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Schepke, Ulf

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CHAPTER

02

Phase transformation and fracture load of stock and CAD/CAM customized zirconia abutments after 1 year of clinical function

• PART C •

This chapter is an edited version of:

Schepke U, Gresnigt MMM, Browne WR, Abdolahzadeh S, Nijkamp J, Cune MS. Phase transformation and fracture load of stock and CAD/CAM customized zirconia abutments after 1 year of clinical function. Submitted for publication.
Phase transformation and fracture load of stock and CAD/CAM customized zirconia abutments after 1 year of clinical function

Abstract

On theoretical grounds, functional loading and low temperature degradation may give rise to impaired clinical long-term service of zirconia implant abutments. The aim of this study was to determine the volume percentage of monoclinic zirconia (m-ZrO₂) and the fracture strength of stock and CAD/CAM customized zirconia abutments after 1 year of clinical service and compare them to pristine specimen in an ex vivo experiment.

Twenty-three stock (ZirDesign™) and 23 CAD/CAM customized (Atlantis™) zirconia implant abutments were retrieved after 1 year of clinical service. They were reassembled and compared with exact pristine copies on visual inspection of the implant-abutment contact area, with respect to the volume fraction of the monoclinic phase using Raman spectroscopy and their fracture load on static loading by means of a single load-to fracture test ex vivo. Failure analysis was performed using optical and SEM microscopy. After verification of normal distribution, t-tests were used for comparisons in fracture loads, both between pristine abutments of both abutment types and relative reduction in time. P-values <0.05 were considered significant.

Visual inspection suggested a difference in implant-abutment contact area between the two abutment types, with the stock abutments exhibiting a more uniform fit. No m-ZrO₂ volume percentages beyond the detection threshold of 5% were observed in any of the samples. Mean relative fracture loads were 78.8% (SD 29.5%) for stock abutments and 103.9% (SD 15.1%) for CAD/CAM abutments after one year of clinical function. The reduction in fracture strength for stock zirconia abutments was statistically significant (p<0.05).

After 1 year of clinical service, no substantial tetragonal to monoclinic transformation was observed on the surface of the zirconia abutments. The studied CAD/CAM customized zirconia implant abutments were as strong as their pristine copies, whereas the stock zirconia abutments demonstrated a considerable reduction in fracture strength.
Introduction

Traditionally, titanium (Ti) is chosen as the ground material for implant abutments because of its well-documented biological properties and mechanical strength. Unfortunately Ti has some drawbacks, primarily because of its color that may cause blue-greyish shimmering in cases with thin overlying mucosa.\(^1\,^2\) Modern high strength ceramics such as Yttria-stabilized Tetragonal Zirconia Polycrystal (ZIRCONIA) exhibit similar biological,\(^3\,^4\) but better optical dynamics than Ti.\(^2\) It is white and can be stained by adding traces of rare earth elements.\(^5\)

Results from in vitro experiments indicate that, like Ti, they should be able to withstand physiological, functional occlusal forces.\(^6\,^10\) The material and design of an abutment reflects on the mechanical aspects such as the bending moment as demonstrated in many in vitro studies. In general and in overview, Ti abutments with internal, conical connections are stronger than abutments with an external, hexagonal connection and stronger than zirconia abutments. Hybrid zirconia abutments with a secondary metallic ring are stronger than one-piece, monolithic zirconia abutments.\(^11\,^23\) In addition, the implementation of a Ti interface induces less wear to the Ti internal implant body than when a monolithic abutment is used.\(^24\,^26\) Differences in mechanical strength between geometrically identical stock and CAD/CAM customized abutments are not observed.\(^12\) Small diameter zirconia abutments are less resistant to static loads than abutments with greater diameters and should be used with caution.\(^27\) Angulated zirconia abutments are more prone to fracture than straight ones.\(^28\,^29\) Fracture behavior of a zirconia abutment is also dependent on whether or not the abutment is restored\(^16\) and by the geometry of the crown.\(^30\) Preparation of zirconia implant abutments does not reduce its fracture resistance significantly.\(^7\)

The few clinical studies with medium to long term results that are available present acceptable results for various abutment types. Failure rates and incidence rates of technical complications are limited and appear similar for ceramic and titanium implant abutments.\(^4\,^31\,^38\) However, fracture of zirconia implant abutments is both anecdotic and reported in the literature.\(^36\,^39\,^40\)

