⁵

Due to the anatomical angulation of the maxillary anterior region, the presence of buccal concavities, and the resorption of the maxillary alveolus, implants in this region often require cement-retained crowns with custom abutments to correct for angulation discrepancies and prevent facial screw-access holes. The implant is often placed with an angulation in which the apex of the implant is palatal to where the position of the apex of the tooth root existed pre-extraction.

The mean maximum occlusal force in the anterior region is 250 to 300 N, with some patients able to generate a force of 605 N. An ideal material should have a fracture resistance equivalent to a patient’s potential maximum occlusal force.⁶

Many clinicians use ceramic implant...
abutments for their superior mechanical properties and white color. Zirconia is such a material and has a high elastic modulus of 215 GPa and a flexural strength exceeding 1,000 MPa. Zirconia is a brittle material that requires a minimal thickness of 0.5 to 0.7 mm, which must be increased in areas of high stress.

Research has demonstrated two-piece zirconia abutments with a metallic base present higher fracture resistance and superior strength when compared to one-piece ceramic abutments. Alternatively designed abutments (compared to the original manufacturers) have the potential to decrease fracture resistance due to removal of the metallic interface and introduction of zirconia into the implant.

The angulated screw channel (ASC; Nobel Procera, Nobel Biocare) was designed to be inserted with a titanium screw with a 45-degree angled portion seating against a 45-degree angled zirconia seat. This special screw is torqued to 35 Ncm as recommended by the manufacturer, and therefore the zirconia abutment, titanium adapter, and implant fixture are held together with a clamping force. This clamping force may be detrimental to these restorations. Pressure from the abutment screw creates wedging forces, which generate high hoop stresses on the inner walls of the ceramic abutment, leading to catastrophic failures. In a 2009 study, five clinically failed abutments with an external metal hex were evaluated. Fractographic examination revealed a critical crack in three of the five abutments, located on the internal surface of the zirconia where it contacted the metallic screw nut.

In a 2016 study, examining the fatigue behavior between full zirconia and titanium-based abutments, failures of titanium-based abutments were either due to zirconia fracture or debonding of the titanium insert to the zirconia abutment. Another mechanism of failure is internal, due to the differences in hardness of titanium and zirconia. Zirconia is five to nine times harder than titanium. There have been documented cases of the “titanium tattoo.” This occurs when the zirconia wears the titanium, and titanium particles embed in the peri-implant tissues.

The rotational torque force generated by torqueing a screw in place causes elongation of the screw and a clamping force. This clamping force provides the stable joint between implant and abutment. The higher the preload, the higher the fatigue strength and the lower the risk of screw loosening. The preload is transferred through the ASC system and results in a compressive force between: screw and zirconia crown; crown and titanium adapter; adapter and implant; and screw and implant (Fig 2). The torque within the screw when the screwdriver access is tilted 25 degrees from the screw is decreased by 10% compared to the torque applied at the screwdriver access if the driver access is in line with the screw. This decrease in effective torque at the screw head will result in a decrease in preload and a less stable joint.

As the angulation of correction is increased from 0 to 25 degrees, not only does the preload decrease but the amount of material used in crown fabrication decreases. With larger angulation correction, the crown access opening increases and there is a less-circumferential ceramic material. To complete dynamic fatigue testing of a dental implant system, ISO 14801, developed in 2007, is used. The system should be tested in its “worst case” scenario. Therefore, experiments conducted

Fig 1 The use of the ASC system in the anterior maxilla.
on the ASC should be with the use of the 25-degree correction.

In a 2017 study, Greer et al looked at 60 patients who received 84 conical connection implants. Ninety percent of the implant crowns were restored with an ASC implant crown. Three patients (4%) returned with mechanical complications, including a loose screw, ceramic fracture, and implant failure. This study does not break down the degree of correction used in the ASC. Two other publications are only case reports with no long-term follow-up. A PubMed search of the literature, there is no research on the ASC and its fracture strength.

The purpose of this study was to evaluate the fracture strength of monolithic zirconia screw-retained implant crowns placed with an ASC vs a straight screw channel on a maxillary central incisor implant. The null hypothesis was that there is no difference in fracture strength between straight-channel and ASC systems of one-piece monolithic zirconia crowns.

**Materials and Methods**

An articulated soft gingiva Dentof orm (SM-PVR-860, Columbia) with removable Ivorine teeth was used to fabricate maxillary central incisor crowns. The maxillary left central incisor was removed from the dentoform and a polyvinyl siloxane (Heavy-Body SHARP Premium Wash, Parkell) impression was captured using a stock tray. Impressions were poured in type IV dental die stone (GC FUJIROCK EP, GC America) according to the manufacturer’s recommendations in a vacuum mixer.

