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Occlusal geometrical considerations in all-ceramic pre-molar crown failure testing

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ABSTRACT

Objectives. To evaluate the influence of occlusal geometry of all-ceramic pre-molars, namely cusp angle and associated notch radius, on the scatter of load to failure tests.

Methods. Forty-five all-ceramic upper pre-molar crowns with three zirconia core thicknesses (0.4, 0.6 and 0.8 mm) were broken on dental implant abutments oriented in three angulations (0°, 15°, and 30°). The crowns were loaded using a 4 mm diameter steel cylindrical bar placed along the midline fissure at a crosshead speed of 1 mm min⁻¹. The scatter of the failure load was evaluated using Weibull analysis. The cusp angle of each crown was critically evaluated to determine the cusp angle and effective radius of the fissure notch root. The relationship between failure load and cusp angle was compared with that between failure load and effective radius as well as notch induced stress concentration by considering R² values of fitted trend lines with these relationships.

Results. The fracture load differences either between abutment angulations or zirconia thicknesses were not clearly revealed in this study. Except for the group of 30° abutment angulation, the crowns present high scatter of failure loads with low Weibull modulus. However, a simple dependence between fracture load and effective cusp angle was observed. **Significance.** Occlusal geometry is an important issue that affects the degree of stress concentration and should be understood by both technician and clinician for appropriate design and material selection of all-ceramic crowns.

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1. Introduction

All-ceramic restorations are a reliable treatment, which fulfill increasingly esthetic demands of patients. The long-term outstanding properties of dental ceramics have resulted in the development of many metal-free restorative treatments. This esthetic driven demand has also led many manufacturers to develop novel ceramic systems with microstructural diversity for compensating the traditional problems of ceramics,

namely their brittleness. Indeed, the differences in chemical constituents and crystalline phase arrangements results in a wide range of fracture strength values being reported in the literature [1–3]. Recently yttria tetragonal zirconia polycrystalline (Y-TZP) based materials have been introduced that exhibit “transformation toughening” [4], which contributes significantly to its high flexural strength of 900–1200 MPa [1].

Not only novel ceramic properties have been developed but designs of the restorations have also improved. Due to the fact that all-ceramic crowns must withstand many challenges in

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oral environment especially cyclic fatigue and wet conditions, critical demands are placed upon restoration design. Based on fractographic studies of clinically failed crowns, fracture origins were claimed to initiate from the cementation surface of the core [5,6]. As a consequence, crown design has mainly focused on loading induced stress distribution at this interface along with design of the cervical region [7,8]. Unfortunately, even with higher strength Y-TZP cores the failure of restorations is widely reported and the success rate related with position in the mouth (anterior or posterior region) rather than materials used [9,10]. These observations suggest that other factors influence the stress generated in the tested crown and laboratory tests still cannot be used to predict the clinical crown performance [11].

There are several *in vitro* laboratory procedures called “crown fracture resistance tests” that attempt to simulate failure of anatomical ceramic crowns from different manufacturers with an assigned factor of interest [12–15]. These are tested under controlled conditions and the load the crowns can resist before fracture under quasi-static uniaxial or non-axial loading or cyclic loading is evaluated. Although, this has enabled comparison of the effects of various factors on the failure load of different kinds of materials, the results appear to be of limited clinical relevance. The reason for this is that not only is there difficulty relating the laboratory fracture strength test to the oral loading environment [16] but also the scatter of the failure loads is considerable making comparison with other studies difficult. It is possibly for this reason that all-ceramic crowns, which have high failure loads under laboratory tests compared with the maximum human biting forces, fail frequently in a patient’s mouth. The study by Aboushelib et al. confirms that even for all-ceramic crowns replicated directly from failed clinical crowns, the failure loads are significantly different compared with the clinically broken restorations with the same shape and dimension [16].

A number of variables appear to affect this unpredictable scatter of the strength such as loading system, indenter radius, contact surface area, mismatch of the elastic modulus of supporting structures, core to veneer thickness ratio, whether a sharp or blunt contacting indenter was used and even the consistency of the indenter (that is, whether it is soft or hard) [17–19]. In addition the complex occlusal geometry such as cusp height and cusp angle would also be anticipated to play an important role in this scatter of failure load. Unfortunately, the influence of occlusal geometry on crown performance is not well documented.

The complexity of tooth morphology is an important factor that is responsible for the stresses developed within the tooth during mastication. According to the literature, there is a relationship between the palatal slope of anterior teeth and cuspal slope of posterior teeth with the inclined planes of the articular surface of the glenoid fossa [20]. Moreover, Spears and Crompton found differences of stress patterns in simulated food particles, which were generated for different contact surfaces of human’s cusp slope [21]. Furthermore, the steep cusp incline and/or deep grooves have been of concern as one of the predisposing factors for the incidence of tooth fracture in posterior teeth [22]. Undoubtedly, intricate occlusal geometry should have an influence on the stress patterns within the

prostheses and should be considered when performing crown testing or restoration design.

To understand the complexity of occlusal surface of the restoration, many approaches have been used from basic mechanical equations through to sophisticated finite element analysis. Using mathematical analysis, Inglis considered the effect of notch induced stress concentration in bars loaded in tension [23]. This concept may be used to rationalize the effect of cusp inclination on stress concentration at the fissure area of a premolar as the notch is present between buccal and lingual cusps. Following a 2D finite element analysis (FEA) of biting forces on a bucco-lingual cross section of molar restored tooth, Magne and Belser found that the horizontal force component induces flexure of the cusp and the wedging effect leads to considerable tension about the central groove area [24].

Additionally, to better relate the laboratory test data with clinical outcomes, the failure origin from fractographic analysis should be directly compared with failure of similar all-ceramic crowns that failed intraorally [5]. There has also been considerable focus on the role of contact induced fracture of multi-layer representations of crowns by Lawn et al. [25]. This work has provided clear guidelines for material selection for contact induced failure under static and cyclic loading conditions. However, for actual all-ceramic crowns, the occlusal geometry is more complicated. The effect of curved surfaces and contact size has been studied and indicated that these factors are associated with changes of the stress distribution, which differ from the conventional Hertzian model [19,26,27].

In this study, the effect of occlusal geometry is the main focus and why variations in this feature are associated with the scatter of failure loads of *in vitro* “crown fracture resistance tests”. Basic stress concentration concepts are invoked to relate fracture strength of crowns with occlusal geometry. The fracture surfaces of the broken crowns were also explored fractographically to determine crack propagation pathways for comparison with other studies.

2. Materials and methods

In this study, the failure loads of forty-five layered all-ceramic upper premolar-like crowns broken on dental implant abutments have been analyzed and the fracture surfaces explored fractographically using optical and scanning electron microscopes.

2.1. Fabrication of the zirconia cores

All ceramic bilayer crowns were fabricated on three angulations (0°, 15°, 30°) of implant abutments (ANKYLOS® FRIADENT GmbH Mannheim/Germany). At each angulation, five zirconia cores each with different core thickness (0.4, 0.6 and 0.8 mm) were made using a CAD/CAM system (Cercon Brain, Degudent) with Cercon art 2.2 software. The milled zirconia cores were sandblasted to remove excess zirconia and margins refined using a water-cooled turbine and suitable rotary instruments.

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