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Research Paper

Fracture origins in twenty-two dental alumina crowns

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ABSTRACT

Objectives: The causes of *in vivo* fractures of all-ceramic dental crowns are not yet fully understood. The fracture origins often occur in the cervical margin in the approximal area, but the reason for this is unclear. The aim of this study was to evaluate the fracture origin of 22 of clinically-failed alumina crowns.
Methods: The fracture surfaces of alumina crowns fractured *in vivo* were inspected by optical microscopy to evaluate the fracture patterns and identify the cause of fracture. Fracture maps were constructed as needed to interpret the patterns of breakage and to back track to a fracture origin area. A scanning electron microscope (SEM) was used to characterize the fracture origins of the 22 cases where the origin site was available.
Results: The most common fracture origins were marginal defects either in the alumina core or in the veneer. The defects included thin, chipped, cracked or uneven crown margins and excess veneer on the inside of the crown. Multiple flaws were present along the margins in most specimens, but fracture origins were usually located in the region of the shortest axial wall. A few crowns had pores, contamination, or incomplete sintering that acted as fracture origins.
Significance: Production method, handling, design and material insufficiencies influence the fracture of dental ceramic crowns. Machining defects and other margin flaws seem to be the most detrimental factors for alumina crowns. Feather-edge or sharp margins should be avoided. Smooth and moderately thick crown margins would probably dramatically improve the durability.

1. Introduction

The high-strength ceramic core materials used as substitutes for metal in dental all-ceramic crowns should be sufficiently strong for dental use based on their mechanical properties as measured by *in vitro* methods (Raigrodski, 2004; Al-Makramani et al., 2009). Even though alumina has very high fracture strength, fractures are frequent in clinical use (Wang

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et al., 2012; Øilo and Gjerdet, 2013). Based on *in vitro* testing it has been difficult to explain why the crowns break in the clinical use (Kelly et al., 2012). It has been speculated that the CAD/CAM production technique creates defects in the material that may affect the crown strength (Luthardt et al., 2004; Quinn et al., 2005; Rekow and Thompson, 2005; Denry, 2013). Machining defects are observed in most dental ceramic CAD/CAM systems but the extent and size vary among different systems (Denry, 2013). Machining defects as the cause of fractures during clinical function have not been confirmed in clinical trials, however. This is probably due to the lack of thorough fractographic analyses of clinical failures (Øilo and Gjerdet, 2013, Øilo et al., 2013). The causes of fracture of dental ceramic crowns in clinical use are not yet fully understood.

Most *in vitro* tests of crown shaped specimens load the crowns on the occlusal surface until fracture occurs from contact damage cracking created directly under the loading device (Pallis et al., 2004; Snyder and Hogg, 2005, Lawn et al., 2007; Bonfante et al., 2010; Aboushelib, 2012). Several investigations of *in vivo* failures indicate that this is not a common clinical failure mode (Quinn, 2007; Scherrer et al., 2009; Quinn et al. 2012; Øilo and Gjerdet, 2013; Øilo et al., 2014). Retrieved crowns analyzed by fractographic methods reveal several modes of fracture. One common fracture mode causes the crown to split in half from cracks that propagate upward from a margin, in response to hoop stresses on the margins. The location of the fracture origins is usually in the approximal area. The reason that the fractures start there is not yet evident from the available evidence. Other common fracture modes are chipping and delamination starting from worn or damaged surfaces in the veneering ceramics.

Although there have been some thorough fractographic analyses of clinical fractures in recent years (Scherrer et al., 2006, 2008, 2009; Quinn et al., 2012), the analyses usually have been on isolated examples. The location of crack initiation and the direction of crack propagation have been identified in the previous works, but the original flaws are not identified or described. Furthermore, it is not clear whether these isolated examples have been representative of clinical fractures in general. There has been no systematic study of a larger number of fractures for a single restoration system. Retrieval of failed dental crowns is complicated and based on voluntary submission from practicing dentists. Very few have access to large numbers of such specimens. Knowledge of why the crowns fracture during clinical function is essential in order to reduce the number of fractures in the future.

Therefore, the aim of this study was to evaluate the fracture origins to detect the originating flaws of a large number of clinically failed alumina crowns from one particular commercial system to find the causes of failure.

2. Materials and methods

Twenty-seven alumina crowns with core-veneer fractures failed during clinical function were retrieved by public and private dentists and sent to us for analysis. The overall fracture features of these have been analyzed previously (Øilo and Gjerdet, 2013). The earlier work identified the patterns and general locations of fracture, but not the exact origin sites and flaws. It was originally believed that all 27 were a high purity, dense single phase. That study revealed that many of the crowns had split into two or more pieces with the fractures usually starting at margins and propagating due to hoop stresses in the crown walls. The precise character of the fracture origins was not determined, however. All 27 specimens were re-examined by both the authors on optical microscopes and then in a scanning electron microscope (SEM) to confirm the directions of crack propagation, to verify the location of the fracture origin and to characterize the actual flaw at the origin.

In most instances the critical pieces were retrieved. Both sides of the fracture origin were examined, if the matching pieces were available. The crown margins in the fracture origin area were examined from both outside and inside of the crown to investigate the quality of the crown margin. Energy-dispersive x-ray spectroscopy (EDS) was used to identify the components of the specimens and to identify whether foreign materials were present in flaws. Special emphasis was put on regions with unusual microstructure.

All acquired images from SEM and optical microscopy were assembled into extensive fractographic maps of each specimen where orientation, crack propagation and images of fracture origin and other findings are put together. Following procedures pioneered by S. Scherrer and J. Quinn for dental restoration analysis (Quinn et al., 2006, 2007; Scherrer et al., 2006, 2009; Quinn, 2007), and the general principles of fractographic analysis (Quinn, 2007), fracture maps were constructed for each crown to organize the dozens of photographs taken of the different pieces at different locations and different illumination modes (direct, low angle grazing, or transmitted illumination), with and without green dye or gold coatings, from different viewing angles, and different optical and SEM microscopes. For each crown, as few as 20 or as many as 100 photos were taken. The findings were used to establish the most likely cause of fracture in each specimen. For ease of interpretation, convenience, and assemblage of so much information, the images with labels of all 27 crowns were pasted into a single PowerPoint file which comprises almost 400 slides and over 2000 images.

3. Results

The original flaw was identified in 22 of the crowns. All but one of the fracture modes was confirmed to be identical as in the previous optical microscopy only study (Øilo and Gjerdet, 2013). The earlier study emphasized the general fracture pattern and location of the fracture origin, but not the flaw at the fracture origin itself. We reinterpreted one crown to have a fracture origin not on the margin, but actually on the internal occlusal surface. It was extremely difficult to detect that flaw and it appeared to be a material sintering defect (Fig. 1A). This was an unusual outcome. All the other crowns had origins on the margins as discussed below (Fig. 1B).

During the new examinations, it was noticed that one additional crown seemed to have a different microstructure than the others. It was reinterpreted as probably being an alumina crown infiltrated with glass and was excluded from