Zirconia Implant Abutment Fracture: Clinical Case Reports and Precautions for Use

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Purpose: Zirconia was recently introduced as a ceramic implant abutment due to its superior mechanical properties and white color. Nevertheless, it requires careful handling to avoid unexpected failure. The aim of this study was to examine five clinically broken zirconia implant abutments using fractography principles. **Materials and Methods:** Five clinically fractured zirconia abutments were retrieved for fractographic analysis. The specimens were cleaned, sterilized, and reassembled to allow reconstruction of the broken abutments. Each fragment was gold sputter–coated and individually examined using scanning electron microscopy. The location of the crack origin was identified and the stress at failure was estimated using fracture marks observed on the broken surfaces. **Results:** For three abutments, the critical crack was located at the internal ring where the abutments met the internal metallic component. The estimated stress at failure ranged between 978 and 1,228 MPa. Friction landmarks were observed on the surface of the fixation screw, which could be responsible for the generation of high internal stresses. Two abutments broke due to overpreparation and thinning of the lateral walls. **Conclusion:** A confirmatory radiograph is recommended before the final zirconia abutments are screwed into place to prevent improper seating and the generation of damaging internal stresses.
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Due to their superior mechanical properties, zirconia-based materials expanded the design scope and application limits of all-ceramic restorations. When combined with modern computer-aided design/computer-assisted manufacture (CAD/CAM) systems, the production of accurate and complex zirconia frameworks requires little more than a few keyboard clicks. Additionally, zirconia is a white framework material that provides superior esthetics, especially when the margin of the preparation is located supragingivally and the available space cannot accommodate the required minimal thickness to build the required ceramic veneer.[1]

On the other hand, zirconia has different mechanical and physical properties when compared to the standard titanium implant abutments, and requires meticulous attention to numerous factors to achieve optimal results. One of the most important factors that can directly affect its performance is the abutment design. Despite a high elastic modulus (215 GPa) and flexure strength (1,000 MPa) that exceed those of many metallic alloys, zirconia cannot be used in thin sections due to its characteristic brittleness.[2] For fixed restorations, the required minimal thickness lies between 0.5 and 0.7 mm, which must be increased in areas subjected to high stresses (eg, connector regions) and demands careful handling of these abutments.[3]

Using zirconia for the production of implant abutments is further complicated by the problem of providing adequate screw fixation to the implant body. This problem is solved by insertion of a friction fit screw-nut, which provides an external or internal hex for the establishment of a proper connection with the implant body (Procera Zirconia, Nobel Biocare). Nevertheless, this unique assembly demands sensitive handling to perform its expected function and to prevent damaging either of its components. The aim of this study was to examine five clinically broken zirconia implant abutments using fractography principles.

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Table 1 Specimen Data and Fractographic Analysis

Specimen*	Location†	Age (y)/ sex	No. of screw loosenings	Service time (d)	Location of critical crack	Stress at failure
1	14	25/F	2	97	Internal ring where zirconia abutment meets metallic nut	1,010 MPa
2	14	37/M	1	132	Internal ring where zirconia abutment meets metallic nut	978 MPa
3	24	45/F	3	28	Internal ring where zirconia abutment meets metallic nut	1,228 MPa
4	14	34/M	3	98	Lateral wall, overreduction	–
5	12	42/M	2	188	Lateral wall, overreduction	–

M = male; F = female; – = not calculated.
*All abutments were Procera Nobel Biocare with an external metallic hex and standard platform. All implants were Straumann Standard RN 4.8 restored with zirconia-veneered crowns.
†FDI tooth-numbering system.

Materials and Methods

Five clinically fractured zirconia abutments (Procera Zirconia, Nobel Biocare) were retrieved by the authors for fractographic analysis, and patient dental records were provided by the treating clinicians (Table 1). Treating clinicians indicated that on more than one occasion, the metallic screw-nut was loosened from the fitting surface of the zirconia abutment and that they had to manually reassemble the components. The metallic screw was tightened using a torque control system suggested by the manufacturer (35 Ncm). All abutments were produced using CAD/CAM technology, giving customized individual abutments for a Straumann implant body. After sintering, a metallic screw-nut (friction fit) was inserted using a special press so as to provide connection with the implant body.

Digital photographs of the broken fragments were taken and the fragments were ultrasonically cleaned, sterilized, dried, and gold sputter–coated for scanning electron microscopic (SEM) examination (XL30, Philips). The fragments were morphologically reassembled according to the shape of the abutments to allow the establishment of proper orientation during examination.

