

IMAGING EVALUATIONS OF UNICA CERAMICS UNDER THERMAL CYCLE CONTROL CONDITIONS

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ABSTRACT

Aim of the study: To evaluate the efficacy of Optical Coherence Tomography (OCT) in non-invasively monitoring temperature variations during ceramic sintering for dental prosthetics, emphasizing the importance of precise temperature control for optimal material properties and structural integrity. **Materials and Methods:** The study utilized OCT to examine 17 metal-ceramic restorations at various sintering temperatures (standard, 80°C below, and 50°C above the standard). The method involved generating 61 cross-sectional images per prosthesis to identify defects and structural changes. **Results:** OCT revealed significant insights into the impact of temperature deviations on ceramic microstructure, including uniform grain sizes at standard temperatures and areas of reduced retention at elevated temperatures, highlighting the technology's potential in quality control. **Conclusions:** OCT offers a rapid, accurate, and non-destructive means to assess sintering temperatures and detect defects in dental ceramics, facilitating improvements in dental prosthetics' fabrication process. The study advocates for OCT's integration into routine dental laboratory practices to enhance prosthesis quality and reliability.

Key words: Optical Coherence Tomography (OCT), ceramic sintering, dental prosthetics, temperature monitoring.

INTRODUCTION

The sintering process, crucial in ceramic fabrication, involves the thermal activation of matter transport to transition a porous powder compact into a dense solid, thereby reducing porosity through atom diffusion across various phases. This process aims to lower the material's energy state from a higher-energy porous structure to a lower-energy dense form, driven by surface energy reduction through minimized gas-liquid/solid interfacial areas.

Both solid-state and liquid-phase sintering are discussed, highlighting the importance of controlling process parameters to influence grain growth and densification, which in turn affects the ceramic's final microstructure and properties. Techniques to manage the microstructure vary, including pressureless sintering with specific thermal treatments to promote densification-friendly atom diffusion and employing strategies like fast firing, controlled rate sintering, or additives to curb

excessive grain growth. Advanced methods that apply external pressures or electric currents, along with utilizing fine, well-dispersed powders, offer pathways to achieve fully dense ceramics with limited grain growth, lower sintering temperatures, and durations, presenting significant energy-saving potentials [1].

The production of fixed partial dentures utilizing ceramic materials, encompassing both metal-ceramic and all-ceramic variants, is susceptible to the entrainment of air bubbles. These air inclusions can precipitate defects across various depths of the ceramic veneer, potentially leading to the initiation of fracture lines within the ceramic body. Such fractures can culminate in the detachment of the ceramic from the metal framework under the influence of masticatory forces. Conventional examination techniques for dental prosthetics, which involve sectioning the specimens for metallographic microscope analysis, may compromise or obliterate minute defects, with their effectiveness being constrained by the sectioning capabilities of the equipment. Furthermore, the destructive nature of these methods precludes the possibility of reusing the prostheses post-analysis [2-5].

Given these challenges, there emerges a clear imperative for the development of a non-

destructive diagnostic technique that can accurately identify material defects within dental prostheses. This novel method should not only offer high precision but also integrate seamlessly into everyday clinical practices, thereby facilitating the preservation and continued utility of dental prosthetics after evaluation [5].

Originally developed for ocular imaging, Optical Coherence Tomography (OCT) has transcended its initial scope, presenting a revolutionary, non-invasive approach for the in vivo exploration of biological tissues. This advancement is particularly impactful in the field of dentistry, where OCT has unveiled new dimensions in the analysis of both soft and hard dental structures. The technology's utility is primarily explored through two innovative modalities: en-face OCT and spectral domain OCT. These methodologies have paved the way for a diverse array of dental applications, including the assessment of anomalies in dental materials, examination of marginal discrepancies in prosthetic fittings, evaluation of orthodontic bracket adhesion to dental surfaces, and detection of infiltrations subsequent to laser-assisted root canal treatments. OCT's versatile capabilities thus mark a significant leap forward in dental diagnostics and treatment planning [6-12].

