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Research Paper

Effect of contact stress on the cycle-dependent wear behavior of ceramic restoration

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A R T I C L E   I N F O

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A B S T R A C T

Aim: Ceramic restoration experiences the non-linear wear process during the chewing simulation, which contains running-in, steady and severe wear stages. However since various levels of contact stress may be applied on the occlusal surface during chewing, the cycle-dependent wear behaviors of ceramic crowns may differ. The aim of this study was to investigate the effect of contact stress on the development of wear behavior, as tested in a chewing simulator.

Materials and methods: Thirty-six anatomical metal-ceramic crowns using Ceramco III as the veneering porcelain were randomly assigned to two groups based on the contact stress applied in the wear testing. Stainless steel balls served as antagonists. The specimens were dynamically loaded in a chewing simulator up to 2.4×10^6 loading cycles, with additional thermal cycling between 5 and 55°C. For each group, several checkpoints were employed to measure the substance loss of the crowns' occlusal surfaces and to evaluate the microstructure of the worn areas.

Results: After 2.4×10^6 cycles, the ceramic restorations with lower contact stress demonstrated a long steady wear stage following the running-in, but without the severe wear stage. And a slowly microstructural degradation was observed that the subsurface defect could not be seen until final. With higher contact stress, however, the ceramic restorations experienced a faster transition from running-in to severe wear stage that the steady wear stage nearly disappeared. And an early formation of subsurface defects and the deterioration of microstructure were observed.

Conclusions: Contact stress is a key factor affecting the wear development of ceramic restoration. The higher contact stress promotes the veneering porcelain to evolve into severe wear stage. In contrast, lower contact stress is prone to keep the veneering porcelain operating in steady wear stage, which delays the arrival of severe wear region.

1. Introduction

Intraoral wear damage between natural enamel and ceramic restoration is an irreversible and unavoidable process. After incorporation of ceramic crown, it would be preferable if dental restoration could show a tribological similarity to natural enamel (Lambrechts et al., 1989; Seghi et al., 1991), which would keep functional stability of ceramic/enamel pairing. However, some studies both *in vitro* (Kim et al., 2012; Kwon et al., 2015) and *in vivo* (Mundhe et al., 2015) showed that the wear performance of dental ceramic was not compatible with that of natural tooth. Especially when natural tooth opposed by veneering porcelain antagonist, both sides demonstrated the severe wear (Lawson et al., 2014; Preis et al., 2011), compared with enamel–enamel wear.

Besides the unrecoverable damage of enamel, the severe wear process may also lead to premature failure of ceramic restoration. According to a fractographic analysis of clinically failed prostheses, the fracture initiated from the wear facet at the occlusal surface in all observed cases (Pang et al., 2015). With cyclical chewing, wear facets of ceramic restoration become rougher due to the greater wear (Amer

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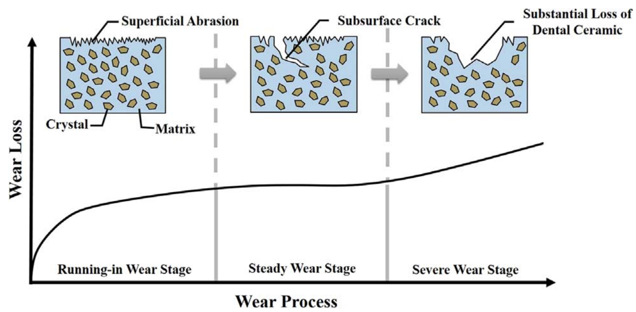

Fig. 1. A schematic diagram showing a typical wear curve.

et al., 2015), which may lead to higher friction coefficient. Thus, higher tangential force is generated under frictional sliding on the rougher surface relative to the sliding on the smooth surface, which could significantly reduce the critical loading of dental ceramic (Ren and Zhang, 2014).

Many previous studies (D Arcangelo et al., 2016; Kim et al., 2012; Zandparsa et al., 2016; Zhi et al., 2016), estimating and rating the wear resistance of dental ceramics, exclusively focused on the final value of wear loss after pre-defined wear cycles. However, some features of wear behavior hidden below the surface of the wear development might be ignored. Our previous study reported that the cycle-dependent wear behavior of ceramic restoration was a development of nonlinear relationship during the chewing simulation (Guo et al., 2014). The entire wear process contained three featured wear stages (Running-in wear stage, Steady wear stage, Severe wear stage) (Fig. 1). During the running-in period, higher wear rate was detected and ceramic surfaces exhibited extensive wear. During the steady wear period, the ceramic restorations showed lower wear activity that the wear rate maintained at a lower level. But the propagation of subsurface cracks could be observed. When reaching the severe wear stage, the dramatic increase of wear loss was the result of penetrating of cracks and separation of porcelain pieces. With the evolution of wear stages, the mechanism of wear behavior experienced a transition from superficial abrasion to subsurface brittle fatigue. The catastrophic propagation of subsurface cracks was also an indication of inferior wear resistance even with a low wear loss. Therefore, in design philosophy, it is crucial to keep ceramic prostheses operating in a steady wear phase as long as possible.

