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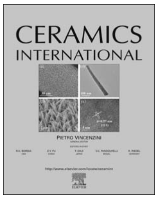

Speed sintering translucent zirconia for chairside one-visit dental restorations: Optical, mechanical, and wear characteristics

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ABSTRACT

The fabrication of zirconia dental restorations is a time-consuming process due to traditional slow sintering schemes; zirconia (Y-TZP) produced by these conventional routes are predominantly opaque. Novel speed sintering protocols have been developed to meet the demand for time and cost effective chairside CAD/CAM-produced restorations, as well as to control ceramic microstructures for better translucency. Although the speed sintering protocols have already been used to densify dental Y-TZP, the wear properties of these restorations remain elusive. Fast heating and cooling rates, as well as shorter sintering dwell times are known to affect the microstructure and properties of zirconia. Thus, we hypothesize that speed sintered zirconia dental restorations possess distinct wear and physical characteristics relative to their conventionally sintered counterparts. Glazed monolithic molar crowns of translucent Y-TZP (inCoris TZI, Sirona) were fabricated using three distinct sintering profiles: Super-speed (**SS**, 1580 °C, dwell time 10 min), Speed (**S**, 1510 °C, dwell time 25 min), and Long-term (**LT**, 1510 °C, dwell time 120 min). Microstructural, optical and wear properties were investigated. Crowns that were super-speed sintered possessed higher translucency. Areas of mild and severe wear were observed on the zirconia surface in all groups. Micropits in the wear crater were less frequent for the **LT** group. Groups **S** and **SS** exhibited more surface pits, which caused a scratched steatite surface that is associated with a greater volume loss. Tetragonal to monoclinic phase transformation, resulting from the sliding wear process, was present in all three groups. Although all test groups had withstood thermo-mechanical challenges, the presence of hairline cracks emanating from the occlusal wear facets and extending deep into the restoration indicates their susceptibility to fatigue sliding contact fracture.

1. Introduction

Full-contour monolithic zirconia crowns are increasingly used in prosthetic dentistry because of their strength, resistance to fracture, and fabrication simplicity [1–3]. Although only some preliminary clinical trials on monolithic zirconia dental restorations have been published [1,4–7], in vitro studies revealed that monolithic zirconia crowns can endure the highest fracture load among all ceramic restorative systems [3,8]. In addition, laboratory testing [9–12] and clinical researches [5,13,14] have shown that polished zirconia causes less tooth enamel wear than glazed zirconia, whereas glazed zirconia exhibits comparable or better results than other dental ceramic materials.

Monolithic zirconia dental restorations are produced from a somewhat translucent, strong and dense zirconia. These desirable properties can be obtained by manipulating sintering additives and conditions. The elimination of light-scattering alumina sintering aids and porosities improves translucency, but requires a higher sintering temperature (1530 °C) in conjunction with a longer dwell time (6 h) [8]. Reducing the grain size and increasing the green compact density also improves translucency. In this case, a lower sintering temperature (1450 °C) and shorter dwell time (2 h) are necessary [8]. A further increase in translucency can be achieved by keeping zirconia grain size under 100 nm while eliminating defects such as pores and oxygen vacancies [15]. Such a microstructure would allow light transmission without substantial scattering, yielding a translucency similar to that of dental porcelains. To date, it is still challenging to densify Y-TZP with a sub-100 nm grain size. Speed sintering is one of the plausible routes to

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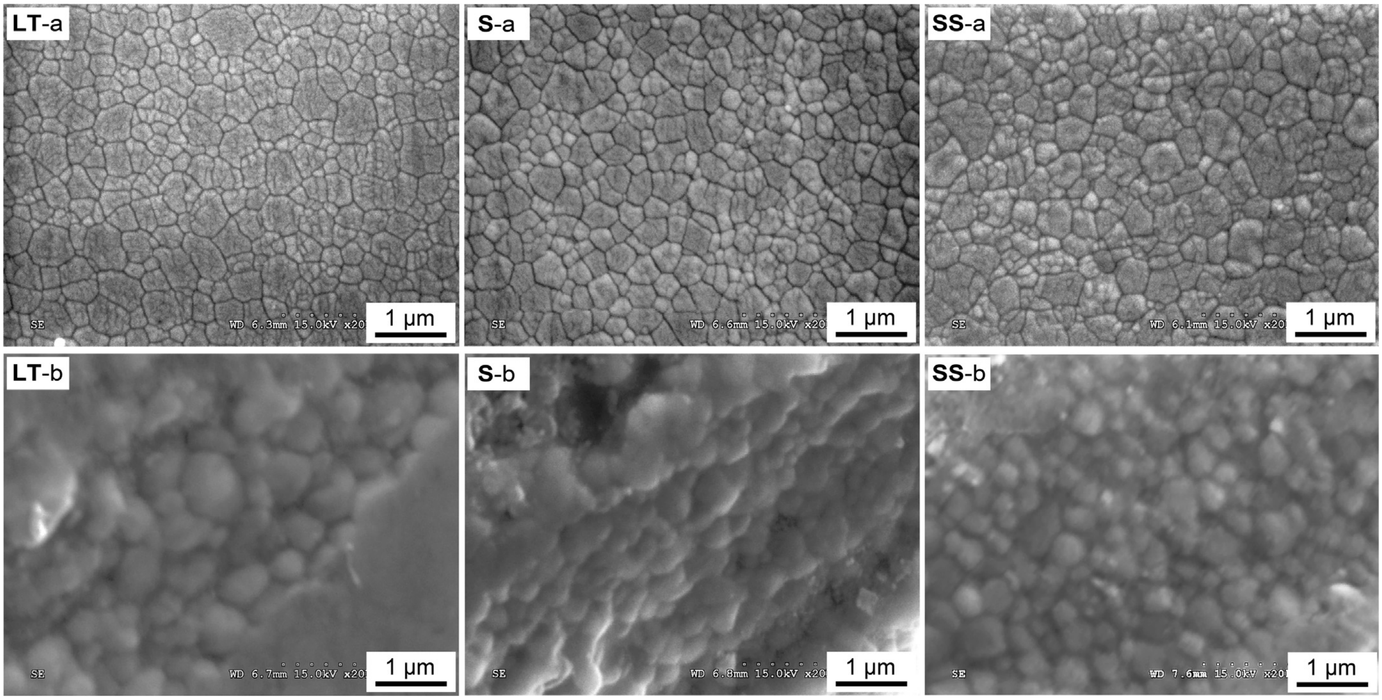

