FACTORS INVOLVED IN THE CHROMATIC FAILURES OF NON-METALLIC FIXED DENTAL PROSTHESES

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ABSTRACT

Aim of the study In the field of digital dentistry, Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems have changed the fabrication of prosthetic restorations by fulfilling both the aesthetic requirements and mechanical performance. This study aims to highlight, by conducting a chromatic evaluation of zirconium oxide when altering the sintering parameters **Materials and methods** Four groups of zirconium oxide each group formed by 5 copings were made through milling and Exocad digital design software. The design was completed and the files were processed with the Zeno 4030 M1 milling machine (I-MES Wieland). Following milling, the copings were sintered in HTS MIHM-VOGT furnace at a maximum sintering temperature of 1650°C and heating rates of 30°C/min or a rapid rate of 90°C/min. Controlled cooling prevented rapid temperature decrease, thereby minimizing internal stress. Modifications of time and temperature parameters were applied to groups 2, 3, and 4. Chromatic analysis of the specimens was registered with the Vita Easy Shade spectrophotometer. **Results** It was found that adjustments in sintering temperature and timing are significantly affecting the chromatic outcomes of the non-metallic zirconium structures. Temperature adjustments facilitate the coalescence of zirconium oxide particles and the formation of a robust structure, with changes in it affecting the optical behaviour of the structure. Deviations from the optimum temperature and sintering timing parameters negatively affect the shade. **Conclusions** In conclusion, milled and sintered zirconium oxide structures can achieve aesthetic excellence, provided by the sintering protocol when the temperatures and sintering furnaces are accurately calibrated.

Key words: yttrium stabilized zirconium, sintering temperature, shade, sintering parameters

INTRODUCTION

Colour perception is a subjective visual experience generated by the light reflected and/or transmitted by an object. The complexity of dental colour evaluation lies in its subjectivity and variability, influenced by external factors like lighting conditions and relative factors, including individual experience, age, eye fatigue, and physiological conditions, including colour perception deficiencies often referred to as colour blindness. In dentistry, translucency, contrast, and opalescence are considered key elements in dental shade selection, each playing a crucial role in determining the final appearance of restorations [1,2].

Translucency, defined as the degree of light transmission or diffuse reflection from a

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material, is influenced by the material's composition, its crystalline structure, and density in relation with the wavelength of the incident light. This parameter is assessed by measuring the translucency parameter (TP) and the contrast ratio (CR), which provide insights into the material's ability to mimic the optical properties of natural teeth. TP measures the colour difference of the material on a black-and-white background, and CR compares reflectance on different contrast backgrounds, providing a picture of the material's opacity or transparency [3].

Opalescence, manifested as a spectacular play of colours depending on the angle and quality of light, is another determining factor in the selection of ceramic materials for dental restorations. This optical property is assessed by the opalescence parameter (OP), which reflects how the material scatters the wavelength of light [4].

Furthermore, colour perception is deeply influenced by the psycho-physiological responses of the observer to light, implying variability among individuals. Therefore, it is crucial to evaluate the performance of colorimeters not just in technical terms but also in comparison with a recognized reference standard, to ensure concordance between instrumental and visual evaluations [5].

For dental restorations, matching the colour with the adjacent natural teeth constitutes a significant challenge. All-ceramic, with its superior translucency, is the preferred material in dental aesthetics, although its initial brittleness limited its indications. Technological advances in high-strength alumina- and zirconia-based materials have significantly improved their durability and aesthetics.

Factors influencing the final colour of a ceramic crown include the shade of the prepared tooth, the actual colour of the crown, and the colour of the luting cement. Harmonizing these elements is essential for accurately reproduction of the natural tooth's appearance. In practice, it is recommended that the ceramic layer thickness be sufficient to mask the influence of the substrate colour without compromising dental structure or pulp integrity [6].

