Fracture of Reduced-Diameter Zirconia Dental Implants Following Repeated Insertion

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Purpose: *Achievement of high insertion torque values indicating good primary stability is a goal during dental implant placement. The objective of this study was to evaluate whether or not two-piece implants made from zirconia ceramic may be damaged as a result of torque application.* ***Materials and Methods:*** *A total of 10 two-piece zirconia implants were repeatedly inserted into polyurethane foam material with increasing density and decreasing osteotomy size. The insertion torque applied was measured, and implants were checked for fractures by applying the fluorescent penetrant method. Weibull probability of failure was calculated based on the recorded insertion torque values.* ***Results:*** *Catastrophic failures could be seen in five of the implants from two different batches at insertion torques ranging from 46.0 to 70.5 Ncm, while the remaining implants (all belonging to one batch) survived. Weibull probability of failure seems to be low at the manufacturer-recommended maximum insertion torque of 35 Ncm. Chipping fractures at the thread tips as well as tool marks were the only otherwise observed irregularities.* ***Conclusion:*** *While high insertion torques may be desirable for immediate loading protocols, zirconia implants may fracture when manufacturer-recommended insertion torques are exceeded. Evaluating bone quality prior to implant insertion may be useful.* INT J ORAL MAXILLOFAC IMPLANTS 2017;32:971–975. doi: 10.11607/jomi.5592

Keywords: *dental implant, fluorescence penetrant method, fracture torque, zirconia*

Primary stability of dental implants is a decisive goal during implant surgery in order to minimize micromotion[1–3] at the implant-bone interface that may lead to fibrous encapsulation instead of osseointegration.[4,5] Major contributing factors determining the primary stability of dental implants are bone quality, the surgical technique used, and the design of the implant system.[6,7] In the case of poor bone quality, implantologists tend to opt for undersized drilling,[7,8] the use of bone-condensing osteotomes[9] instead of burs, and implant insertion without thread preparation.

From a biologic point of view, these measures lead to compression and trabecular fractures[10,11] of the bone surrounding the implant osteotomy, resulting in pronounced bone remodeling during the healing phase.[9] From a technical point of view, the high insertion torques applied may either cause immediate implant fractures[12,13] (Fig 1) or initiate a fracture process that leads to failure of the implant body following subcritical crack growth during the loading phase.[14]

Besides titanium, zirconia is increasingly used as material for dental implants due to obvious advantages with respect to esthetics and biocompatibility.[15] In addition to one-piece zirconia implants, implants with separate abutments have also been introduced either using screws or alternative interlocking features to connect the implant and the abutment.[16] Recent clinical studies show competitive success rates of zirconia implants,[17] although laboratory investigations advocate caution when using zirconia implants.[15] Despite the well-understood transformation-toughening process of zirconia, predamage seems to be more critical in zirconia implants compared with titanium implants due to the brittleness of the material.[18]

The goal of this in vitro study was to investigate by means of the fluorescent penetrant method[19–21] whether inadvertent fractures of the implant body can occur in response to torque during implant placement.[22]

MATERIALS AND METHODS

A convenience sample consisting of 10 two-piece zirconia implants (Zeramex P, Small Neck, 3.3 mm diameter,

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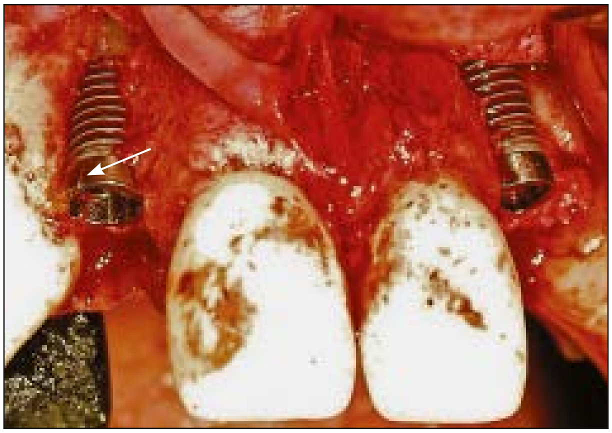


Fig 1 Clinical example of a titanium implant fractured during insertion in an undersized osteotomy created in the area of the maxillary right lateral incisor. The arrow indicates the fracture line in the region of one of the lobes forming the prosthetic interface.