The fragments, including the overlying zirconia-veneered crowns, were first examined under oblique light to allow recognition of the critical failure site, followed by SEM examination at different magnifications. The location and dimensions of each critical crack were identified using the mirror, mist, and hackle regions as characteristic landmarks.[4] The dimensions of the critical crack (Cr) were calculated using the following equation[5]:

$$Cr = 0.75(a \times b)^{1/2}$$

where "a" is the crack depth and "b" is half the crack width. The stress at failure (Q) was calculated using the following equation[6]:

$$Q = K_{ic}/1.24 \times (Cr)^{1/2}$$

where "K_{ic}" is the critical stress intensity factor of zirconia (set to 5.7 $MPam^{1/2}$ according to a previous publication[7]). Further signs of damage such as friction marks, microcracks, and grain pull-out were identified and used to elaborate on the failure mechanism of the broken restorations.

Results

Fractographic examination of the fragments was successful in recognizing the critical crack for three abutments (Figs 1 to 3). The location of each critical crack was on the internal surface of the zirconia abutments, where it made contact with the metallic screw-nut (Figs 1a and 1b). The dimensions of the critical crack allowed for an accurate estimation of the generated stress at failure (978 and 1,228 MPa), which was very close to the internal strength of zirconia materials used for dental applications (Figs 1c, 2b, and 3). SEM examination revealed the presence of friction and abrasion marks on the internal surface of the zirconia abutments, as well as on the head of the fixation screw (Fig 1e). The other two specimens were fractured due to overreduction of the lateral walls (Figs 4a and 4b), which resulted in thin cross sections at the site of fracture (ca: 324 μm) (Table 1).

Patient records indicated that they reported minor movements of the implant-supported crowns, which required crown removal (temporarily cemented for all patients) and tightening of the fixation screw. The clinicians also reported difficulty related to reinsertion of the metallic screw-nut in the fitting surface of the zirconia abutments.

Fig 1a Digital photograph of specimen 1 indicating the location of the critical crack in one of the fragments.

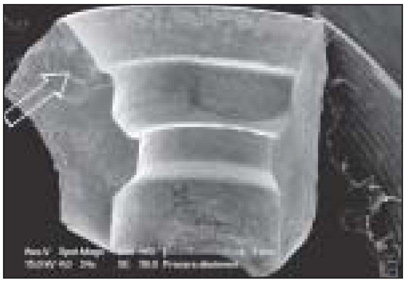
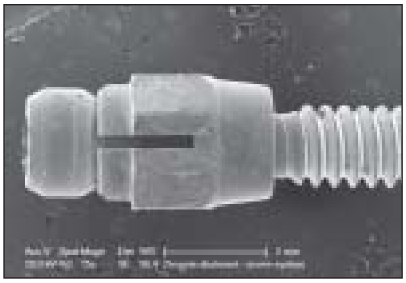


Fig 1b SEM image of specimen 1 indicating the location of the critical crack where the abutment made contact with the metallic fixation screw. White arrows indicate the location of the arrest lines (magnification ×24).

Fig 1c SEM image of specimen 1 demonstrating the dimensions of the critical crack (magnification ×50).



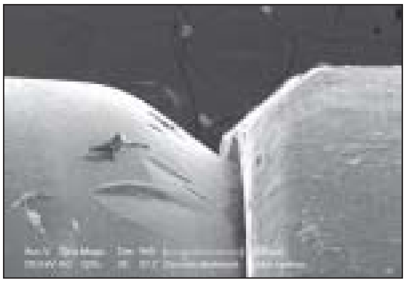


Fig 1d *(left)* SEM image of specimen 1 demonstrating the fixation screw and metallic nut assembly. The vertical slit in the nut is designed to allow a frictional fit, and pressure from the screw head could generate wedging forces (magnification ×15).

Fig 1e *(right)* SEM image of specimen 1 demonstrating friction marks on the fixation screw, which could result in opening the vertical slit and the generation of internal stresses inside the zirconia abutment (magnification ×120).

Fig 2a Digital photograph of specimen 2 demonstrating fragments of a broken specimen.

Fig 2b SEM image of specimen 2 demonstrating the dimensions of the critical crack (magnification ×650).

Fig 3 SEM image of specimen 3 demonstrating the dimensions of the critical crack (magnification ×800).

Fig 4a Digital photograph of specimen 4 demonstrating fracture of the axial walls due to overreduction.