Concerns have been raised with respect to the reduction in strength of zirconia materials in time. It has been demonstrated that cyclic-loading causes a reduction of fracture strength of various abutment types.\(^10\) In addition, it is hypothesized that detrimental tetragonal-to-monoclinic phase transformation occurs resulting from mechanical stresses or more spontaneously, as a consequence of hydrothermal degradation, also described as Low Temperature Degradation (LTD) or aging.\(^5\,^41\) In vitro data indeed seem to confirm that the strength of zirconia implant abutments is susceptible to both mechanical and hydrothermal aging.\(^42\) Accelerated aging induces LTD at the surface and concomitant increased roughness. This in turn facilitates the initiation of micro-cracks, which in the laboratory may or may not contribute to a decrease in strength.\(^43\,^44\)

However, the data of the in vitro studies that are available in the literature should be interpreted with care as the studies from which they are derived are rather heterogeneous. Both pristine and mechanically and/or hydrothermically aged implant-abutment assemblies were tested under various load situations.\(^10\)
A shift in volume percentage of monoclinic zirconia (m-ZrO$_2$) can be interpreted as aging of the material and serve as an indirect indication of the reduction in strength of the bulk. ISO 13356:2015 sets the acceptable norm for m-ZrO$_2$ when used as implants for surgery at a maximum of 25% after accelerated aging, which could serve as some kind of reference.\textsuperscript{45}

From a consensus report dating back to 2009\textsuperscript{38} based on the results of a systematic review\textsuperscript{4}, standardisation of strength tests was advised and since then, more \textit{in vitro} studies in the literature abide by the applicable standards set by the International Organisation of Standardisation (ISO 1099:2017 and 14801:2016) on static and fatigue loading of the dental implant-abutment assembly.\textsuperscript{46,47} It is noteworthy that these standards do not include accelerated, artificial hydrothermal aging of the ceramic abutments. In laboratory studies, this is achieved in different ways, i.e. by means of performing the mechanical fatigue loading test in water at room or body temperature (37°C), by means of thermocycling (various numbers of cycles in water of 5-50°C), in steam chambers or steam autoclavation (various spells, under different pressures in 134°C) or is omitted altogether. Ambivalent data are reported with respect to the effect of these hydrothermal challenges on the fracture strength of zirconia in general and implant abutments in particular. From a meta-analysis in which various autoclave protocols of hydrothermal aging were grouped, it was concluded that such protocols indeed promote hydrothermal degradation of zirconia materials, whereas in a recent study that specifically attempted to compare different hydrothermal aging methods, none of them induced reduction of mechanical properties of zirconia and the development of new methodologies is advised.\textsuperscript{48,49} More specifically with respect to the strength of zirconia implant abutments, their susceptibility to hydrothermal manipulations is reported\textsuperscript{42}, whereas others report that artificial aging did not always affect their fracture resistance.\textsuperscript{30}

Drawing conclusions from \textit{in vitro studies} on mechanical behaviour and strength of ceramic implant abutments and relating them to clinical practice is troublesome and gives rise to risky assumptions\textsuperscript{5}, predominantly because the test methods that have been employed in various studies differ considerably and their external validity, both with respect to the mechanical as with the hydrothermal accelerated aging methods has not yet been established, which makes time-consuming clinical studies the more relevant.

The aim of the present study is to compare the volume percentage of m-ZrO$_2$ and the fracture strength of stock and CAD/CAM customized zirconia implant abutments that functioned clinically for 1 year with geometrically identical pristine controls. The null hypotheses are that both volume percentage m-ZrO$_2$ and the fracture strength of a zirconia abutment, be it stock or CAD/CAM customized do not deteriorate significantly after 1 year of clinical function.
Materials and Methods

A single-center, randomized controlled clinical trial was designed, for 52 participants, missing a single mandibular or maxillary premolar. In- and exclusion criteria are listed in table 1.