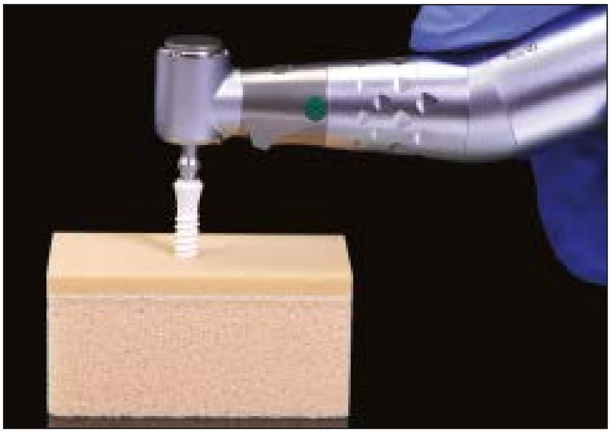


Fig 2 Experimental setup showing polyurethane foam material used as bone surrogate for inserting zirconia implants with a surgical motor (Note: Homogeneous polyurethane blocks were used for the experiment; the composite block shown here was used for pretesting).

Table 1 Characteristics of the Implant Insertion Processes

Insertion	Bone type	Osteotomy size	No. of surviving implants	Mean insertion torque (Ncm)	SD
1	Solid 30 pcf	2.8 mm	10	18.01	3.20
2	Solid 30 pcf	2.7 mm	10	28.98	2.31
3	Solid 40 pcf	2.8 mm	10	31.84	4.38
4	Solid 40 pcf	2.7 mm	9	50.04	2.38
5	Solid 40 pcf	2.7 mm cervical and 2.6 mm apical	6	57.02	7.37
6	Solid 40 pcf	2.7 mm cervical and 2.5 mm apical	5	70.05	0.00

10 mm length, Dentalpoint Germany) was used for this study. According to the manufacturer, the implants are made out of alumina-toughened zirconia (ATZ)–hot isostatic postcompaction (HIP) zirconia consisting of 76% ZrO_2, 20% Al_2O_3, 4% Y_2O_3, which shows a flexural strength of 2,000 MPa.[23] Following the manufacturer's guidelines with respect to insertion speed (15 rpm) and insertion depth, the implants were repeatedly inserted in homogeneous polyurethane foam material (Fig 2) with increasing density simulating clinically relevant classes of alveolar bone (Solid 30pcf, Solid 40pcf, Sawbones Europe). To achieve an increase in insertion torque, osteotomies with decreasing diameters and step cylinder osteotomies were created. The surgical motor (iChiropro, BienAir) used for implant insertion allowed for actively recording the actual torque applied, with the maximum applicable torque being 70.5 Ncm. Following placement, the implants were retrieved from the bone surrogate material for inspection. This procedure was repeated either until the implant fractured or until the maximum torque of 70.5 Ncm had been applied. All details with respect to bone type, osteotomy size, and insertion torque applied are given in Table 1.

Following cleaning with isopropanol (MET-L-CHEK Spezial-Reiniger NPU, Helling), implant bodies were immersed in fluorescent dye (MET-L-CHECK, FP 97 A (M) & MET-L-CHECK Developer D70, Helling) for 24 hours. The specimens were then dried under ambient conditions and inspected under a fluorescent light source (HBO 100, Zeiss) and a microscope (20× magnification; AxioImager A.1, Zeiss). All visible cracks in an implant body were recorded[19–21] using a digital camera (AxioCam MR C5, Zeiss) mounted on the microscope and corresponding software (Imaging Software AxioVision 4.6.3, Zeiss). In addition to inspection after each insertion process, all samples underwent baseline inspection in the state as received by the manufacturer.

A Weibull probability of failure distribution was fitted to the insertion torque values obtained with the following parameters: $\beta = 5.126365$; $\eta = 72.207058$; $\rho = 0.911881$ (ReliaSoft Weibull++; ReliaSoft).