Fig. 1. Microstructure of the three zirconia groups (**LT**: Long-term, **S**: Speed, and **SS**: Super-speed). (a) Microstructure after polishing and thermal etching, and (b) Exposed grain facets in the wear micropits.

Table 1
Optical and mechanical properties of the zirconias tested, showing mean (standard deviation) for grain size (*D*), translucency (TP), hardness (HV), and flexural strength (*σ*)*.

	SS	S	LT
D (μm)	0.59	0.50	0.66
TP	4.6 (0.4)^{a}	4.2 (0.5)^{b}	4.3 (0.4)^{ab}
HV (GPa)	13.1 (0.2)^{b}	13.1 (0.2)^{b}	13.3 (0.1)^{a}
σ (MPa)*	904.2.7 (115.7)^{a}	622.3 (82.7)^{b}	579.7 (130.6)^{b}

TP and HV data were analyzed using One Way ANOVA and Tukey test (5%), comparing the zirconia groups. Distinct superscript letters within the same row indicate statistical differences among groups.
*The flexural strength data were published by Dr. Ersoy and colleagues in 2015 [16]. Data were obtained using the 3-point bend test with bar specimens of 1.2 × 4 × 25 mm in dimension (*n* = 20) according to ISO 6872.

produce dense, ultrafine-grained Y-TZP.

Traditionally, the sintering of Y-TZP for engineering applications is a time consuming process, which involves a 'slow' heating and cooling rate (typically 5 – 10 °C per minute) coupled with a prolonged dwell time (often amounting to several hours). The resulting materials are strong but largely opaque. Dentistry is now redefining protocols for ultrafast ceramic sintering. Novel speed and super-speed sintering protocols have been developed [16] to meet the demand for time and cost effective chairside one-visit CAD/CAM-produced restorations, as well as to prevent Y-TZP grain growth for better translucency. The effect of speed sintering on the flexural strength of monolithic Y-TZP has been investigated [16], showing that no significant difference was observed in the flexural strength of Y-TZP when speed sintered with a dwell time of 25 min at 1540 °C (σ=622.3 ± 82.7 MPa) and conventionally sintered with a dwell time of 120 min at 1510 °C (σ=579.7 ± 130.6 MPa). However, when super-speed heating and cooling rates, as well as a short dwell time, were used (the sample was placed in a 1580 °C pre-heated furnace and removed after 10 min dwell time), the flexural strength achieved was much higher (904 ± 115.7 MPa). It is unclear why super-speed sintering may lead to a superior flexural strength in Y-TZP; such a phenomenon appears to defy the theory of thermal stress resistance of ceramics. Nevertheless, speed and super-speed sintered dental zirconia are already in the market, and likely in patients' mouths, although their fatigue and wear properties remain elusive. To the best of our knowledge, nothing has yet been published on how speed sintering of monolithic zirconia dental restorations would affect its microstructure, translucency, and wear characteristics.

2. Experiment

2.1. Specimen preparation

The monolithic translucent zirconia molar crowns (inCoris TZI, Sirona) tested herein were CAD/CAM-milled, sintered and glazed by Sirona. Sintering was carried out according to the following protocols:

- Long-term sintering (**LT**): served as a reference group: heating at 25 °C/min to 800 °C, then at 15 °C/min to 1510 °C, dwelling for 120 min, followed by cooling at 30 °C/min down to 200 °C before removing from the furnace. Total sintering time 4 h.
- Speed sintering (**S**): heating at 99 °C/min to 1100 °C, then at 50 °C/min to 1510 °C, dwelling for 30 min, followed by cooling at 99 °C/min down to 800 °C dwelling for 5 min before removing from the furnace. Total sintering time 60 min.
- Super-speed sintering (**SS**): Crown is placed in a pre-heated furnace at 1580 °C, dwelling for 10 min, and immediately removed from the furnace. Total sintering time 10 min.

2.2. Microstructure

One crown per group was polished to a flat surface with a 1 μm diamond suspension finish, and then thermally etched at 1150 °C for 20 min with a heating and cool rate of 40 °C/min. Imaging was performed in a scanning electron microscope (Hitachi 3500 N, Japan). The zirconia grain size was measured using the linear intercept method [17].