Table 1
Inclusion and exclusion criteria

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
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<tr>
<td>Missing a first or second premolar in the maxilla or mandible</td>
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<tr>
<td>Desire to replace the missing premolar with an implant</td>
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<tr>
<td>Willing to sign for informed consent</td>
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<tr>
<td>Bone height ≥10 mm beneath the maxillary sinus and ≥10 mm above the mandibular nerve and a bone width of at least 6 mm</td>
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<table>
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<tr>
<th>Exclusion criteria</th>
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<tbody>
<tr>
<td>Missing teeth mesial or distal from implantation site</td>
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<tr>
<td>Orthodontic treatment at the time of impression taking</td>
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<td>Severe bruxism</td>
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<td>Acute periodontitis</td>
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<td>History of implant loss</td>
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<td>Documented extreme gagging reflex</td>
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<tr>
<td>Poor medical condition (ASA* score 3 or higher)</td>
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<td>Previous therapeutic radiation of the head–neck region</td>
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<tr>
<td>Chronic pain in orofacial system</td>
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<tr>
<td>Younger than 18 years at time of inclusion</td>
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<tr>
<td>Reduced mental capacity</td>
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</table>

Permission from the medical ethics committee of the university medical center Groningen, the Netherlands was granted (METc number 2012.388, ABR number NL 42288.042.12) and informed consent was obtained. Primary outcome measure was the relative reduction in mean fracture strength upon static loading between pairs of pristine zirconia abutments and abutments that had functioned clinically for a year, be it stock and CAD/CAM customized.
Implant placement and restorative procedures

Implant treatment consisted of the placement of a single implant (Astra Tech Implant System OsseoSpeed TX 3.5x, Dentsply Sirona Implants, Mölndal, Sweden) in accordance with the manufacturers’ recommendations.

Restorative treatment commenced 3 months later. A screw-retained implant restoration was provided consisting of Resin Nano Ceramic crown (RNC crown, Lava Ultimate, 3M ESPE, Seefeld, Germany), bonded to either a stock (ZirDesign™, Dentsply Sirona Implants) or a CAD/CAM customized zirconia abutment (Atlantis™, Dentsply Sirona Implants) Ground material for both abutment types was Yttria-stabilized Tetragonal Zirconiumdioxide Polycrystal (Y-TZP) according to the requirements of ISO 13356.

After verification of adequate fit and proximal contact points the abutment fixation screw was tightened, using a wrench at the recommended torque (20 Ncm). The abutment fixation screw was protected by sterile teflon tape and the screw access hole was sealed with a glass ionomer restorative material (Fuji II, GC Europe, Leuven, Belgium). Static and dynamic occlusion were checked meticulously.

All restorations were made in triplicate: one served as test specimen to be retrieved after 1 year of clinical service (test), one as a pristine control for paired comparison in the planned, future ex vivo experiments (control). A third, geometrically identical set was made to replace the one that was to be retrieved in order to ensure continued function for the patient. The control specimen were carefully stored in an air tight, dry environment until the time of analyses, in order not to alter the characteristics of the material.

All restorations were made by one and the same dental technician. Occasionally, the stock abutment needed to be shortened to obtain adequate occlusal clearance. This was performed under copious water cooling following a transfer key made from silicone. No further preparation or manipulation of the abutments was performed. The abutment type (figure 1-2), stock or CAD/CAM customized was randomly allocated to each of the participants (www.sealedenvelope.com).
Figure 1
Connection area of two abutments with the characteristic appearance after one year of clinical service. The dotted line denotes the different, predominant fracture lines for CAD/CAM and stock implant abutments - CAD/CAM abutment demonstrating a coronal and apical positioned grey line (left, type I). Stock abutment demonstrating a uniformly distributed grey band right (type II).
Figure 2
Consort flow diagram. Treatment consisted of implants restored with Resin Nano Ceramic crowns that were extraorally bonded to (A) ZirDesignTM (stock) or (B) AtlantisTM (CAD/CAM) customized zirconia abutments.
Raman spectroscopy

Raman spectroscopy is a physical method that can be used to determine the volume percentage of m-ZrO$_2$ in a non-destructive manner. It relies on Raman scattering of monochromatic light, usually from a laser source in the visible, near infrared of near ultraviolet range. Its spectrum forms a crystallographic fingerprint of the material studied, among which is m-ZrO$_2$. The Raman spectroscope that was utilized employs a 632.8 nm laser (HeNe Laser, Thorlabs Inc Newton, New Jersey, USA) and a Shamrock 163 spectrograph with an iDus-420-OE CCD, Andor Technology. An optical Olympus BX51 microscope is used to focus the laser on the region of interest. The scattered light is captured by the same apparatus. The Raman spectrometer was calibrated with polystyrene prior to each measuring session, according to protocol.