RESULTS

Implants from three different batches were received following the placement of two regular orders (LOT

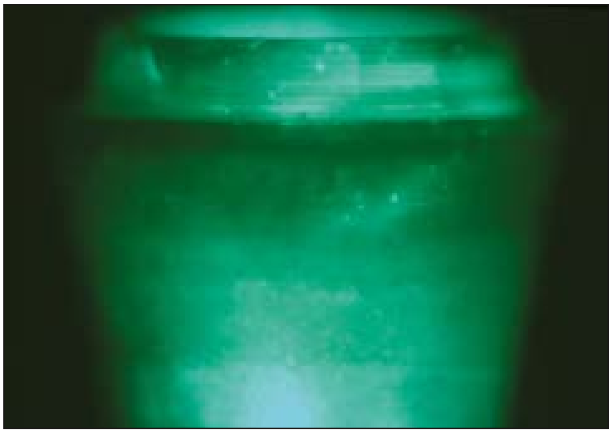


Fig 3a Neck of a Zeramex P, Small Neck, 3.3-mm-diameter implant showing horizontal grooves in the area of the prosthetic interface, indicating tool marks resulting from the fabrication process.

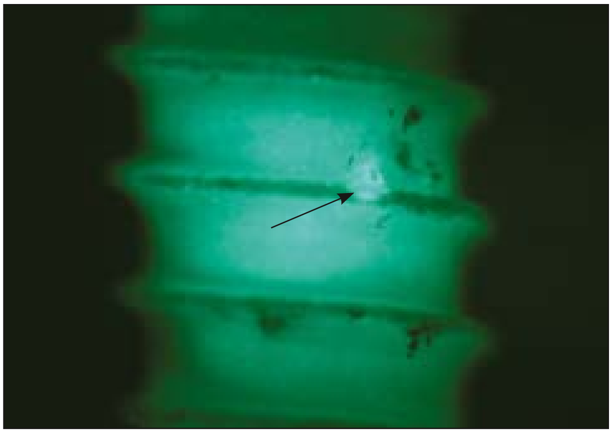


Fig 3b Body of a Zeramex P, Small Neck, 3.3-mm-diameter implant showing a chipping fracture *(arrow)* of thread tip identified with the fluorescent penetrant method.

(10)101131: four implants; LOT (10)101113: one implant; LOT (10)101144: five implants). Besides minor tool marks (Fig 3a), none of the implants received from the manufacturer showed any signs of predamage or fractures during initial inspection. Also, no cracks could be observed in the implant bodies following the various insertion processes (Table 1). Three implants showed minor chipping fractures at the tip of the threads after repeated insertion (Fig 3b). Two of those implants (implants #8 and #10) survived the testing series, while one implant (#6) fractured at a torque of 70.5 Ncm.

Five implants (all belonging to LOT (10)101131 and LOT (10)101113) fractured at torque values ranging from 46.0 to 70.5 Ncm (Fig 4), clearly beyond the manufacturer-recommended maximum insertion torque of 35 Ncm. In all instances, the fracture involved the bottom of the implant-abutment connection, which had already reached a subcrestal position. The remaining implants (all belonging to LOT (10)101144) survived a total of six insertion processes with a maximum torque of 70.5 Ncm.

A Weibull cumulative failure distribution curve was established to assess the probability of failure for the zirconia implants investigated (Fig 5). According to this analysis, the unreliability at a torque of 40 Ncm would be in the range of 4%, whereas approximately 60% of failures should occur at torque levels of 70 Ncm.