MATERIALS AND METHODS

The fabrication of the metal ceramic restorations

The first step was the fabrication of the working model utilizing Class IV gypsum procured from SynaRock, Hungary. Subsequent to the gypsum's solidification, the mold was detached and refilled using a model pourer from the Sirio company, Italy. The working model underwent sculpting and finishing before the creation of holes via a Pindex device, also from Sirio, Italy. Pins were then meticulously placed into the model,

which was subsequently isolated with IsoWax, an isolating substance from Infradent, Baia Mare.

For the base of the model, we employed Class III gypsum (Moldano) sourced from Fertisol, Hungary. Following the solidification phase, the model was prepared for the sectioning of stump teeth utilizing a Model Cut device from TAG 96, Italy. Abutment processing was executed with a micromotor from Kawo, Germany.

A separating lacquer from Durolan DFS,

Germany, was applied, followed by a second isolation with IsoWax from Infradent, Baia Mare. The wax pattern was sculpted using induction units from SKYSEA, China, complemented by the Peter Kynaston "PK" Thomas addition kit, England. The wax from BREDENT, Germany, and casting pins from Fertisol, Hungary, were utilized in the process.

The patterns were placed into a silicone ring from BEGO, Germany, and encapsulated with refractory material from Heraeus, Germany, using a vacuum mixer from BEGO, Germany. The casting ring was preheated in an oven from TISI Dental, Italy, before the casting process with metal from Wiron 99, Germany, executed using a casting machine from Sirio, Italy.

Post-casting, the metal infrastructure was revealed through unpacking and subjected to sandblasting using equipment from TISI Dental, Italy. Pin sectioning was performed with a Biax motor, and the metal infrastructure's finishing was completed with a micromotor from KaVWo, Germany (Fig.1).



Fig.1. The metal infrastructures sandblasted, and prepared for oxidation.

A subsequent round of sandblasting for the ceramic infrastructures was conducted with the TISI Dental's sandblasting device, Italy. The processes of oxidation sintering, application of opaque and ceramic layers (Fig.2) were carried out using a ceramic oven from IVOCLAR VIVADENT EP 5000,

Germany, utilizing materials from Wegold UNICA, Germany.



Fig.2. Deposit of the first layer of dentine on the upper central incisor.

Scanning samples with OCT (Optical coherence tomography)

In this investigation, Optical Coherence Tomography (OCT) served as the primary non-invasive diagnostic tool for identifying defects within the ceramic layers applied to the frameworks of fixed partial dentures. The study utilized 17 metal-ceramic restorations, within which the OCT method successfully revealed structural inconsistencies distributed across various depths of the ceramic mass. For each dental prosthesis examined, the technique involved the acquisition of 61 cross-sectional images (slices), each spaced 66 microns apart. The OCT device employed for this purpose operated at a wavelength of 670 nm, ensuring detailed visualization of the internal structure of the ceramic material. To facilitate precise and reproducible positioning for the scans, each prosthesis was mounted on a specially designed sample holder. This holder allowed for controlled adjustments in all three spatial dimensions, courtesy of an integrated mechanical system, thereby enabling comprehensive and accurate assessment of the prosthetic structures.

The operational procedure for activating the Optical Coherence Tomography (OCT) analysis system adheres to a meticulously

defined sequence for initiating its component parts. The system's software plays a pivotal role in configuring the parameters for the scanning process, particularly the step intervals between successive scans. To reduce the risk of generating excessively large intervals between acquisitions, the sections were strategically set approximately 66 microns apart. Notably, the system's precision capabilities extend far beyond this, allowing for sectioning at intervals as fine as 1 micron. Upon accurately focusing on the designated area of interest, the system is capable of generating around 61 consecutive images (investigation slices). These images serve as a comprehensive dataset for analysis, revealing the presence of defects within the ceramic mass. The defects identified exhibit variability in their location and extent, thereby providing

RESULTS AND DISCUSSIONS

The OCT scans provided a detailed view of the internal structure of the ceramics, enabling the identification of temperature-related anomalies and their distribution within the material. This approach facilitated a comprehensive evaluation of how deviations from the recommended sintering temperature influence the formation of defects in ceramic dental restorations [13].

Figure 3 presents three-dimensional rendered images, illustrating the homogeneity in grain sizes of the ceramic particles as identified by the Optical Coherence Tomography (OCT) system at the recommended sintering temperature. This uniformity is indicative of optimal sintering conditions, underscoring the precision and reliability of OCT in assessing the microstructural properties of ceramic

a nuanced understanding of the structural integrity of the ceramic material used in dental restorations.

