Ceramics International 42 (2016) 15709–15717

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Fatigue resistance of monolithic CAD/CAM ceramic crowns on human premolars

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ARTICLE INFO

Article history:
Received 13 June 2016
Received in revised form
4 July 2016
Accepted 4 July 2016
Available online 5 July 2016

Keywords:
Dental crowns
CAD/CAM ceramics
Cerec
Fatigue
Lithium disilicate
Polymer infiltrated ceramics

ABSTRACT

The aim of this study was to determine the fatigue strength of two contemporary crown ceramics, lithium disilicate e.max® CAD (LD) and polymer-infiltrated ceramic Enamic® (PIC) and examine their failure mode. Twenty extracted human maxillary premolars were divided into two groups. The teeth were prepared and restored with either LD or PIC crowns. The restored teeth were subjected to cyclic chewing simulation (9 Hz). The sinusoidal loading was started with 500 N followed by a stepwise increase of 100 N for every 100,000 cycles until fracture occurred or, alternatively, after one million cycles. The Kaplan-Meier survival analysis was applied on fatigue loadings. Differences in the failure modes were analyzed by Fisher Exact tests. The average failure load of LD group was 1400 N (904,728 cycles) with 70% survival rate, while the average failure load of PIC group was 870 N (378,167 cycles) with 0% survival. Regarding the failure mode in both test groups, the crowns tended to fail above the cemento-enamel junction (CEJ) and both combined adhesive and cohesive failure mode were commonly observed rather than cohesive failure. No significant difference was found between the test groups. The failures were initiated from a contact point or central fossa. The fatigue resistance of LD crowns on premolars was significantly higher than the PIC ceramic crowns.

1. Introduction

Full-coverage crown is a common method for restoring damaged teeth due to caries, wear, and trauma [1,2]. An ideal restoration should provide a reliable long-term performance [3,4]. In recent years, because of the increasing aesthetic demand, the use of all-ceramic prostheses has become popular [5]. Furthermore, ceramic materials are more biocompatible and do not cause allergic (or other adverse) reactions when compared with traditional metal-ceramic restorations [6–8]. However, the high failure rate due to susceptibility to flexure, especially in the posterior regions was found in all-ceramic restorations [9,10], and this could be due to the brittleness of ceramics that are weak in high tensile stress conditions [10,11]. The voids and imperfections produced during fabrication procedures of traditional porcelains are known to be the weakest link in ceramic crowns [12]. To overcome the problem, new materials and technologies such as CAD/CAM ceramics, have been developed [13,14]. CAD/CAM ceramics are more homogeneous in structure and they could be milled into a full restoration with minimal processing [2,15]. Furthermore, CAD/CAM technology has facilitated the scanning of complex tooth geometry which is used for ceramic manufacturing [16]. CAD/CAM restorations have accurate marginal adaptation and they could be fabricated at chairside and that saves time and minimizes laboratory cost [17].

Lithium disilicate (LD) reinforced ceramic, commercially available as e.max® CAD, is a kind of CAD/CAM glass ceramic which is partially crystallized [15]. After milling, it should be sintered for the final crystallization and its structure would contain

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http://dx.doi.org/10.1016/j.ceramint.2016.07.029
0272-8842/

approximately 70% lithium disilicate [18]. It experiences a nearly 0.2% volume shrinkage during firing and this is taken into account during the crown manufacturing process [19]. Despite the material is aesthetically pleasing with good translucency and color stability, it is known as a brittle material with fracture susceptibility [14]. Thus, a more ductile material which is a polymer infiltrated ceramic (PIC) has been newly developed (commercially available as enamic®). This hybrid ceramic is composed of 86% ceramic (by weight), where its voids have been filled with a polymer (14 wt%) [20]. Its ceramic network consists of feldspar and its polymer is consisted of PMMA [21,22]. The manufacturer claims the existence of polymer in its microstructure can reduce brittle fractures as observed in pure ceramics [23]. Both LD and PIC can be acid-etched to allow adhesive bonding to tooth structures [24].

Dental restorations are always suffering repeatable chewing forces and an ideal restorative material should withstand such masticatory loads. Cyclic fatigue is the major cause of mechanical failures in dental restorations which cause failure from stress concentration areas or loading contact point [25,26]. Microcracking propagation during mastication reduces material's strength and may lead to a catastrophic failure [12,27]. Mechanical fatigue happens in cyclic loading and it can hardly be inferred by static tests [28]. For having credible information on the longevity of dental ceramics, preclinical *in vitro* studies on fatigue behavior are the first step to evaluate them.

Two studies investigated fatigue resistance of simple LD and PIC bars [29,30]. However, in clinical practice, the factors such as complexity of crown anatomy and adhesion on tooth structure would affect the fatigue behavior and that should be taken into account in the experimental design. There are a few studies done on fatigue resistance of LD crowns [2,14,31,32], but none of them applied fatigue tests for more than 185,000 cycles. Regarding PIC, only fracture strength under static loading has been reported [33]. However, fatigue fracture often occurs at loads lower than monotonic loading [34,35]. To date, there is a lack of evidence regarding the long-term behavior of CAD/CAM ceramics.