DISCUSSION

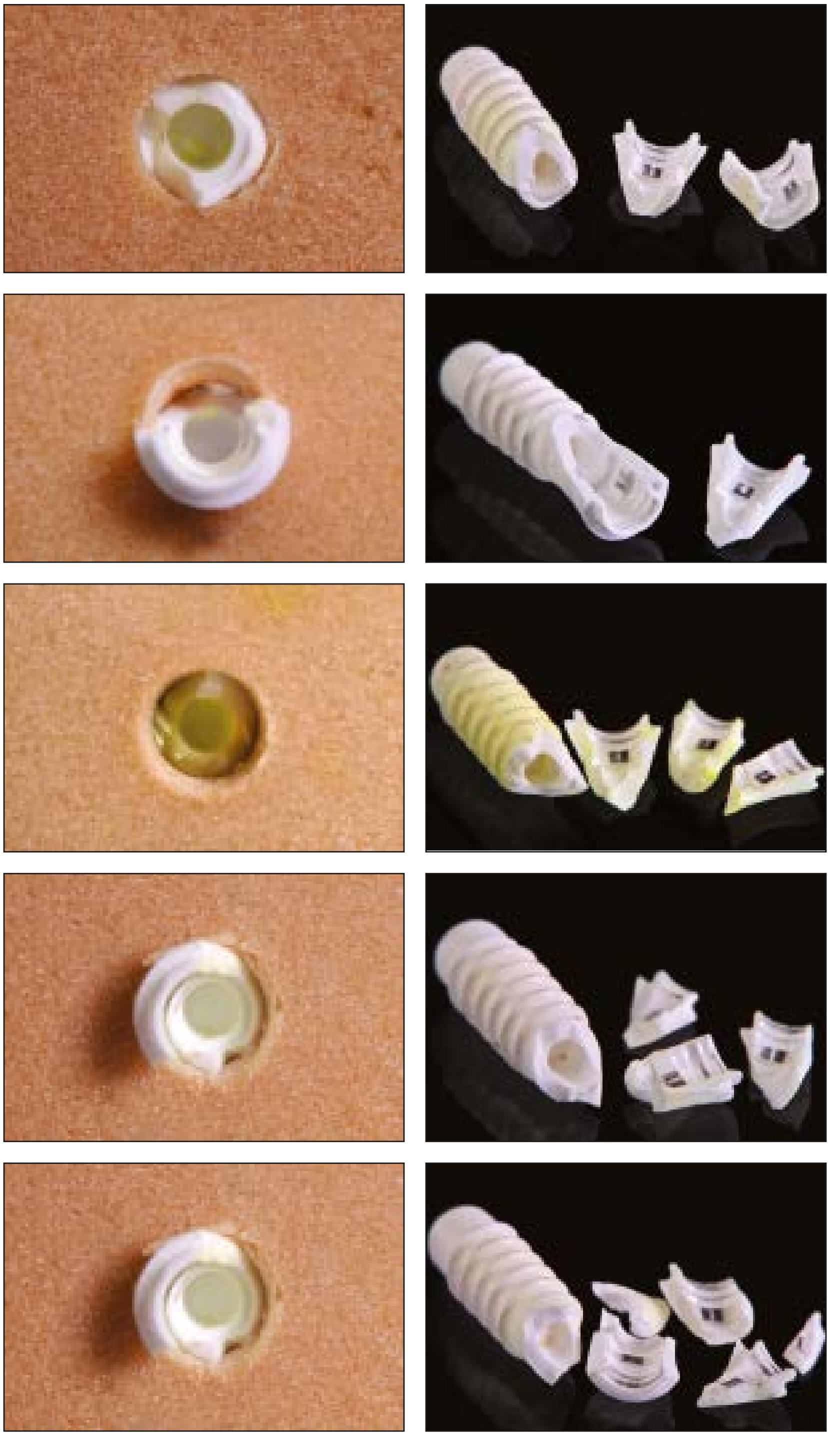
Despite recent clinical studies showing competitive success rates of zirconia implants,[17] concerns exist with respect to the brittle behavior of zirconia ceramic.[15,18]

In this context, it was the goal of this study to evaluate whether or not repeated torque application at clinically relevant levels may cause damage in two-piece zirconia implants.

Other than anticipated, no cracks were detected in the implants, but instead, high insertion torque values caused catastrophic fracture in 50% of the specimens investigated. The torque values required for fracturing the specimens were beyond the maximum torque of 35 Ncm recommended by the manufacturer. As a safety measure, the implant manufacturer offers an insertion tool with a predetermined breaking point. Based on the Weibull analysis performed, this measure should allow for a sufficient safety margin. However, with the maximum applicable torque level being much lower compared with what has been reported by Khayat and coworkers for titanium implants reaching torque values of up to 176 Ncm,[8] immediate loading protocols requiring high levels of implant stability seem to not be feasible.