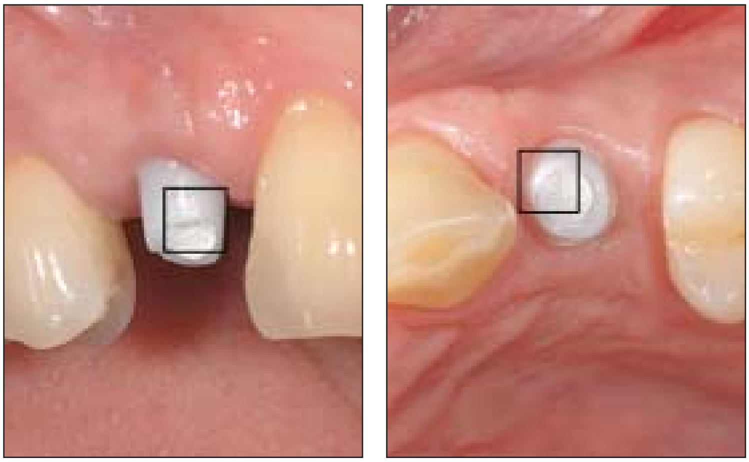


Fig 4b *(right)* Intraoral view of specimen 4 demonstrating thinning of the axial wall due to overreduction.

Discussion

Even though laboratory fracture strength tests indicate that zirconia-based materials are strong enough to resist loading forces in the posterior dental region, they do not account for the significant influence of design, pattern of stress distribution, and degradation of material properties as a result of fatigue. This fact underscores the clear need for long-term clinical studies with a larger data pool to support such findings.[3]

The design and application procedures of metallic abutments were idealized to gain full benefit of the elastic behavior of these materials. This permits the accommodation of some degree of elastic deformation during screw tightening, resulting in a reliable fixation to the implant body. Moreover, these alloys can also accommodate the plastic deformation generated due to friction between the different components.

Unfortunately, zirconia is a very sensitive material and fracture is the first sign of stress overloading—a characteristic feature of all-ceramic restorations. Due to its high surface hardness and brittleness, high stresses are generated at contact points between the ceramic abutment and any other implant component. A limited degree of rotational freedom in combination with a slight misfit could result in the generation of high stresses at the abutment–screw-nut interface, leading to a loosening of the assembled components.[8,9]

Fractographic examination of the broken abutments revealed that the critical crack was located where the zirconia abutment made contact with the fixation metallic screw. Tightening the fixation screw beyond the recommended torque could not only lead to the generation of very high stresses in this region, but could also induce high stresses at the screw head, which generates wedging forces inside the abutment. SEM examination of the metallic screw-nut revealed the presence of a vertical slit that is designed to allow a frictional fit between the metallic nut and the inner walls of the abutment (Fig 1d). Pressure from the fixation screw could generate wedging forces, which in turn could generate very high Hoop stresses on the inner walls of the ceramic abutment. It should be emphasized that the history of screw loosening in the fractured specimens, the influence of fatigue, and the surface damage observed on the screw surface failure could also have occurred at much lower values.[8,10] It may also be surmised that careful seating of the zirconia implant abutment and using torque control instruments could possibly prevent the generation of these destructive forces. A radiograph is therefore recommended before the final tightening of the fixation screw to make sure that the whole assembly is properly oriented.[9] Additionally, unexpected failure of zirconia abutments could be related to other causes such as defects in the fabrication process, fractures in the green structure, sintering prestresses, or handling errors.

Two abutments fractured due to overreduction of the axial walls. In order for the zirconia abutment to resist the applied functional loads, the minimal wall thickness should not be reduced beyond 0.5 to 0.7 mm. Overreduction could be a result of a correction of the path of insertion of angled zirconia abutments. In such cases, using a titanium abutment may be more advantageous.

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References

1. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent 2007;35:819–826.
2. Wang H, Aboushelib MN, Feilzer AJ. Strength influencing variables on CAD/CAM zirconia frameworks. Dent Mater 2008;24:633–638.
3. Aboushelib MN, Feilzer AJ, Kleverlaan CJ. Bridging the gap between clinical failure and laboratory fracture strength tests using a fractographic approach. Dent Mater 2009;25:383–391.
4. Taskonak B, Yan J, Mecholsky JJ Jr, Sertgöz A, Koçak A. Fractographic analyses of zirconia-based fixed partial dentures. Dent Mater 2008;24:1077–1082.
5. Mecholsky JJ Jr. Fractography: Determining the sites of fracture initiation. Dent Mater 1995;11:113–116.
6. Mecholsky JJ Jr. Fracture mechanics principles. Dent Mater 1995;11:111–112.
7. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. Dent Mater 2004;20:449–456.
8. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. An in vitro evaluation of titanium, zirconia, and alumina procera abutments with hexagonal connection. Int J Oral Maxillofac Implants 2006;21:575–580.
9. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. An in vitro evaluation of ZiReal abutments with hexagonal connection: In original state and following abutment preparation. Int J Oral Maxillofac Implants 2005;20:108–114.
10. Wiskott HW, Jaquet R, Scherrer SS, Belser UC. Resistance of internal-connection implant connectors under rotational fatigue loading. Int J Oral Maxillofac Implants 2007;22:249–257.