Unlike some intrinsic mechanical properties, wear behavior of ceramic restoration is dependent on patient-related factors (Heintze et al., 2008), such as occlusal force, number of chewing cycles, properties of saliva, etc. This may lead to inconsistent wear performance of dental ceramic under various experimental settings associated with different applied contact stresses. According to Dupriez's research (Dupriez et al., 2015), lithium disilicate glass ceramic (IPS e.max Press) showed significant higher wear loss than that of leucite-reinforced glass ceramic (IPS Empress Esthetic). While in another study, the same brand materials demonstrated nonsignificant differences in volumetric wear (Albashaireh et al., 2010). Therefore, the wear behavior is strongly affected by the parameters of the wear test.

The contact stress induced by occlusal force is a key factor in causing the oral wear. So the occlusal force of a wear simulation is considered as a critical parameter. Usually, the force is set as a value chosen from the physiological range of masticatory forces in many studies (Ghazal et al., 2008; Mehl et al., 2007; Preis et al., 2016), which was measured directly in human subjects using force or pressure transducers (Gibbs et al., 1981; Hidaka et al., 1999). According to some clinical observations, the wear loss was higher in posterior region than anterior region (Mundhe et al., 2015), which suggested that higher occlusal force might account for the greater wear. In addition, various bite forces were detected when chewing solid foods with different textures (Takahashi et al., 2009). As the food bolus was compressed, corresponding force of mastication applied on the surface of ceramic crown. Therefore, the dental ceramic may experience different levels of contact stress due to various individuals and service conditions, which would affect the cycle-dependent wear behavior. Moreover, the distribution of three wear stages and the duration of each stage may differ. However, no research has reported on the effect of the contact stress on the cycle-dependent wear behavior of ceramic restoration for a long term oral service.

Three contact stress levels were involved in the current study including two testing groups and a baseline group that had been measured in our previous study (Guo et al., 2014). The wear test was conducted by a custom-designed chewing simulator. Although clinical tests are the ideal method for estimating the complex wear performance of ceramic restorations, *in vitro* wear testing with tribosystems usually referred to as chewing simulators may be the best option for investigating single parameter of the wear process and identifying underlying wear mechanisms. The objective of this study was to investigate the effect of loading stress on the cycles-dependent wear behavior of the anatomical porcelain-fused-to-metal (PFM) crowns, using the chewing simulator to mimic the masticatory movement and moisture conditions of the oral cavity. The tested null hypothesis was that the cycle-dependent wear behavior would change with the magnitude of contact stress applied on the ceramic restoration, and the distribution or the duration of three wear stages would change also, during the entire wear process.

2. Materials and methods

2.1. Sample preparation

An artificial mandibular first molar (dental study model; Nissin Dental Products Inc, Kyoto, Japan) was employed for a complete crown preparation using a mannequin. The tooth was prepared with the following standardized criteria: 6-degree axial taper, 1.0-mm shoulder finish line with rounded internal angles placed 0.5 mm occlusal to the cementoenamel junction (CEJ), 2-mm occlusal reduction and 1.5-mm axial reduction. Then, thirty-six analogues made of resin-based composite (Z100, 3M ESPE, St Paul, MN, USA) were duplicated from the prepared molar by the impression technique (Express, 3M ESPE, St. Paul, MN, USA). After incubated in water for 30 days, the replicas were embedded in epoxy resin surrounded by PVC tubes 25 mm-diameter with the finish line of preparation 2 mm higher than the resin surface. The long axes of both the analogue and the tube were arranged perpendicular to the horizontal plane. Then each of the analogue assembly received an impression with polyether material (Impregum F, 3M ESPE, St. Paul, MN, USA), and working dies of each replica impression were made of class IV dental stone (Die-Stone, Heraeus Kulzer Dental, Shanghai, China).

Thirty-six stone dies were randomly assigned to two groups (n=18) according to the applied contact stress. Based on these stone dies, thirty-six metal cores in the same nickel–chromium alloy (Heraeus Kulzer Dental, Shanghai, China) with an even thickness of 0.5 mm were cast using the lost-wax technique, following the manufacturer's instructions. All castings were inspected with a light microscope, and the irregularities were removed with a round bur. After sandblasted with 50-μm aluminum oxide and steam-cleaned, the castings were hand-layered with a feldspathic-based veneering porcelain (Ceramco III; Dentsply, Burlington, NJ, USA) by the same experienced technician, according to the manufacturer's guidelines. In order to obtain a total thickness (metal core and veneering porcelain) of approximate 2.0 mm on the occlusal surface and approximate 1.5 mm on the axial, the impression of a full contour mandibular first molar was used to guide the veneer-layering procedures. Then the PFM crowns were glazed. After the appropriate internal adjustments, the crown was cemented on its corresponding analogue assembly, using a resin cement (PANAVIA F, Kuraray Medical Inc, Tokyo, Japan). The essential cementation procedures are summarized here: Prior to cementation, the intaglio