The study involved subjecting samples to sintering at three distinct temperature settings: **80°C below** the standard sintering temperature, at the **standard temperature**, and **50°C above** it. These varied temperature conditions were established to assess the impact of sintering temperature on the integrity of ceramic materials. Following the thermal treatment, each sample was meticulously examined using Optical Coherence Tomography (OCT). This non-invasive imaging technique was employed to elucidate the presence and nature of defects induced by sintering at low, optimal, and elevated temperatures.

materials utilized in dental restorations.

Results depicted in Figure 4 feature 3D rendered images that illustrate regions of diminished retentivity, situated centrally within zones of standard reflectivity. These findings were unveiled using the Optical Coherence Tomography (OCT) system, following a temperature elevation of +50°C above the recommended sintering temperature.

The visualizations highlight the adverse effects of excessive temperature on the ceramic's microstructure, specifically indicating areas where the ceramic's inherent retention has been compromised. Such alterations in the material's properties can significantly impact the longevity and mechanical performance of dental restorations.

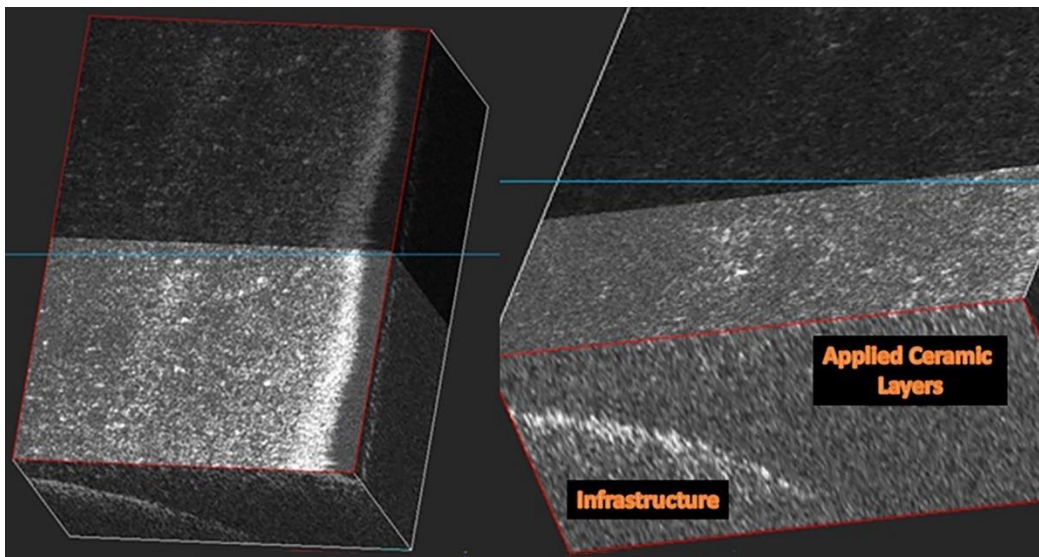


Fig.3. 3D rendered images showing the uniform grain sizes of the ceramic particles detected with the OCT system at the normal indicated temperature.

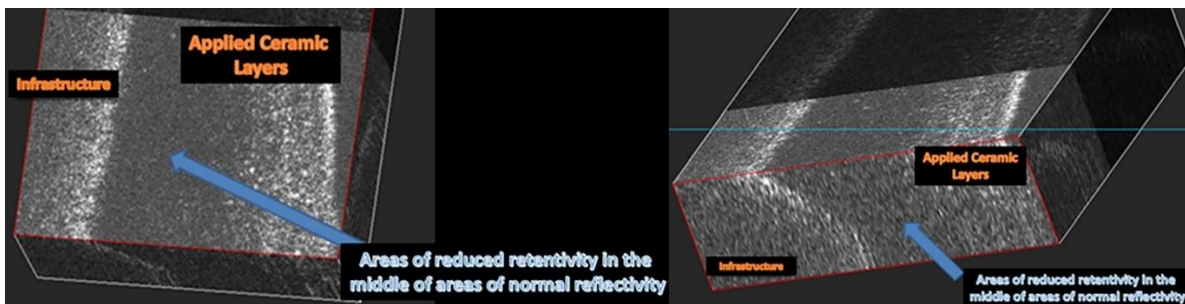


Fig.4. 3D rendered images presenting areas of reduced retentivity in the middle of areas of normal reflectivity discovered with the OCT system at a variation of + 50°C above the indicated temperature.

