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Influence of surface and heat treatments on the flexural strength of a glass-infiltrated alumina/zirconia-reinforced dental ceramic

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Summary *Objectives*. The purpose of this study was to investigate the influence of sandblasting, grinding, grinding orientation and polishing before and after heat treatment, on the flexural strength of a glass-infiltrated alumina/zirconia-reinforced dental ceramic (In-Ceram Zirconia).

Methods. The uniaxial flexural strength was calculated on 160bar-shaped specimens (20×4×1.2 mm) divided equally into eight groups as follows: sandblasted; sandblasted heated; polished; polished heated; ground parallel to the tensile axis; ground parallel heated; ground perpendicular; and ground perpendicular heated. Data were analyzed with multiple regression analysis, one-way ANOVA and Tukey's pairwise multiple comparisons and Weibull analysis. The treated and fractured surfaces were observed with SEM. The relative content of the monoclinic phase was quantified with an X-ray diffraction analysis.

Results. A thin layer of glass was present on the surface of the specimens after heat treatment and contributed to an improvement of the flexural strength. Surface treatment (not followed by heat treatment) generated phase transformation which, however, was not sufficient to avoid strength degradation caused by the flaws introduced with the surface treatments. Sandblasting caused the most marked strength degradation. Polishing alone increased the reliability, but did not improve the strength. The orientation of grinding in respect of the direction of the tensile stresses did not influence the ultimate tensile strength.

Significance. The present study suggests that any surface treatment performed on In-Ceram Zirconia should always be followed by heat treatment to avoid strength degradation.

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Introduction

It has recently been advocated by Lawn et al. that a stronger and tougher core material would improve the reliability and therefore the lifetime of an all-ceramic crown. An improvement of the clinical performance of the restoration is also expected, if steps are taken to avoid the formation of flaws [1]. Flaws may be introduced as a result of grinding and sandblasting, which are common stages of the fabrication and clinical adjustment of all-ceramic restorations.

In-Ceram Zirconia (IZ) (Vita Zahnfabrik, Bad Säckingen, Germany) has been developed by adding 33% of Ceria partially stabilized zirconia (PSZ) to the initial compound In-Ceram Alumina (IA) (Vita Zahnfabrik, Bad Säckingen, Germany) in order to provide a stronger and tougher core material. IZ is available either as slip or dry-pressed blank. The dry-pressed form of the material is supplied in different shapes to fit a number of CAD/CAM systems. Regardless of the system used to fabricate the restoration, processing commonly involves milling and sandblasting at different stages of the fabrication. For example, milling is used to shape the framework before glass-infiltration, and to improve fitting during the issue of the restoration. Sandblasting is used to remove the excess glass after infiltration and suggested before cementation to enhance the adhesion of the luting agent [2–4]. Furthermore, these procedures may or may not be followed by further heat-treatment before the cementation of the restoration. For example, heat treatment (veneering of the core material with porcelain) follows sandblasting used to remove excess glass. However, it does not follow sandblasting when the latter is used to improve the adhesion of the luting agent. The addition of zirconia to IA has resulted in a moderate improvement of the mechanical properties of IA [5–7]. Nevertheless, there are no studies which illustrate the influence of grinding, sandblasting and heat treatment on the ultimate strength of IZ.

Several investigations indicate that grinding generates two counteracting effects, namely, it introduces surface flaws and creates a thin superficial layer of compressive stresses [8–15]. The grinding-induced surface compressive layer is the result of the overlapping of elastically/plastically displaced material. The compressive stresses may counteract tensile stresses acting at the crack tip and thus increase the strength of a given ceramic [10–12]. In phase transforming materials, the magnitude of the compressive stresses is further improved by the tetragonal to monoclinic ($t \rightarrow m$) phase transformation. Such transformation results in 3–4% volumetric expansion of the particles, and may be exacerbated by externally applied stresses exerted by, for example, grinding and sandblasting [8]. The increase in strength is related to the volume of transformed zirconia and to the depth of the surface compressive layer, which in turn are influenced by the metastability of zirconia and the severity of grinding [10,16]. On the other hand, the surface flaws introduced by grinding and sandblasting act as stress concentrators and may cause strength degradation [13]. The orientation of grinding can also influence the mechanical properties of ceramics, as shown by Mecholsky et al. and by Swain [17,18]. Grinding introduces two primary strength reducing flaw systems; deeper median cracks parallel to the grinding direction and shallower surface flaws associated with lateral cracks orthogonal to the grinding direction [18]. Grinding perpendicular to the tensile axis generates flaws which are effectively 60% deeper with an associated greater stress intensity factor than flaws resulting from parallel grinding. Grinding perpendicular to the tensile axis is thus expected to cause greater strength reduction [17,18].

Annealing [19–23] as well as polishing [13,24] has been commonly used to reduce the size of flaws and thus increase the strength of a ceramic. Heat treatment is also responsible for blunting of flaws thereby resulting in a decrease of the stress intensity factor at the crack tip and an associated increase in fracture strength [19,20,25]. However, in zirconia-based ceramics the $t \rightarrow m$ transformation may be reversed by heat treatment reducing the magnitude of the surface compressive stresses layer and hence the ultimate strength [16].

The aim of the present study is to investigate the influence of sandblasting, grinding, grinding orientation, polishing and heat treatment on the flexural strength of a glass-infiltrated alumina/zirconia-reinforced dental ceramic. Two hypotheses are explored. Firstly, as a result of the surface compressive stress layer generated by the $t \rightarrow m$ transformation of the zirconia particles, the ground and sandblasted specimens without heat treatment will have greater strength than the corresponding heat-treated specimens and the polished samples (samples with or without heat treatment and used as the control group). Secondly, the specimens which are ground parallel to the tensile axis will be stronger than those where grinding is oriented perpendicular to the tensile axis.