Shaded cements are a practical solution for adjusting the final shade, especially when the ideal ceramic thickness cannot be achieved. Although the effects of cement colour on ceramic restorations have been studied, specific clinical recommendations for optimal cement shade selection in various clinical situations are lacking. The introduction of new ceramic materials with variable translucencies calls for further research to better understand the interaction between the substructure, cement colour, and their impact on the final aesthetics of restorations.

In the sintering process for obtaining high-quality ceramic structures, adopting a rigorous protocol that includes optimized temperature settings, heating rate, and holding stage duration is essential for all ceramic and metal-ceramic prosthodontic restorations. Critical factors influencing the final quality of sintering include the firing capacity and chamber volume of the sintering furnace, the dimensions and volume of the restauration and the management of volume in the firing chamber, involving both sintering aids and the number of structures processed [7].

To ensure optimal results, selecting a sintering program that facilitates uniform and adequate heating of all structures placed in the furnace is imperative. This is a major challenge, especially for structures with varying thicknesses, such as crowns or bridge elements, which require an adjusted period to achieve thermal equilibrium, thus avoiding deformations and crack formation caused by too rapid heating regime. These risks are accentuated in the case of large structures or those with anatomical complexity. Digital Smile Design can be associated to achieve

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high aesthetics and predictable treatment plan [8].

The sintering process, involving the gradual heating of parts to the specified temperature to allow zirconium oxide particles to coalesce into a solid structure, is crucial for achieving the desired mechanical and aesthetic properties. The HTS ZIRCON 120 furnace exemplifies advanced technology by facilitating controlled cooling, essential for minimizing internal stresses and preventing post-sintering structural defects [9].

Studies, such as those conducted by Caner Öztürk and Gülşen Can, highlight the importance of adjusting time and temperature parameters in sintering to influence the optical and mechanical properties of monolithic zirconia without significantly affecting surface roughness or flexural strength. Different approaches in the fabrication of zirconia restorations, whether through soft machining followed by final sintering or direct hard machining, have direct implications on durability and structural precision [10].

In the context of dental restoration aesthetics, the translucency of the ceramic material plays a crucial role, being significantly affected by the light scattering phenomenon. Strategies for enhancing the aesthetics of zirconia, including veneering with porcelain, are essential for overcoming material limitations, although they present specific challenges, such as the risk of chipping the veneering porcelain [11].

MATHERIALS AND METHODS

The samples were obtained using the Zeno 4030 M1 milling machine produced by I-MES WIELAND, after establishing the milling strategy (Figure1a) and using Zircostar Kerox Dental zirconium oxide discs, colour B3. After milling the copings, before being placed in the HTS ZIRCON 120 sintering furnace (Figure 1b), the zirconia frameworks are properly prepared and cleaned, placed on a support for uniform heating.

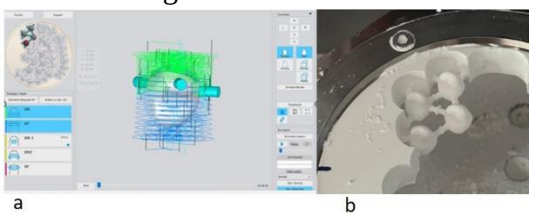

Figure 1. Fabrication of zirconium oxide copings through the CAD/CAM process: (a) establishing the milling strategy; (b) appearance of the copings after milling.

Samples of group 1 were sintered by respecting the standard sintering protocol and timing for zirconia crowns: heating for 15 minutes at 2000C, 5 minutes at 9000C, 12 minutes at 15300C and 12 minutes at 9000C followed by slow cooling (Figure 2a).

Samples of group 2 were sintered by respecting the recommended temperature curve but the maximum firing temperature was 10000C (Figure 2b).

Samples of group 3 were sintered at 15300C for 12 minutes, as recommended but the heating was fast and the cooling was slow (Figure 3a).