First, the spectrum of pure, 100% m-ZrO$_2$ was determined, which produces characteristic bands at wavenumbers 384 cm$^{-1}$ and 477 cm$^{-1}$ which serve as a fingerprint during further analysis (figure 3).

**Figure 3**
Raman spectrum for 100% monoclinic zirconia with characteristic, ‘fingerprint’ bands at 384 cm$^{-1}$ and 477 cm$^{-1}$.

By adding small amounts of m-ZrO$_2$ to pure tetragonal zirconia powder (Sigma-Aldrich Chemie B.V., Zwijndrecht, Nederland), it was determined that these characteristic bands only become discernible at $\geq$ 5% volume percentage m-ZrO$_2$, which should be considered the detection threshold of the method.

The abutment samples were stabilized by means of a putty and the mesial, distal, labial and palatal surfaces of each abutment were examined. The test abutment and its pristine copy were measured consecutively, in random order (Research Randomizer, version 4.0, http://www.randomizer.org), in order to minimize measurement error because of differences in positioning of the specimen. The evaluator was blind to which group the abutment belonged to: test or pristine. The site where most
stress was anticipated is located directly below the implant margin at the cervical level and served as the region of interest.

All data were stored in Andor SOLIS for Imaging X-0000 (version 4.24.30004.0, Andor Technology Ltd. Belfast, United Kingdom). Subsequently, the data were analysed to identify the characteristic bands and the volume percentages m-ZrO₂ was determined, based on the intensities of the peaks.

**Visual inspection of the connection area, fracture load testing and failure analysis**

The restoration (crown-abutment complex) was retrieved from the patients’ mouth, photographed (EOS 600D, EF 100mm f/2.8 USM Macro and MT-24EX Macro Twin Lite, Canon, Shimomaruko, Japan) and the observations were categorized.

After the Raman analysis, the RNC crowns were carefully removed and the abutments were mounted on a 3.5 mm implant (Astra Tech Implant System OsseoSpeed TX 3.5x, Dentsply Sirona Implants). New fixation screws were tightened to 20 Ncm. Testing of the implant-abutment assemblies was carried out in accordance with the NEN-ISO 14801:2016 standard and as described by Truninger et al, who also tested abutment strength without restorations. In contrast to Truninger however, the screw access holes were not covered so failure modes could be better established running the fracture test. The implants were embedded in acrylic holders, with the resin at 3 mm from the edge of the implant, simulating some marginal bone loss. Static load was applied at a 45 degree angle to the vertical implant axis. A steel indenter with a round tip (⌀ 1 mm) was positioned on the highest point of the chamfer outline and tested in a universal testing machine (MTS 810, Eden Prairie, USA) at a crosshead speed of 1 mm/min). The specimen were loaded until failure, maximum load to failure was noted. Types of fracture were observed using an optical microscope (Wild M3Z, Heerbrugg, Switzerland (figure 4).

**Figure 4**

Stock (left) and CAD/CAM customized (right) zirconia test abutments mounted in the universal test machine. The load cell was place at the highest point of the chamfer outline.
Additionally, in order to observe the fracture behavior, representative specimen were first sputter-coated with a 3nm thick layer of gold (80%)/palladium (20%) (90s, 45mA; Balzers SCD 030, Balzers, Liechtenstein) and analyzed using cold field emission Scanning Electron Microscope (SEM) (LyraTC, Tescan, Brno, Czech Republic).

**Statistical analysis**

Mean volume percentages of m-ZrO₂ and the fracture load for pristine and clinically aged stock and CAD/CAM customized abutments were calculated, as were relative differences by abutment type. T-tests for independent or paired samples were used for comparison, where appropriate. Verification of normality was tested by means of the Shapiro-Wilks test and eye-balling of the histograms. The level of significance was set at 5% (α=0.05). All computations were performed using a standard statistical program (SPSS, version 23.0 for Windows, SPSS inc., Chicago, USA).

**Results**

On visual inspection of the retrieved abutment samples (n=25 stock and n=25 CAD/CAM abutments), two appearances were predominant: either two small, separate grey stripes (type I) or a grey band running uniformly along the connection area were noted (type II, figure 1). Type I was predominantly seen in the CAD/CAM abutments (64%, 16 out of 25) whereas type II was typically observed in the stock implant abutments (96%, 24 out of 25).