Two 4.3-mm implant replicas (NobelActive, Nobel Biocare) were embedded in GC resin. One implant was inserted in resin vertically (0 degrees) with the aid of a Ney surveyor. It was placed palatally and 3 mm apical to the midfacial tissue for access through the cingulum (Figs 3a and 3b). The second implant was placed at a 25-degree angle from the occlusal plane and 3 mm apical to the midfacial tissue with the aid of a Ney surveyor (Figs 3c and 3d). The maxillary central incisor was waxed and scanned. Ten computer-aided design/computer-assisted manufactured (CAD/CAM) maxillary central incisor monolithic zirconia crowns (Nobel Procera, Nobel Biocare) were fabricated. Crowns 1 through 5 were monolithic zirconia with a titanium insert and 25-degree angulated screw channel. The 25-degree abutment passed the default settings. Crowns 6 through 10 were monolithic zirconia with a titanium insert and straight screw channel.

The screw-retained restorations were directly attached to actual implants (4.3 × 10 mm, NobelActive) embedded in GC resin to the height of the platform to simulate an implant placed to bone crest. The most common length of a dental implant employed is between 8 to 15 mm and the length of the root of a maxillary central incisor is 13 mm. Simulating the clinical environment, a 10-mm implant was selected. The holder for the implant was custom-milled to the exact specifications of the vice grips on the cyclic loading machine. Each crown was torqued with a torque driver and Omnigrip Screwdriver to 35 Ncm as recommended by the manufacturer. After a 15-minute waiting period, the occlusal screws were retightened again to 35 Ncm. All access holes were closed with polytetrafluoroethylene film (Teflon tape) to 2 mm apical to the direct buccal occlusal access hole measured with a periodontal probe. Bulk composite resin (Esthet-X HD, Dentsply Sirona) was placed, light cured for 30 seconds, and finished with composite finishing burs and an enhance PoGo cup (Enhance PoGo, Dentsply Sirona). This experiment adapted and modified the ISO 14801:2007. The implant was embedded in GC resin to the height of the platform to simulate the implant placed at crest. Due to the limitations of testing conditions, the samples were not embedded in a solution during testing and a maximum of 334,800 cycles were run. ASC crowns are one-piece monolithic crowns. Therefore, to simulate a clinical scenario, a hemispherical loading member was not placed on each sample. Loading was directly on the crown specimen.
Each specimen was subjected to an off-axis compression load from a calibrated MTS cyclic loading machine (MTS 810, MTS). This is a closed-loop servohydraulic testing machine run in load control. Compressive sinusoidal fatigue load cycles (minimum load: 10 N; maximum load: 200 N) were applied to the specimens at 15 Hz, with a maximum number of 334,800 cycles. It is important to note that 250,000 cyclic loading cycles represent 1 year of clinical service. Two-hundred N was selected as the maximum load at which the endosseous dental implant system was tested.

Each specimen was contacted approximately 2 mm from the incisal edge with a 5-mm stainless steel ball indenter to measure fracture resistance (Fig 4). The indenter measured a Rockwell hardness of C28, which is equivalent to a Vickers hardness of 286. Enamel measures a Vickers hardness of 274.8 ± 18.1. Therefore, the indenter simulated an opposing natural dentition. A failure was defined as ceramic fracture. A catastrophic failure was defined as screw bending, screwhead fracture, or a ceramic fracture that would not allow the crown to be left intraorally. All failed abutments were photographed with a light microscope (SZX12, Olympus; Bioquant Osteo Software). Survival analysis was performed with IBM SPSS Statistics software, version 24. Kaplan-Meier statistical analysis was used to estimate survival functions.

Results
CROWNS 1 THROUGH 5 (ASC) ALL FAILED, WITH FOUR (80%) HAVING CATASTROPHIC FAILURES. CROWNS 1, 2, 4, AND 5 (FIG 5) EXPERIENCED AN INCISAL-CERVICAL CINGULUM FrACTURE FOLLOWED BY A CATASTROPHIC FrACTURE AT THE PALATAL...
junction of the titanium insert and zirconia. Crown 3 fractured at the cingulum with no catastrophic fracture. Crowns 6 through 10 were the straight screw channels. Two (40%) straight screw-channel crowns catastrophically fractured: Crowns 7 and 10 experienced an incisal-cervical cingulum fracture and a catastrophic fracture at the palatal junction of the titanium insert and zirconia crown. Crowns 6 and 9 (Fig 6) fractured at the cingulum with no catastrophic fracture. Crown 8 did not experience any fractures.