Samples of group 4 were sintered through a fast heating, maintained for 12 minutes at the maximum temperature of 7500C followed by a slow cooling (Figure 3b)

The present study explores the influence of sintering parameters on the aesthetic and structural properties of dental crowns made from zirconium. Sintering is a crucial stage in the fabrication of prosthetic restorations, involves heating the material to high temperatures to induce crystallization and densification. This research focuses on evaluating the effects of temperature variations and heating/cooling regimes on the final quality of zirconium crowns, aiming to optimize sintering procedures for superior aesthetic and mechanical outcomes. Through

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comparative analysis of four different sample groups, the study aims to identify the sintering methodology that offers the best combination of aesthetics and structural integrity.

Group 1: Adhering strictly to the predefined sintering protocol, the first group, consisting of 5 samples, was sintered maintaining the recommended time and temperature of 1530^0C, followed by a slow cooling process (Figure 2a). The macroscopic appearance of the resulting crown, highlighted in Figure 5a, reflects the outcomes of this rigorous sintering method.

Group 2: These 5 samples underwent a slow heating process, but the recommended sintering temperature was not reached, deviating from the standard protocol (Figure2b). The maximum temperature for this group was 1000^0C. The macroscopic appearance of the crown, presented in Figure 5b, illustrates the effects of this deviation from the recommended procedure.

Group 3: For the 5 samples of this group, the recommendations on time and temperature for sintering were maintained (Figure 3a), but the change was a rapid heating followed by slow cooling. Figure 6 reveals the appearance of the crown, demonstrating the impact of rapid heating on the final result.

Group 4: The last group of 5 samples was sintered at a lower temperature of 750^0C temperature, with a rapid heating ramp, as indicated in Figure 3b. The macroscopic post-sintering appearance is presented in Figure 6b, providing insight into the effects of this procedural change.

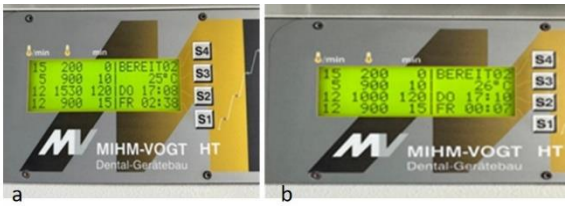

Figure 2. (a) Standard sintering parameters for group 1; (b) Sintering parameters for group 2 with decrease of the maximum temperature.

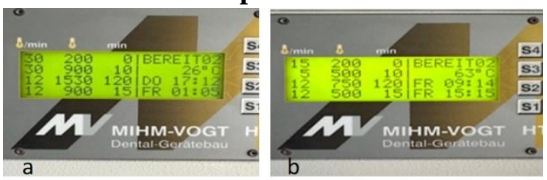

Figure 3. (a) The standard recommended sintering parameters but the heating was fast and the cooling was slow; (b) Sintering with fast heating, 12 minutes maximum temperature of 750^0C followed by a slow cooling.

The samples were macroscopically evaluated and the shade of the group 1 which was sintered after the recommended parameters was compared with the samples of the other three groups. The colorimetric analysis of the four samples was assessed using the Vita EasyShade spectrophotometer. The procedure involves placing the device on the front surface of the tooth to measure the incisal third, on the central area for the middle third colour, and near the gum line for evaluating the cervical third shade. The device generates a specific light, capturing and displaying the specific dental colour of different areas of the buccal surface of crown (Figure 4). This advanced methodology allows dentists to obtain detailed information on the chromatic variations of teeth, facilitating the selection of materials and optimal aesthetic techniques for natural results.

Figure 4. Colorimetric measurements of the samples of group 2 with Vita Easy Shade.

RESULTS AND DISCUSSIONS

The colorimetric values obtained, presented in

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Table 1, reflect the precision and utility of the Vita EasyShade spectrophotometer in determining the color of zirconium dental crowns. The spectrophotometer's benefits is the ability to ensure exact chromatic concordance, faithful long-term colour reproduction, and facilitating effective communication between the clinician and the dental technician.