For Raman spectroscopy, 21 pairs of stock and 23 pairs of CAD/CAM abutments were available for analysis (figure 2, n=88 abutments). Volume percentages of m-ZrO₂ beyond the detection threshold of 5% were never observed (figures 3 and 5).
Figure 5
Assembled graph including several representative samples and the anticipated typical spectrum for monoclinic zirconia (m-ZrO$_2$, black line). Note the absence of a characteristic band at 384 cm$^{-1}$ in the samples (colored lines), indicating m-ZrO$_2$ beyond the detection threshold of 5% (ww) is not present.

Hence statistical analysis was not performed.
Subsequently, the fracture test was performed. In 3 abutment pairs, different failure types were observed and deemed unfit for paired numerical comparison of fracture loads. Sometimes it proved impossible to load the abutment due to a shallow chamfer. Consequently, another 9 pairs of stock and 7 pairs of CAD/CAM abutments were excluded. In total, 11 pairs of stock abutments and 14 pairs of CAD/CAM abutments were included for analysis (n=50 abutments, figure 2).
Plastic deformation of the titanium test implant after fracture of the abutment was obvious from visual inspection in approximately half of the cases.
The data were considered normally distributed. The mean fracture load values for stock and CAD/CAM customized zirconia test abutments and their pristine controls, as well as the relative change in strength are presented in table 2 and figure 6.

Table 2
Mean absolute fracture strength in Newton (SD) and relative change after clinical aging, split by abutment type and clinical status.

<table>
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<th>Pristine</th>
<th>Aged</th>
<th>Relative change</th>
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<tr>
<td>CAD/CAM customized (n=14)</td>
<td>1176 (74)</td>
<td>1219 (89)</td>
<td>+ 3.9 % (4.0) P=0.411</td>
</tr>
<tr>
<td>Stock (n=11)</td>
<td>1237 (123)</td>
<td>922 (105)</td>
<td>- 21.2 % (8.9) P=0.028</td>
</tr>
</tbody>
</table>

P=0.658  P=0.011
An independent-samples t-test was conducted to compare the initial mean fracture strength for pristine CAD/CAM customized (1176 N, SD=74) and stock abutments (1237 N, SD=123) and revealed no statistical significant difference between the two types, despite their obvious geometric differences ($t[23]= -0.446, P=0.658$). Clinical function had not affected the fracture strength of the CAD/CAM customized abutments (paired-samples t-tests, $t[13]= -0.849, P=0.411$). Stock abutments had weakened significantly after 1 year function by -21.2 N (SD=8.9%) of their initial average strength (paired-samples t-test, $t[10]= 2.571, P=0.028$). The relative change in fracture strength differed among the 2 abutment types (independent samples t-test, $t[23]= -2.764, P=0.011$). Failure analysis showed that all included and tested abutments broke inside the implant contour. In contrast to others, sometimes under high load the implant had plastically deformed at the neck area. Fracture analysis and SEM analysis showed that the critical flaw for the CAD/CAM abutments was mostly seen just below the neck of the implant and for the stock abutments in the internal connection part, where it was seated. As can be seen in the SEM pictures of one of the stock abutments, the critical flaw was detected at the internal connection and hack lines could be observed after the critical flaw (figure 7).
Figure 7
SEM images of a stock zirconia abutment with an overview (left) and two close-up views from the point of critical flaw (middle and right). The hackles originate from the failure and the fracture moves through the zirconia abutment ending on the other side of the abutment in a symmetrical way. The arrow is pointed at the initiation point of the fracture.

Discussion

The volume percentage of monoclinic zirconia (m-ZrO₂) and the fracture load of clinically aged stock and CAD/CAM customized zirconia abutments were pairwise compared to those of pristine exact copies. The fact that these abutments functioned for a period of 1 year under clinical loading is an important asset of this study, although a period of 1 year is still relatively short. Original implants were used for the implant-abutment assembly which also enhances external validity. The use of stainless steel implant analogues, as in some other studies, presumably adversely affects the mechanical behavior under testing conditions.

On retrieval and visual inspection of the conical contact area, the two abutment types had quite a different appearance: either a grey band or two grey stripes. Although advanced chemical analysis of the constituents of these grey areas was not performed, it is tentatively suggested that they indicate the contact areas between the zirconia abutment and the titanium implant, resulting from micro-movement. Titanium is less wear resistant than zirconia. Apicella et al (2010) evaluated the accuracy of fit of the stock and CAD/CAM abutments of the exact brand used in the present study by evaluating radiographs and ground samples under SEM. From their in vitro study they concluded that both abutment types exhibited excellent marginal adaptation, without a marked difference between the two. Their findings were based on a static setup, without (artificial) loading whereas our observation was after one year of clinical function suggesting a better, more uniform fit of the stock abutments.