The aim of this laboratory study was to investigate the fatigue resistance of LD and PIC ceramic crowns bonded on human premolars and to compare their failure mode. The null hypothesis was that there would be no significant difference in fatigue resistance and failure mode between lithium disilicate and polymer-infiltrated ceramic.

2. Materials and methods

The study was approved by the Institutional Review Board (IRB number: UW 15–578) of The University of Hong Kong and the Hospital Authority Hong Kong West Cluster. Twenty caries free and crack free human maxillary premolars of similar size extracted due to orthodontic reasons were collected and cleansed. The maximum buccolingual, maximum mesiodistal, cervical buccolingual, cervical mesiodistal, height, and intercuspal dimensions of each tooth were measured with a digital caliper (Shanghai Tool Works, Shanghai, China) before storing in 0.1% thymol solution at room temperature. According to the cervical buccolingual size, the teeth were equally divided into two groups with similar mean ($\pm$0.05 mm) and variance in a normal distribution. One group was restored with a LD glass ceramic, e.max® CAD (Ivoclar Vivadent, Schaan, Liechtenstein), while the other group was restored with a PIC ceramic, enamic® (VITA Zahnfabrik, Bad Säckingen, Germany) (Table 1).

2.1. Tooth preparation

Standard full crown preparation using a high speed hand piece with copious air and water spray was carried out on all the teeth [36,37]. A 1 mm round shoulder with 6° of convergence angle was created with a FG 846–014M flat end taper diamond bur (NTI-Kahla, Rotary Dental Instrument, Kahla, Germany) and 2 mm of occlusal reduction was performed following the cuspal inclination of the tooth. The cervical margin was kept approximately 1 mm above the cemento-enamel junction (CEJ) and it was smoothed by an end-cutting bur (0688, Shofu, Kyoto, Japan). The prepared teeth were finally polished (Dura-White Stones FG FL2, Shofu, Kyoto, Japan).

Table 1
Mechanical properties of the studied materials.

Material	Symbol	Manufacturer	Young's modulus, *E* (GPa)	Flexural Strength (MPa)	Lot No.	Shade
IPS e.max® CAD	LD	Ivoclar Vivadent	95.93 (6.37)	356.70 (59.62)	K11235	LTA2
enamic®	PIC	Vita Zahnfabrik	30.15 (1.79)	135.77 (8.35)	32960	2M2T

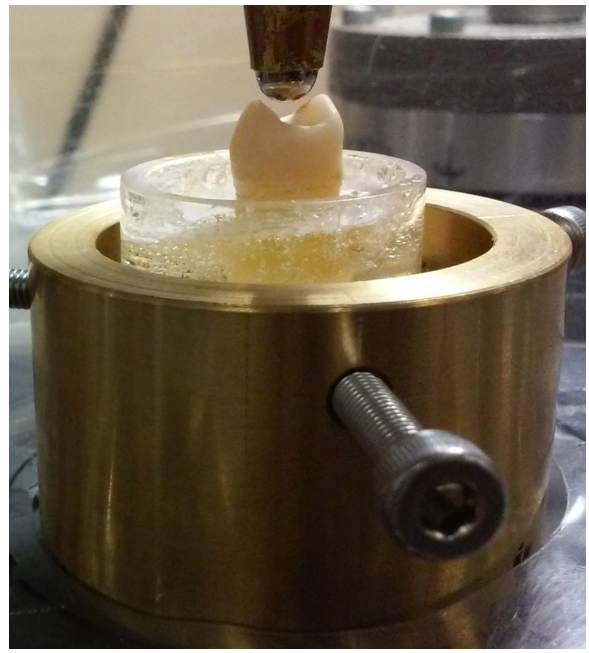

Fig. 1. Setting of the plastic ring under the spherical indenter.

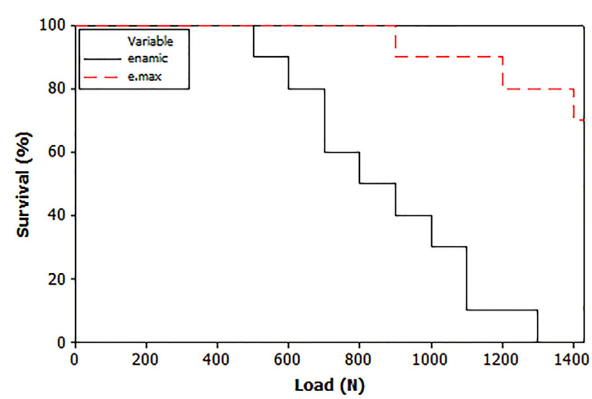

Fig. 2. Kaplan-Meier curve for survival probability.