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Short communication

Fractographic analysis of a dental zirconia framework: A case study on design issues

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ABSTRACT

Fractographic analysis of clinically failed dental ceramics can provide insights as to the failure origin and related mechanisms. One anterior 6-unit all-ceramic zirconia fixed partial denture (FPD) (Cercon®) has been clinically recovered and examined using qualitative fractography. The purpose was to identify the fracture origin and to state the reasons for failure. The recovered parts of the zirconia FPD were microscopically examined to identify classic fractographic patterns such as arrest lines, hackle, twist hackle and wake hackle. The direction of crack propagation was mapped and interpreted back to the origin of failure at the interface of the occlusal–palatal tip of the core and the veneering ceramic. An inappropriate core drop design favoring localized stress concentration combined with a pore cluster in the veneering ceramic at the core tip interface were the reasons for this premature through-the-core thickness failure.

1. Introduction

An increasing number of all-ceramic materials are being used in prosthetic dentistry. All-ceramic prostheses, the so-called fixed partial dentures (FPDs) in most cases consist of a supporting high strength zirconia framework structure and an esthetic veneering ceramic (Raigrodski, 2004).

Clinical studies in an academic environment using zirconia supported FPDs reported promising results for an observation time of two to five years (Raigrodski et al., 2006; Tinschert et al., 2008; Sailer et al., 2007; Vult von Steyern et al., 2005; Molin and Karlsson, 2008; Beuer et al., 2009). The zirconia frameworks showed excellent mechanical stability as only one fracture occurred in each of two studies on FPDs (Sailer et al., 2007; Beuer et al., 2009). However, several authors reported up to 15% of the frameworks had minor chipping of the veneering ceramic (Raigrodski et al., 2006; Tinschert et al., 2008; Sailer et al., 2007; Vult von Steyern et al., 2005). Nevertheless, when using anatomically designed frameworks, Molin and Karlsson (2008) observed no veneer chipping after five years of observation time. A five year follow-up in three dental private practices (Kerschbaum et al., 2009), re-

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grouping 259 bridges and 957 crowns (Cercon® system), reported 8% veneer and framework fractures. The authors suspected the early framework fractures in the connector area were caused by an inadequate connector cross-section and subsequent grinding without water cooling of the zirconia frameworks as well as a learning curve of the laboratories working with CAD–CAM technology. Connector areas are at an increased risk of failure if the radius of curvature is reduced (Plengsombut et al., 2009; Oh and Annusavice, 2002). The gingival embrasures of connectors are shown to be the site of highest stress concentration when using finite element (FE) modeling (Dittmer et al., 2009). Insufficient connector dimensions, framework grinding damage while making shape adjustments, positioning of the connector outside the arch of occlusion, all contribute to connector failures (Aboushelib et al., 2009). In the anterior sector, connector dimensions may be difficult to achieve and dental technicians tend to create sharp embrasure forms to improve the esthetics (Oh and Annusavice, 2002).

Fractography is a well established tool in engineering to examine fractured, brittle surfaces (Frechette, 1990; Mecholsky, 1995; Quinn, 2007). The use of fractographic pattern and surface feature recognition has been applied in dentistry to clinical ceramic restoration failure analyses (Thompson et al., 1994; Quinn et al., 2005; Scherrer et al., 2006, 2007, 2008; Taskonak et al., 2008a). Features like compression curl, hackle, wake hackle, twist hackle, and arrest lines were the most commonly found markings in failed all-ceramic restorations. (Quinn et al., 2005; Scherrer et al., 2006, 2007, 2008). Those markings are all contribute to identify the direction of crack propagation (dcp) and failure origin to finally state the specific reasons for failure.

The purpose of this work was to fractographically analyze the broken parts of an in vivo fractured six unit anterior zirconia FPD, revealing the responsible causes for premature failure.

2. Materials and methods

A 24 h in vivo fractured anterior (canine to canine) six-unit maxillary FPD was provided by a dental clinician, as shown in Fig. 1. The FPD was manufactured by a dental technician in a private laboratory who had been trained in CAD/CAM techniques and handling the Cercon® system (Cercon® base, Degudent, Hanau, Germany)[1] for the zirconia framework. The Cercon® framework consisted of a Y-TZP sintered at 1350 °C, (coefficient of thermal expansion (CTE): $\alpha_f = 10.5 \times 10^{-6}$ 1/K) and veneered with a feldspar-based porcelain ($\alpha_V = 9.9 \times 10^{-6}$ 1/K) (Elephant® Sakura, Elephant Dental, Hoorn, Netherlands). For FPDs, connector dimensions of 9 mm^2 are recommended by the Cercon manufacturer. According to the dental technician, after CAD–CAM machining, the framework was manually adjusted by reshaping the palatal surface.

[1] Commercial products and equipment are identified only to specify adequately experimental procedures and does not imply endorsement by the authors, institutions or organizations supporting this work, nor does it imply that they are necessarily the best for the purpose.

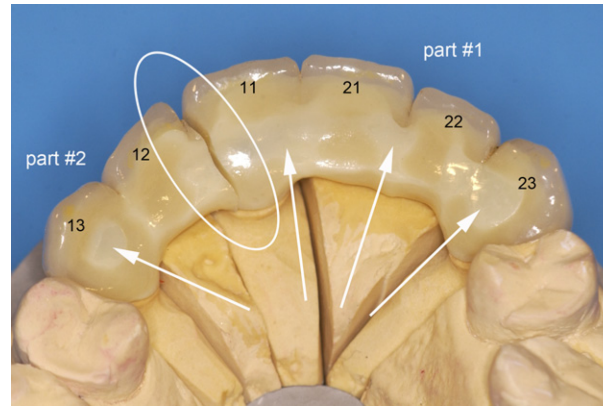

Fig. 1 – Cercon® veneered six-unit anterior zirconia bridge, fractured between the upper teeth #11 and #12 in the maxillary arch (FDI numbers for each relevant tooth are labelled). The fracture surface distal of tooth #11 is labelled part #1, the fracture surface mesial of tooth #12 is labelled part #2. The region of fracture and exposed zirconia core structure are indicated by the circle and arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

A final regeneration firing was conducted at 1000 °C for 15 min, even though not necessarily recommended by the manufacturer. According to the clinician, additional occlusal grinding adjustments were performed as a fine-tuning step after veneering prior to luting the bridge with a temporary cement (Temp Bond®, Kerr Hawe, Bioggio, Switzerland) on the three abutment teeth, two canines and the central right incisor (#13, #11, #23, FDI numbering system), for an initially planed one week try-out period. A through-the-core fracture occurred while chewing after 24 h in vivo at the connector level between the abutment teeth #11 (central incisor) and the lateral incisor pontic #12. The patient reported no excessive or abnormal loading events during the day.

The fractographic examination of the two retrieved fragments was performed using a systematic approach (Scherrer et al., 2008) with light stereomicroscopy (LM) as well as scanning electron microscopy (SEM). Prior to the microscopic investigation, the broken pieces were cleaned in an ultrasonic alcohol bath for 10 min. The macroscopic appearance was examined using the LM (SV11, Zeiss, Oberkochen, Germany) under different illumination. The SEM (Leitz ISI SR 50, Akashi, Japan) was used for characterization of morphology, microstructure and fractographic details on the fractured surfaces.

3. Results

Fig. 1 shows the global palatal overview of the Cercon® six-unit anterior zirconia bridge repositioned on the working stone model. The fracture is located at the connector level (white circle) between the central right incisor (tooth #11) and the pontic tooth #12. The two fractured parts analyzed have been labeled part #1 for the fractured surface view towards