Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

Fracture strength of machined ceramic crowns as a function of tooth preparation design and the elastic modulus of the cement

Shirin Shahrbaf[a,*], Richard van Noort[a], Behnam Mirzakouchaki[b], Elaheh Ghassemieh[c], Nicolas Martin[a]

[a] The University of Sheffield, Academic Unit of Restorative Dentistry, The School of Clinical Dentistry, Claremont Crescent, Sheffield, UK

[b] Tabriz University of Medical Sciences, Tabriz Dental School, Orthodontic Department, Tabriz, Iran

[c] School of Mechanical and Aerospace Engineering, Queen's University of Belfast, Ashby Building, Room 3020, Stranmillis Road, Belfast, BT9 5AH, UK

ARTICLE INFO

Article history:
Received 11 February 2013
Received in revised form
21 August 2013
Accepted 25 November 2013

Keywords:
Maxillary premolar
CAD/CAM
Vita MK II
Anatomic design
Flat design
Elastic modulus
Resin luting agent
Mechanical test

ABSTRACT

Objectives. To determine, by means of static fracture testing the effect of the tooth preparation design and the elastic modulus of the cement on the structural integrity of the cemented machined ceramic crown-tooth complex.

Methods. Human maxillary extracted premolar teeth were prepared for all-ceramic crowns using two preparation designs; a standard preparation in accordance with established protocols and a novel design with a flat occlusal design. All-ceramic feldspathic (Vita MK II) crowns were milled for all the preparations using a CAD/CAM system (CEREC-3). The machined all-ceramic crowns were resin bonded to the tooth structure using one of three cements with different elastic moduli: Super-Bond C&B, Rely X Unicem and Panavia F 2.0. The specimens were subjected to compressive force through a 4 mm diameter steel ball at a crosshead speed of 1 mm/min using a universal test machine (Loyds Instrument Model LRX.). The load at the fracture point was recorded for each specimen in Newtons (N). These values were compared to a control group of unprepared/unrestored teeth.

Results. There was a significant difference between the control group, with higher fracture strength, and the cemented samples regardless of the occlusal design and the type of resin cement. There was no significant difference in mean fracture load between the two designs of occlusal preparation using Super-Bond C&B. For the Rely X Unicem and Panavia F 2.0 cements, the proposed preparation design with a flat occlusal morphology provides a system with increased fracture strength.

Significance. The proposed novel flat design showed less dependency on the resin cement selection in relation to the fracture strength of the restored tooth. The choice of the cement resin, with respect to its modulus of elasticity, is more important in the anatomic design than in the flat design.

* Corresponding author at: Academic Unit of Restorative Dentistry, The School of Clinical Dentistry, Claremont Crescent, Sheffield, S10 2TA, UK. Tel.: +44 114 2717932; fax: +44 114 2265484.
E-mail address: s.shahrbaf@sheffield.ac.uk (S. Shahrbaf).

0109-5641/$ – see front matter © 2013 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dental.2013.11.010

1. Introduction

A major disadvantage of dental ceramic materials relates to their brittle nature owing to their atomic bonds that inhibits the atomic planes to slide apart when subjected to load [1].

The applied stresses resulting from masticatory loads are concentrated on the inherent flaws that exist in the ceramic, which have the ability to amplify an applied stress leading to rapid crack propagation that can in turn lead to brittle fracture of the ceramics [2]. As a result, it is probable that, ceramic materials fracture at a fraction of their theoretical strength due to the flaws' stress-raising effect [3,4]. It has been shown that porosities and microcracks are the sites of fracture initiation [5].

The inherent properties of the ceramic crown, as a stand-alone item, are of limited interest as it is the overall strength of restored tooth-crown complex that is clinically relevant. The materials used, their geometrical configuration and the manner in which they are integrated and joined to each other and to the dental tissues determine the ability of the restored tooth to withstand the occlusal stresses placed upon them. Thus, in addition to the properties of the ceramic material, the performance of the other constituent parts of the compound system should be considered, principally: the geometrical configuration of the crown (thickness and occlusal cuspal morphology); the quality of the established bond between the all-ceramic crown, the resin cement and the dentin structure; the characteristics of the adhesive lute (dimensions and elastic modulus) and the amount and quality of the remaining dentin structure (support and preservation of pulp vitality). Moreover, while some ceramic systems have truly impressive fracture strength properties (e.g. zirconia core crowns), this is at the expense of aggressive tooth preparations (1.5 mm shoulder and 3 mm occlusal reduction) that compromise the amount of remaining dentin support and pulp vitality.