The volume percentage of m-ZrO₂ phase and particularly a shift in tetragonal-monoclinic phase distribution is a marker for degradation or aging of the material. Two recent in vitro studies using...
X-Ray Diffraction analysis focused on shifts in tetragonal-monoclinic phase transformation after thermocycling and mechanical loading, with contradictory results. Almeida et al (2016) concluded that after a 5-year simulation of clinical use, their zirconia abutments did not show any signs of aging. Basilio et al (2016) however suggested, based on their findings, that resistance to fracture and the phase stability of implant abutments were susceptible to hydrothermal and mechanical conditions. In these two zirconia studies different abutment types were used in vitro. In the present ex vivo study volume percentages beyond 5% were not observed, therefore substantial degradation of the zirconia material is not expected in one year of clinical function. This volume percentage of m-ZrO₂ is far below the maximum acceptable percentage of 25% as set by ISO 13356 (2015). The original, total study population consisted of 50 patients: 25 stock and 25 CAD/CAM customized abutments and their pristine copies (figure 2). Two pairs of stock and CAD/CAM customized zirconia abutments were used for microstructural characterization using Electron Back Scatter Diffraction (EBSD). EBSD mapping is a contemporary, be it destructive technique that allows the detection of a rather small amount of monoclinic phase in nano-crystalline zirconia dental abutments, far smaller than with Raman spectroscopy. However, the preparation of the samples is rather time consuming and consequently expensive. The observed volume percentages of m-ZrO₂ with EBSD ranged between 0.6-1.0% and 3.8-6.2% for CAD/CAM customized and stock abutments respectively. These numbers are in line with the data of the other 46 pairs that were analysed with Raman Spectroscopy in the present study. Others, performing X-ray diffraction measurements on pristine zirconia abutments of another brand also noticed only small residues of monoclinic phase and predominantly tetragonal phase zirconia. Particularly the stock abutments exhibited a decrease in fracture strength. The CAD/CAM customized abutments actually showed a small mean increase in strength, for which no logical explanation can be offered and which may be the result of measurement error. However, Alsahhaf et al (2017) also noted an increase in fracture load after artificial, dynamic loading in a chewing machine in several groups of their zirconia abutments luted to a titanium base, but also in a group of monolithic YTZ abutments.

The stock and CAD/CAM customized abutments used in the present study are made from the same ground material. The geometry of the abutment varies because the CAD/CAM abutments were individually designed and the stock abutments were not. Furthermore, the internal connection of the stock and CAD/CAM customized abutments of the studied implant brand is different and may play a role. Both abutment types predominantly failed in the internal connection part, but the location was different depending on the abutment type (figure 1). A slight misfit may have caused a critical flaw.

When testing the fracture strength of implant-abutment assemblies, particularly those without a crown, the risk arises that not so much the strength of the implant-abutment connection, but that of the ceramic abutment wall is tested. This varies per design. See for example Apicella et al (2011). For that reason it was decided to load the abutment at an angle of 45 degrees, instead of 30 degrees as advocated in normative literature. Since fracture resistance is one of the criteria involved in selecting abutment types, a CAD/CAM
customized abutment may be favoured for this particular implant brand. However, the observed 
fracture load after oblique loading of all abutments, both pristine and clinically aged, are much 
higher than is to be anticipated in the anterior maxilla as a result of physiological chewing forces 
that are not likely to exceed 200 N.59,60 During the fracture test some implants had even deformed 
plastically prior to fracture of the ceramic abutments. The suspected difference from visual 
observation in implant-abutment contact area between the two abutment types was not clinically 
relevant up to one year of functional service.

Conclusions

After 1 year of clinical service, substantial degradation of the bulk material of zirconia implant 
abutments was not observed. The studied CAD/CAM customized zirconia implant abutments 
were as strong as their pristine copies, whereas the stock abutments demonstrated a considerable 
reduction in fracture strength.

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The funding sources had no involvement in the study design, collection, analysis and interpretation 
of the data or in the decision to submit the article for publication.
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