Table 1  Incisal-Cervical Fractures of ASC and Straight Crowns

<table>
<thead>
<tr>
<th>No. of cycles per group</th>
<th>Status</th>
<th>Cumulative proportion of surviving crowns at no. of cycles</th>
<th>No. of cumulative events</th>
<th>No. of remaining cases (per group)</th>
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<tr>
<td></td>
<td></td>
<td>Estimate</td>
<td>SE</td>
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<tr>
<td>ASC</td>
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<td>0.800</td>
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<td>3,600</td>
<td>0.600</td>
<td>0.219</td>
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<tr>
<td></td>
<td>6,300</td>
<td>0.400</td>
<td>0.219</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>19,800</td>
<td>0.200</td>
<td>0.179</td>
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<td>53,100</td>
<td>0.000</td>
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<td>5</td>
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<tr>
<td>Straight channel</td>
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<td>0.800</td>
<td>0.179</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2,250</td>
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<td>0.219</td>
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<td>3,600</td>
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</table>

SE = standard error; ASC = angulated screw channel. For the status, 0 indicates no incisal-cervical fracture and 1 indicates incisal-cervical fracture.
Table 1 illustrates the survival times for incisal-cervical fractures for ASC and straight crowns. The mean number of cyclic loads for incisal-cervical fracture in the ASC group was 16,650 (standard error [SE]: 9,691.21). The mean number of cyclic loads for incisal-cervical fracture in the straight channel group was 135,270 (SE: 84,130.39). Although the difference between the groups was not statistically significant ($P = .474$), the straight screw-channel crowns survived a greater number of cycles prior to incisal-cervical fracture than the ASC crowns (Fig 7).

Table 2 illustrates the survival times for catastrophic fracture for ASC and straight crowns. The mean number of cyclic loads for catastrophic fracture in the ASC group was 83,385.00 (SE: 56,833.12). The mean number of cyclic loads for catastrophic fracture in the straight channel group was 212,940.00 (SE: 67,256.25). Although the difference between the groups was not statistically significant ($P = .206$), the straight screw-channel crowns survived a greater number of cycles prior to catastrophic fracture than the ASC crowns (Fig 8).

**Discussion**

Results of this study reveal the potential abutment fracture from hoop stresses at the screw-zirconia and metallic-zirconia interfaces. All the 25-degree ASC specimens failed, with four of the five (80%) catastrophically failing. Four of the five straight-channel specimens failed, with two of the five (40%)...
catastrophically failing. It is interesting to note that all ceramic fractures occurred in the cingulum area in an incisal-cervical direction. The crack occurred from the apical part of the screw-access opening to the level of the titanium adapter.

The fractured specimens were evaluated under a light microscope to identify patterns. Due to the triangular geometry of the titanium adapter, the internal aspect of each ASC crown is also triangular to receive the adapter. It is at the apex of the triangle where the fracture is present. This area of zirconia is 0.432 mm thick and may be a weak point. All fractures within the ASC crowns were through-and-through fractures. Although the thickness of zirconia is the same around the titanium adapter on both the 0-degree (straight screw-channel) and 25-degree crowns, the thickness of zirconia is greater circumferentially around the area of the cingulum in the 0-degree specimens. This may contribute to their ability to withstand catastrophic failure. Moreover, as seen in crowns 3 (ASC), 6, and 9 (straight screw-channel), an incisal-cervical fracture in the cingulum was not followed by a catastrophic failure after 334,800 cycles. The presence of titanium on the zirconia crown reinforces the fact that zirconia is harder than titanium and can cause wear and deformation of the titanium surface over time. This may negatively impact the longevity and survival of the ASC crown and system.

Premachined titanium and cast metal abutments (noble metal) are the standard due to their strength, biocompatibility, and ductile nature. With factors such as gingival recession, thin biotype, and increased demand for esthetic restorations, among other factors, metal abutments can present an esthetic complication. Ceramic abutments are esthetic but they are brittle and function poorly under tensile and functional stresses. Research has proven that two-piece zirconia abutments with a metal insert exhibit a higher fracture resistance than one-piece zirconia abutments. Zirconia is a widely used dental material due to its white color and high strength. However, zirconia is produced in cylindrical blocks and each batch may vary, with differing densities and purities depending on the block.

It should be noted that 200 N may be an inappropriate accelerated load and further investigation is needed. The literature is misleading regarding functional loads and there is a growing need to create an international standardization of fatigue testing of dental restorations. Moreover, in accordance with ISO protocol 14801, a hemispherical loading member (cap) should be placed on the test specimen prior to loading, and the specimen holder should be rotated such that its axis makes an angle of 30 ± 2 degrees with the loading direction of the testing machine.

Conclusions

The null hypothesis that there is no difference in fracture strength between straight-channel and ASC types of one-piece monolithic zirconia crowns was not rejected. However, due to the nature of this study, further research is needed to test the use of all-ceramic ASC crowns with an increased sample size, decreased maximal load (100 N, 150 N), increased sinusoidal fatigue load cycles, and testing in a wet environment to simulate oral cavity conditions. Additionally, comparative studies of ASCs from other companies should be conducted. Until further research is completed, the ASC should be used with caution. If fracture strength proves to be adequate, the clinician can provide an aesthetic and retrievable implant crown for an angulated maxillary implant.

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References