Sintering parameters refer to the set of controlled conditions under which zirconia is heated and cooled to achieve optimal density and translucency, essential for creating aesthetic and long-lasting dental restorations.

The crowns made from the same shade and type of material has changed the shade when some parameters of the sintering process were changed. The shade changes were registered in the same conditions with the spectrophotometer and for some samples the changes are evident.

Samples of group 1 were made after the standard protocol and were compared with the samples of group 2, which were sintered after some after the following parameters: slow heating process, maximum temperature of 1000^0C. The macroscopic appearance of the crown, presented in figure 5 show a darker shade for group 2 (Figure 5b). The shades for group 2 were A4 and A3.5.

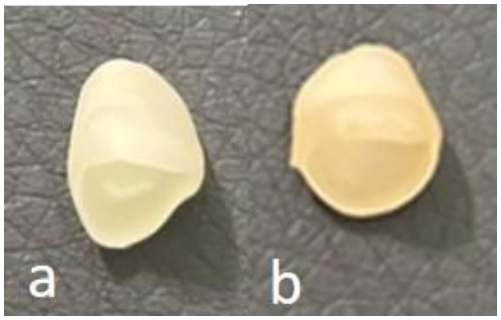

Figure 5. Difference in shade of (a) sample 1 group 1; (b) sample 3 group 2 .

When compared, the shade of group 1 with group 3, which was sintered by respecting the time and temperature of 1530^0C for sintering were maintained. The changes were related only to rapid heating followed by slow cooling, the only one sample registered a shade modification A3 in the third incisal area, third middle and third cervical areas of the buccal surface of zirconium crown.

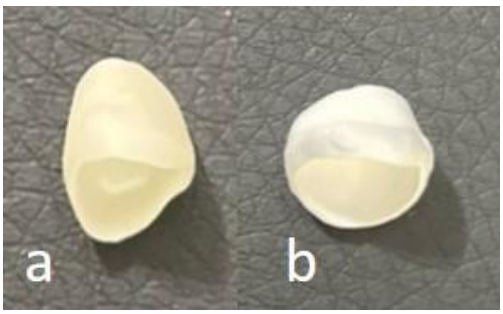

Figure 6. Difference in shade of (a) sample 1 group 1 and (b) sample 2 group 3 .

When compared the shade of group 1 and group 4, shade evaluation of group 4 registered darker shades of C4 in the third incisal, third middle and third cervical areas of the buccal surface.

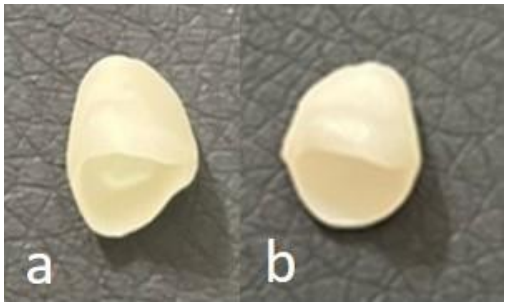

Figure 7. Difference in shade of (a) sample 1 group 1 and (b) sample 1 group 4.

The shades were registered for all the samples of each group in the third incisal, third middle and third cervical area of the buccal surface (Table 1).

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Table 1. Values obtained with the Vita Easy-Shade Spectrophotometer in the 3 areas of the samples of the four groups.

	Vital Classical	Vita Easy Shade		
Groups		Incisal third	Middle third	Cervical third
	B3	2.5L2.5	-	-
	B3	-	2.5L2.5	-
	B3	-	-	2M3
	A4	3.5R2.5	-	-
	A3.5	-	3.5R2.5	-
	A4	-	-	3.5M3
	A3	2.5M2.5	-	-
	B3	-	2.5L2.5	-
	B3	-	-	2.5L2.5
	C4	5M1	-	-
	C4	-	5M1	-
	C4	-	-	5M1

These parameters primarily include the sintering temperature, the holding time at this temperature, and the heating and cooling rates. Changes in these parameters can significantly influence the physical and aesthetic properties of zirconium oxide crowns. Figure 8 represents the graphical description of the sintering temperature for the four groups of samples.