Considering the ceramic material per se, a wide range of ceramic systems are currently available to select from, based on an equally wide range of fabrication technologies. These ceramics, have been shown to have a fracture strength value that should resist normal functional occlusal loads (150–665 N) [6]; ranging from 772.3 N for machined feldspathic ceramics to 1000 N for zirconia machined crowns [7,8]. Machinable ceramics, using CAD/CAM technology, are of interest as they are homogenous and stronger, than conventional sintered porcelains where voids, flaws, and cracks are reduced to minimum and the effects of distortion or shrinkage have been omitted [9]. Moreover, CAD/CAM systems, increase production predictability and reduce the working process and the production cost.

The configuration of the crown (wall and occlusal thickness), as advocated by the manufacturers, is designed with an element of built-in 'insurance' (over-compensation) so that its fracture strength is optimized as a stand-alone item, with less regard for other elements of the crown-tooth complex. This increase in the thickness and overall dimensions of the ceramic walls is undertaken at the expense of conservation of tooth structure and preservation of tooth vitality. The actual geometry of the crown, in particular the shape of the tooth preparation design is based on historical empirical design configurations for non-adhesive full coverage crowns as advocated for cast metal and ceramo-metal restorations [10,11]. To date, little consideration has been given to the performance of all-ceramic adhesive crowns as part of a restored tooth-crown complex and how this can be optimized for the preservation of tooth structure. There is evidence to suggest that the geometry of the crown and the stiffness distribution within it also appears to have an effect on the distribution of the stresses within the tooth-crown complex [12,13].

The propagation of cracks in the ceramic crown is affected by the support offered from the underlying tougher and more elastic structures; the cement and the underlying dentin. The adhesive nature of resin-based cements has the effect of covering the internal surfaces of microcracks and small defects of the ceramic restorations; microcracks are thus blunted and inhibited from propagating [14]. In this way, evidence suggests that resin-based adhesive luting agents that bond to the tooth structure and the ceramic restoration can increase the fracture resistance of the restoration complex [15,16].

The overall dimensions and physical characteristics of the adhesive lute may also play an important role in stress distribution and crack propagation within the overlying ceramic restoration [17]. However, while various resin cements have been advocated for cementation of all-ceramic crowns there is neither guidance nor consensus in the literature regarding the ideal parameters for optimum performance throughout the tooth restored with an all-ceramic crown. Thickness of the cement layer on the stress levels within the crown depends on the nature of the cement; for a thick cement lute, the stress development is faster if this is a glass ionomer and slower with a resin cement [18]; which may be on account of the difference of the elastic moduli of these materials. Also, for an elastic resin-based lute the thickness is only an important determining parameter of fracture strength of machined ceramics when this exceeds 300 μm [17,19].

Concerning the elastic modulus of the lute, the fracture resistance of ceramic crowns is highly influenced by the high elastic modulus substrates [20]. Moreover, high elastic modulus resin cements, assuming that they have acceptable viscosity and thickness, have the best performance in terms of all-ceramic crown survival [21].

It is a more clinically relevant research question to consider how these parameters, in isolation or combined, affect the fracture strength of an adhesively bonded ceramic crown-tooth system with due consideration to the preservation of tooth structure.

The aim of this *in vitro* investigation was to determine, by means of static fracture testing the effect of tooth preparation design and the elastic modulus of the cement on the structural integrity of the cemented machined ceramic crown-tooth complex.

The effect of the cement elastic modulus and the tooth preparation design on the stress state of this same ceramic crown-tooth complex has been investigated by the authors in an earlier study by means of Finite Element Analysis (FEA) [22]. The FEA study revealed significant differences in the stress state that occurs in the crown-tooth complex as a result of both the crown design and the elastic modulus of the cement.

A machined feldspathic ceramic has been selected as a popular machinable ceramic with a low documented fracture