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Fractographic ceramic failure analysis using the replica technique

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ABSTRACT

Objectives. To demonstrate the effectiveness of in vivo replicas of fractured ceramic surfaces for descriptive fractography as applied to the analysis of clinical failures.

Methods. The fracture surface topography of partially failed veneering ceramic of a Procera Alumina molar and an In-Ceram Zirconia premolar were examined utilizing gold-coated epoxy poured replicas viewed using scanning electron microscopy. The replicas were inspected for fractographic features such as hackle, wake hackle, twist hackle, compression curl and arrest lines for determination of the direction of crack propagation and location of the origin.

Results. For both veneering ceramics, replicas provided an excellent reproduction of the fractured surfaces. Fine details including all characteristic fracture features produced by the interaction of the advancing crack with the material's microstructure could be recognized. The observed features are indicators of the local direction of crack propagation and were used to trace the crack's progression back to its initial starting zone (the origin). Drawbacks of replicas such as artifacts (air bubbles) or imperfections resulting from inadequate epoxy pouring were noted but not critical for the overall analysis of the fractured surfaces.

Significance. The replica technique proved to be easy to use and allowed an excellent reproduction of failed ceramic surfaces. It should be applied before attempting to remove any failed part remaining in situ as the fracture surface may be damaged during this procedure. These two case studies are intended as an introduction for the clinical researcher in using qualitative (descriptive) fractography as a tool for understanding fracture processes in brittle restorative materials and, secondarily, to draw conclusions as to possible design inadequacies in failed restorations.

1. Introduction

All-ceramic restorations are being increasingly used on posterior teeth—a zone in which the restorations are subjected to higher masticatory loads than on front teeth. Consequently, an increased frequency of veneer ceramic chipping or through-the-core-thickness fractures of posterior crowns may be expected. While a small veneer chipped crown may often be salvaged, larger chips (i.e. interproximal contact loss, cusp fracture) or through-the-core-thickness factures

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generally result in the complete removal of the failed restoration. Understanding the reasons for such events is of key importance to the dental community as many parameters may be involved such as structure design, choice of ceramic, quality of the final laboratory delivered restoration (i.e. presence of internal defects, damages, residual stresses), and patient specific occlusal contacts and chewing excursion paths. To this end, the analysis of clinical failures using fractographic techniques is gaining momentum in the dental scientific community. The number of related publications, however, is still low [1–7]. The reason pertains to the difficulty in securing pertinent evidence. In particular, it is of importance that the fractured surface of the ceramic part be left undisturbed after failure occurred, that is, that no subsequent grinding, scratching, rubbing or smearing (which in effect "erases" the surface features left during the fracture process) has occurred. Further, while interpreting fractured surfaces from glassy materials is fairly straightforward, recognizing clear surface markings on some of the more coarse-grained or polycrystalline ceramics, may become an intricate procedure [5,8].

Often direct examination of fracture surface under the microscope is not possible because one part of the restoration is still strongly cemented onto its abutment while the other was lost. In these instances a replica of the remaining fracture surface must be obtained. To this end an intra-oral impression of the exposed fractured surface using a low viscosity impression material is taken. The impression (i.e. the negative of the fractured surface) is poured with cold mounting epoxy resin thus producing a positive of the fractured surface which is then gold-sputtered for SEM analysis. Some aspects of the replica technique and the fractographic analysis have been previously published [7]. The objectives of the present report are (1) to detail the steps involved in producing a replica from a fractured surface and (2) using replicas of two clinical fracture sites of all-ceramic restorations to demonstrate the essentials of fractographic analysis.

2. Materals and methods

2.1. *Fracture sites*

Two sites were identified for study: (1) A failure of the veneering ceramic of a Procera AllCeram restoration (Nobel Biocare, Gothenburg, Sweden) located on a first upper molar. This restoration has been in function for 4.2 years. (2) A fracture of the veneering ceramic (Allux, Wieland Dental, Pforzheim, Germany) sintered onto an In-Ceram Zirconia core (Vita Zahnfabrik, Bad Säckingen, Germany). This restoration was screw-fastened onto an implant replacing a first upper premolar and failed after 2 months of function.

2.2. *Replica preparation*

The fracture surface (Fig. 1) was first cleaned with a cotton pellet and alcohol and was then rinsed and thoroughly air-dried. The replicas were produced using a quadrafunctional hydrophilic siloxane impression material (Aquasil ULV, Dentsply De Trey, Konstanz, Germany) whereby the material

Fig. 1 – Fracture of the veneering porcelain (AllCeram) of an upper left Procera Alumina Molar after 4.2 years of intra-oral function.

was syringed onto the fractured surface (Fig. 2) and over the occlusal surface of the crown (Fig. 3) without the use of a tray. Subsequently the impressions were poured with cold mounting epoxy resin (Epofix Resin, Struers, Ballerup, Denmark) (Fig. 4). After setting, the resin was gold-coated for scanning electron microscopy (SEM).

2.3. *Analysis*

The description and interpretation of the fracture patterns were based on textbooks descriptions [8–11] and ASTM standard [12]. The main fractographic features searched for were arrest lines, hackle, wake hackle and compression curl [5,7]. An arrest line is a well-defined line produced when the crack comes to a halt, before resuming its propagation, often in a slightly different direction [9]. Arrest lines are also indicators of the direction of propagation as the beginning of a crack event is always located on the concave side of the first arrest line. Hackle are lines on the fracture surface that run in the local direction of cracking. They separating parallel portions of the propagating crack that are on slightly different planes.

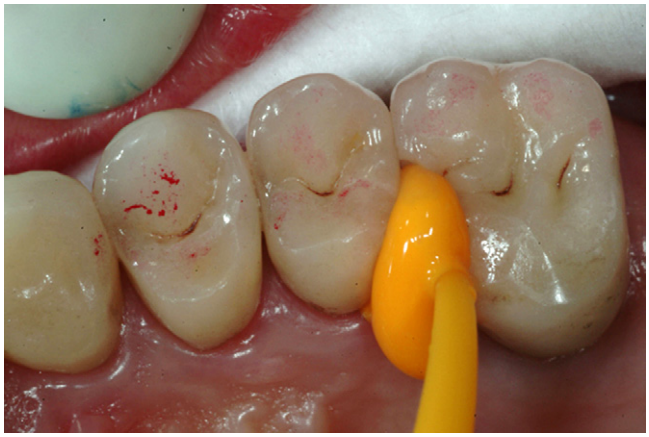

Fig. 2 – After having cleaned the fractured surface with an alcohol cotton pellet and air-dried, the silicone impression material is injected first on the fractured zone.