While obviously not constituting a relevant problem in titanium dental implants,[13] implant fracture seems to be a frequent complication when using orthodontic mini implants,[12,22] which show smaller diameters compared with regular dental implants and are often inserted without extensive osteotomy preparation. The small-diameter zirconia implants used here have to be considered as a worst-case scenario in this context, as comparable implants made from titanium are also not indicated for high loads, specifically to prevent fractures.[24]

Some limitations have to be taken into account when interpreting the results from this in vitro investigation. The fluorescence penetrant method is currently considered as being sensitive enough for detecting relevant cracks in dental restorations. Although it has been shown that this technique is equal or better for detecting cracks than transillumination or scanning electron microscopy,[19–21] it has not been clarified whether all cracks present in a specimen can be identified and whether or not such cracks would ultimately result in clinical fracture of an implant.[18]



Implant #1
(LOT (10)101131)
Fractured at 5th insertion;
46.0 Ncm

Implant #2
(LOT (10)101113)
Fractured at 4th insertion;
47.0 Ncm

Implant #3
(LOT (10)101131)
Fractured at 5th insertion;
61.7 Ncm

Implant #6
(LOT (10)101131)
Fractured at 6th insertion;
70.5 Ncm

Implant #7
(LOT (10)101131)
Fractured at 5th insertion;
53.9 Ncm

Fig 4 Overview of the implants fractured during insertion in polyurethane foam with a density of 40 pcf.

The most relevant limitations of this study pertain to sample size, the chosen in vitro setting, and repeated testing. The bone surrogate material used does not fully mimic the clinical situation of the alveolar bone, which consists of cortical and trabecular layers. Furthermore, lubrication resulting from osseous bleeding following implant site preparation also was not simulated. Instead, increasing bone density and decreasing osteotomy diameters were used for creating a step stress model comparable to implant fatigue testing.[14] However, this approach cannot adequately simulate clinical conditions, as implants normally are only inserted once, which excludes damage accumulation potentially caused by repeated insertion. Fatigue testing of implants showed that remarkable differences may exist between different batches.[14] It may be argued based on the fractures observed here that differences with respect to fracture resistance existed between different batches and that the fractured samples had inherent flaws. Although baseline inspection was performed for all samples, the analyzing method applied may not have been sensitive enough. Consequently, conclusions on batch-dependent behavior should not be drawn due to the limited sample size.

CONCLUSIONS

Within the limitations of this study, it can be concluded that high insertion torque may fracture the body of two-piece zirconia implants. As the exact mechanical properties of a specific implant are unknown, knowledge of the existing bone quality[25,26] and subsequent adaptation of the surgical protocol[11,27] seems to be crucial for avoiding detrimentally high insertion torques. Bone quality testing during implant surgery could aid the clinician in the decision-making process on how to optimize implant surgery without risking implant fractures or unstable implants.[25,26]

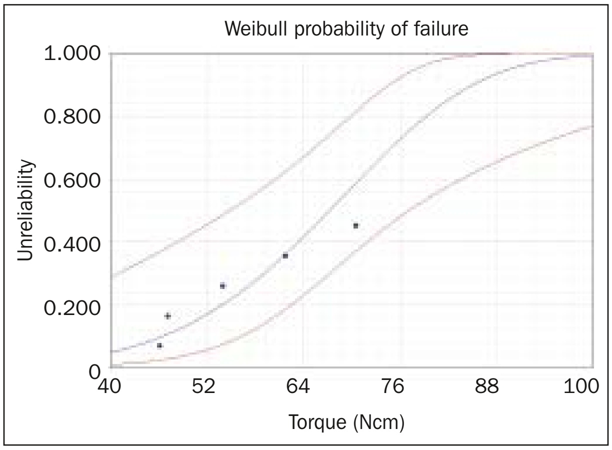


Fig 5 Weibull probability of failure distribution for the zirconia implants tested at increasing insertion torque. The outer lines represent 95% confidence boundaries.

ACKNOWLEDGMENTS

The authors wish to thank Dr Friedrich Graef, Professor emeritus, Department of Mathematics, University of Erlangen-Nuremberg for statistical data analysis. This work has been supported by Nobel Biocare with research grant [2015-1388]. The authors reported no conflicts of interest related to this study.

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