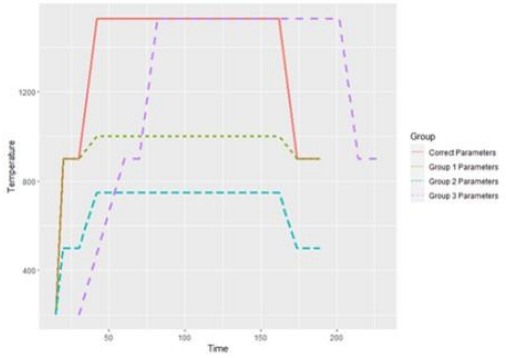

Figure 8. Fig. 6. Graphic description of sintering protocols with modifications to time and temperature parameters.

Differences in sintering parameters have demonstrated a visible impact on the color of zirconium crowns. The sintering process, which involves heating compacted zirconium to high temperatures to induce its transformation into a solid and durable structure, can significantly modify the shade of the crowns. The main variables influencing post-sintering color include the duration and temperature of the process. Prolonged sintering or higher temperatures can intensify the shade, giving the crown a darker or more saturated color, while a short sintering duration or the application of a lower temperature can result in a lighter or more translucent color. Choosing optimal sintering parameters is essential for achieving the desired aesthetic results.

Sintering plays a crucial role in the manufacturing of dental restorations, directly influencing the physical and aesthetic properties of the material. In the sintering process of zirconia, heat transfer from the surface to the core determines the material's maturation, with direct implications on particle size and density. The sintering temperature, having a major impact on density, porosity, and particle growth, can be adjusted to optimize the material's properties. Zirconia, with a relative refractive index of 2.2, exhibits a significant degree of porosity compared to other ceramic materials, and reducing this

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porosity through appropriate sintering can significantly improve translucency and, consequently, the aesthetic appearance of zirconium restorations [12].

By adjusting the sintering conditions, including the temperature, clinicians can influence the crystalline structure of zirconia, thereby enhancing the optical and aesthetic properties of prosthetic restorations. This strategic approach allows for the customization of restorations to align as closely as possible with the appearance and functionality of natural teeth, improving patient satisfaction and long-term clinical outcomes [13,14].

The proper use and precise calibration of medical equipment become imperative in the context of technological advancement. The accuracy of measurements and the correct application of these devices essentially depend on their careful and periodic calibration. Raising medical staff's awareness of the importance of equipment calibration plays a crucial role in ensuring the reliability of results and, consequently, the quality of care provided to patients [15,16].

Thus, integrating this topic into the curriculum of future health professionals and promoting continuing education among active staff constitutes a valuable contribution to improving the quality and safety of medical care.

Selecting optimal sintering parameters and a detailed understanding of their influence on the properties of ceramic materials are essential for producing high-quality dental restorations. Continuous progress in research and technological development is crucial for optimizing manufacturing processes and improving clinical outcomes in dental prosthetics.

Shade identification with spectrophotometer and visual evaluation can be subjective and not always may have the perfect correspondence.

CONCLUSIONS

1. The sintering temperature significantly influences the final shade of the restorations, affecting the chromatic outcome regardless of the direction of change, whether it involves an increase or a decrease..
2. The duration of the sintering process also negatively impacts the final aesthetics of dental works if the manufacturer's recommended specifications are not followed, influencing the visual quality of the final product..
3. Restorations made from zirconium that is milled and sintered can offer significant aesthetic advantages, provided that the sintering protocols recommended by the manufacturer are strictly followed, including precise calibration and periodical checks of the equipment used in the process. The forth conclusion

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