The OCT system's capability to detect these variations at a microscopic level underscores its utility in evaluating the integrity and reliability of dental ceramics, particularly when subjected to non-standard processing conditions. This detailed assessment aids in understanding the thermal tolerance of ceramic materials and the importance of adhering to precise sintering protocols to maintain optimal material characteristics.

Figure 5 presents 3D rendered images that demonstrate a gradient in the reflectivity intensity of the ceramic material, transitioning from left to right, with discernible areas of reduced reflectivity.

These observations were made possible through the application of Optical Coherence Tomography (OCT) at a sintering temperature that was decreased by 50°C below the manufacturer's recommended setting. The images effectively capture the heterogeneity in material properties induced by suboptimal thermal processing, highlighting specific zones where the ceramic's reflectivity and potentially its density and structural integrity is compromised. Such variations can be indicative of incomplete sintering or other alterations in the ceramic microstructure, which may adversely affect the material's mechanical properties and its performance in

dental restorations.

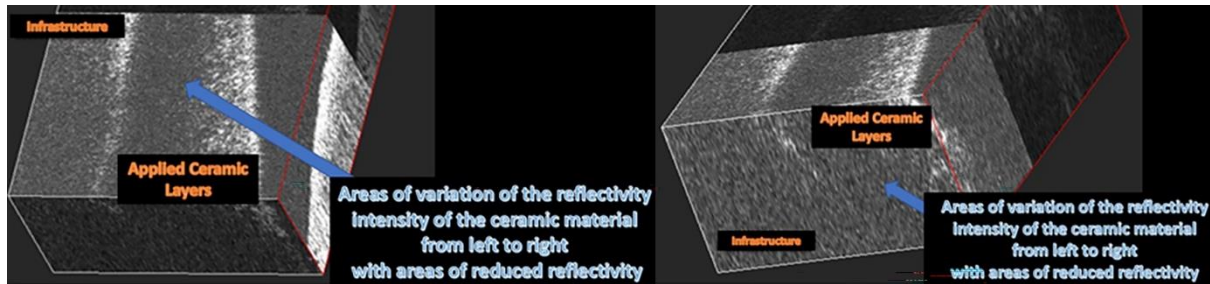


Fig.5. 3D rendered images showing a variation of the reflectivity intensity of the ceramic material from left to right with areas of reduced reflectivity discovered with the OCT system at a variation of -50°C below the indicated temperature.

The ability of the OCT system to reveal these variations in reflectivity provides critical insights into the effects of lower-than-recommended firing temperatures on ceramic materials, emphasizing the necessity for precise control over processing conditions to ensure the quality and durability of dental ceramics.

In the literature is discussed the effectiveness of Optical Coherence Tomography (OCT) in non-invasively monitoring temperature variations during the sintering process of dental prostheses. It

highlights OCT's ability to detect structural changes and defects within ceramic materials at different sintering temperatures. Key findings include the identification of optimal sintering temperatures through uniform grain distribution and reflectivity, the impact of temperature deviations on grain growth and potential defects, and the significance of regular OCT evaluations to prevent errors in the sintering process. The study underscores OCT's potential for enhancing quality control in dental prosthesis fabrication and sustains our results [14].

CONCLUSIONS

This research showcases the use of OCT for straightforward, rapid, and non-destructive monitoring of temperatures within ceramic ovens during the fabrication of metal-ceramic dental prosthetics. Dental technicians can routinely utilize OCT to assess the ceramic layers in depth analysis across samples. The study highlights that a reflectivity change signals the need for oven recalibration, as significant temperature increases may induce material

cracking. Future improvements could involve analyzing the reflectivity's variance, aiming to equip practitioners with a basic method to determine the necessity for recalibration. Monitoring the sintering process has the aim to avoid thermal stress or insufficient sintering, thereby preventing material defects and subsequent fractures in the prostheses restorations.

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