# Fracture-resistant monolithic dental crowns

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## ARTICLE INFO

## ABSTRACT

*Objective.* To quantify the splitting resistance of monolithic zirconia, lithium disilicate and nanoparticle-composite dental crowns.

*Methods.* Fracture experiments were conducted on anatomically-correct monolithic crown structures cemented to standard dental composite dies, by axial loading of a hard sphere placed between the cusps. The structures were observed *in situ* during fracture testing, and critical loads to split the structures were measured. Extended finite element modeling (XFEM), with provision for step-by-step extension of embedded cracks, was employed to simulate full failure evolution.

*Results.* Experimental measurements and XFEM predictions were self-consistent within data scatter. In conjunction with a fracture mechanics equation for critical splitting load, the data were used to predict load-sustaining capacity for crowns on actual dentin substrates and for loading with a sphere of different size. Stages of crack propagation within the crown and support substrate were quantified. Zirconia crowns showed the highest fracture loads, lithium disilicate intermediate, and dental nanocomposite lowest. Dental nanocomposite crowns have comparable fracture resistance to natural enamel.

*Significance.* The results confirm that monolithic crowns are able to sustain high bite forces. The analysis indicates what material and geometrical properties are important in optimizing crown performance and longevity.

## 1. Introduction

Monolithic all-ceramic crowns are increasingly favored over traditional prostheses with porcelain veneers, minimizing issues associated with complex fabrication, presence of residual stresses, and delamination from an inner core [1–4]. Dense zirconia and lithium disilicate glass-ceramics are prime candidates, for their relatively high modulus and fracture resistance along with ever-improving esthetics [5–15]. A stiff all-ceramic crown shields the inner dentin–pulp region by absorbing the bulk of occlusal stresses. However, brittleness remains a concern—failures for monolithic ceramic systems have been reported [16–18]. These failures are sometimes described as 'abrupt', with complete cracking of the crown and sometimes of the entire tooth. But little attempt has been made to examine how cracks evolve in relation to material properties. One effort has been made to elucidate the mechan-

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**Table 1 – Representative properties of crown materials. Data compiled from manufacturer's specifications and previous studies [3]. Uncertainties in property values are typically ~20%.**

| Material | Modulus E (GPa) | Poissons ratio | Toughness T (MPa m$^{1/2}$) | Strength S (MPa) |
|---|---|---|---|---|
| Zirconia (Lava Plus) | 210 | 0.30 | 4.0 | 1200 |
| Lithium disilicate (IPS e.max CAD) | 95 | 0.23 | 1.5 | 376 |
| Resin composite (Lava Ultimate) | 13 | 0.35 | 2.0 | 200 |
| Enamel | 90 | 0.22 | 1.0 | – |
| Dentin | 18 | 0.35 | 3.0 | – |

ics of the less disruptive fracture mode of edge chipping in monolithic ceramics [3], but while such studies are useful for quantifying crack resistance properties of the crown material, they do not address the more serious issue of total crown failure.

An alternative, more recent approach to crown restoration is to fabricate monolith prostheses from particle-filled resins [19–21]. While much more compliant and therefore less protective of the underlayer, dental composite crowns are seemingly less prone to fracture, if not to deformation. They appeal to the practicing dentist because of their ease of fabrication and installation. However, their capacity to sustain high bite forces and to avoid debonding is in question. Again, little attempt has been made to determine the mechanics of failure in composite restorations.

Clues to the modes of potential crown failure can be drawn from recent studies of fracture in natural teeth. Apart from incidental edge chipping [3,22], extensive experimental testing and theoretical fracture mechanics analysis of tooth breakdown under occlusal loading reveals a common mode of fracture in human teeth to be longitudinal cracking from the bite surface to the tooth base (or vice versa) [23–29]. Longitudinal cracks start from 'tuft'-like defects in the enamel close to the junction with dentin and run to the surface before vertical extension along the tooth walls [30,31]. They can remain fully contained as visible 'lamellae' within the enamel, and can even heal to some extent, without causing immediate failure—the fracture to that point is 'contained'. Longitudinal cracks can also act as precursors to whole tooth splitting through the dentin to the root, at which point the tooth is lost [22,32,33]. The question arises as to whether similar fracture processes operate in monolithic crown restorations and, if so, which are the best materials to contain them?

This study addresses these questions, first by conducting *in vitro* laboratory axial-loading fracture tests on manufactured model zirconia, lithium disilicate and dental nanocomposite crown specimens, and then by extending earlier fracture mechanics computations to analyze the fracture modes. The study focuses on anatomically-correct molars, centrally loaded with a hard spherical indenter to wedge open adjacent cusps and thereby split the crown along a fissure plane. However, the conclusions drawn have a broader reach to other tooth forms. Particular attention is given to the role of crown material properties, notably toughness and modulus, as well as to key geometrical variables such as tooth dimensions and sphere radius. The manner in which cracks progress from the occlusal surface to the enamel/cementum junction will be elucidated. It will be confirmed that monolith ceramics are capable of providing long-lasting crown restorations, provided due caution is exercised in fabrication and cementation procedure.

## 2. Materials and methods

### 2.1. Crown preparation and testing

Three candidate restorative materials for monolithic dental crowns were selected for study, each procured in the form of commercially available CAD/CAM blocks: (i) high translucency zirconia, 3 mol% Y-TZP (LAVA Plus, 3M ESPE, St Paul, MN); machinable lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar-Vivadent, Amherst, NY); and resin-based composite with nanoparticle ceramic filler (LAVA Ultimate Restorative, 3M ESPE, St Paul, MN). Six blocks of each material were machined into anatomically-correct mandibular first molar crowns by inputting scanned profiles of standard dental composite dies (Filtek Z100, 3M ESPE, St Paul, MN) into the following machining systems: Lava Milling System (3M ESPE, St Paul, MN) for zirconia and resin-based nanocomposite, and CEREC System (Sirona, Charlotte, NC) for lithium disilicate. The ensuing occlusal crown thickness was 1.0 mm for zirconia and 2.0 mm for lithium disilicate and nanocomposite, with a common proximal wall thickness 1.5 mm. Allowance was made for a cementation thickness 50 μm in all cases. The dies were engineered to provide common external crown dimensions for all materials, specifically tooth radius 5.0 mm (one quarter of sum of maximum buccal/lingual and mesial/distal widths) and tooth height 7.0 mm (average occlusal to enamel/cementum junction distance over all cusps).

Values of representative mechanical properties of the three crown materials in their finished states are given in Table 1, drawn from manufacturers' specifications. The Z100 die material used as substrate in the crown fabrication has near-identical filler content to that of the LAVA Ultimate dental nanocomposite, and is therefore taken to have similar properties. For comparison, some values for enamel and dentin are included in the table. Uncertainties in the values presented, from variations in published literature properties, are estimated at a nominal ~20%.

After milling, the crowns were processed as follows. The surfaces of the zirconia and lithium disilicate crowns were glazed at elevated temperatures and times according to manufacturers' recommendations. The intaglio surfaces of zirconia were sandblasted (aluminum oxide particles, 50 μm at pressure 2 bars, 100 mm standoff distance) to promote a mechanically adherent bond, while those of lithium disilicate