10.21608/adjc.2024.288469.1548 Advanced Dental Journal
Volume 7 (2025) | Issue 2 | Pages 217-227

Original Article

Effect of a Novel Sintering Protocol on the Translucency of Multilayered Monolithic Zirconia Crowns: An Invitro Study

Sohaila Mohamed Yehya Abdelhamid[1], Karim Aboubakr[1], Amina A Zaki[1]

[1] Fixed Prosthodontics Department, Faculty of Dentistry, Cairo University, Cairo, Egypt.

Corresponding Author's Email: Sohaila.yehya@dentistry.cu.edu.eg

Submitted: 9 -5-2024
Accepted: 28-5-2024

Abstract

Aim: to evaluate the effect of a novel speed sintering protocol on the translucency of monolithic zirconia crowns.

Material and methods: 20 Monolithic Zirconia crowns fabricated from CEREC MTL zirconia were divided into 2 groups (10 per group); **Group (I)** Crowns sintered with conventional sintering protocol (control) **Group (II)** Crowns sintered with speed sintering protocol (intervention). Translucency was evaluated and measured quantitatively by comparing the reflectance of light through testing the specimen over a backing with high reflectance (white background) to that of low reflectance or absorbance (black background). Translucency parameter (TP) was calculated using specific equation to give the color difference's degree expressed in ΔE units. The total color difference according to L*, a*, b* coordinates is calculated.

Results : The mean ΔE for Group I was 6.19 ± 0.55 and for Group II was 5.69 ± 0.61 without significant difference in the translucency between both groups. Unpaired Student's t-test performed for the color coordinates ΔL, Δa and Δb showed a significant difference in Δb, but no significant difference in ΔL and Δa.

Conclusion: It was concluded that speed sintering protocol is an acceptable alternative to conventional sintering for chairside use of monolithic zirconia.

Keywords: Monolithic Zirconia, High speed Sintering, Translucency, Zirconia crowns, Conventional sintering.

Introduction

In the past few years, the introduction of the CAD-CAM technologies has paved the way to new materials as advanced all ceramics such as yttria-stabilized tetragonal zirconium polycrystalline (Y-TZP) ceramic materials. **Abdulla et al. (2020)**

Full-contour monolithic zirconia restorations have experienced a surge in popularity recently due to their outstanding mechanical properties associated with the mechanism of transformation toughening. Moreover, its high flexural strength enables milling of full-contour monolithic zirconia crowns with minimal thicknesses while sustaining sufficient strength even for posterior fixed dental prostheses. **Abdulazeez et al. (2021)**

More recently, advancements have been made to enhance the aesthetic qualities of dental restorations by introducing multi layered zirconia systems. These systems are designed to replicate the shade gradient found in natural dentition in which the incisal area of a crown is more translucent and gradually increasing in chroma and opacity towards the gingival area. Various grades of multi layered zirconia are recommended for different types of indirect restorations particularly in aesthetic zones based on their distinct properties. **Kontonasaki et al. (2019)**

In modern dentistry, zirconia prostheses are fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) technology which can be carried out either in clinical setting or in a dental laboratory. There are three distinct manufacturing approaches available: chairside fabrication performed in the dental office, laboratory fabrication using in lab systems or utilizing centralized production in milling centers. **Al-Haj Husain et al. (2022)**

At present, the commonly adopted technique for fabricating zirconia prostheses involves the utilization of partially sintered zirconia blanks. These blanks are produced in a semi sintered and porous state facilitating their milling in a computer-assisted manufacturing (CAM) unit. However, post milling, zirconia prosthesis has to undergo sintering in order to achieve the highest density and optimal strength. This sintering procedure is typically accompanied by approximately 20 to 30% volumetric shrinkage. **Ahmed, W. M. (2019)**

In recent times, new chairside protocols have emerged for zirconia milling and sintering aiming to address the primary limitation of chairside zirconia usage which is the requirement for a lengthy conventional post milling sintering process taking long hours and necessitating a furnace capable of reaching temperatures as high as 1500 °C. The advancements in this area include chairside zirconia milling with varying speeds and high-speed sintering protocols (taking only 10 minutes). These innovations have been made possible through the utilization of innovative induction furnaces that employ electromagnetic induction to generate heat or pass an electric current through an object via an alternating magnetic field. **Ahmed, W. M. (2019)**

Multi-layer monolithic zirconia with the help of the state of art furnace along with high-speed sintering are more preferred over other prosthetic restorations in order to shorten the treatment time and allow its use for chairside restorations. **Coskun et al. (2019)**

The level of translucency plays a crucial role in determining the aesthetic appearance and color matching capability of anterior tooth restorations. **Lim et al. (2010)**

However, there is limited available data in existing literature on the impact of high-speed sintering on the translucency of multi-layered monolithic zirconia. As a result, our study aimed to examine the influence of speed sintering compared to conventional sintering on the translucency of monolithic zirconia crowns designed for anterior teeth. The null hypothesis posited translucency will not be significantly affected by different sintering protocols.

Material and Methods

A. Sample size calculation:

A power analysis was conducted with translucency parameter (TP) as the primary outcome. According to the findings of **Lawson et al. (2020)**; the mean and standard deviation values for TP were 7.64 (0.2) and 7.88 (0.25) for speed and conventional sintering, respectively. The effect size (d) was 1.06. By utilizing alpha (α) level of (5%) and Beta (β) level of (20%) i.e. power = 80%; the minimum required sample size was estimated to be 15 specimens per group. The G*Power Version 3.1.9.2. software was employed for conducting the sample size calculation.

As this was an invitro study, this number has been deducted to be 10 per group as per expert's opinion.

B. Samples grouping:

The total number of samples, which was twenty in total, was categorized into two groups based on sintering protocol in the following manner:

Group (I): (n=10) Crowns sintered with conventional sintering protocol (control).

Group (II): (n=10) Crowns sintered with speed sintering protocol.

C. Die manufacturing:

The maxillary central incisor was selected to be the target tooth to receive a monolithic zirconia crown. To ensure the consistency, a die was designed using ExoCAD Dental CAD 3.0 Galaway software following the manufacturer's recommended preparation parameters as follows; Incisal reduction 1 mm, radial reduction 0.8 mm and Chamfer Finish line 0.5 mm thick. After the completion of the digital design process of the die, the final STL file of the prepared tooth was exported for manufacturing. A titanium die was additively manufactured by direct laser melting (DLM) using VULCANTECH VM120. Following DLM process, the metal die was finished and polished to remove any roughness, **Figure (1).**

D. Die duplication

The metal die was duplicated into colored epoxy resin dies using a silicon index. The duplication process began with creating a silicon index of the original metal die ensuring accurate replication of its intricate details. This was followed by carefully mixing and pouring epoxy resin into the silicon index ensuring complete coverage of the mold. To achieve the desired colors, acrylic pigment was mixed with epoxy resin. For white epoxy resin die, white acrylic pigment was thoroughly blended with the epoxy resin until a consistent color is achieved. Similarly, for black epoxy resin die, a black acrylic pigment was mixed with the epoxy resin.

The epoxy resin was then left to cure and harden following the manufacturer's instructions. Once fully cured, the white and black epoxy resin dies were demolded resulting in colored replicas of the original metal die, **Figure (2).**

E. Restoration fabrication:

The fabrication of the 20 monolithic crowns was performed entirely through digital workflow. First, using CEREC software (SW 5.2.4, 2022), upper left central incisor was selected followed by selection of restoration type (anatomic crown) and material (CEREC MTL

Zirconia). One anatomical design was selected (Biogeneric individual mode) and applied. Dry milling mode was selected for all crowns. For the speed sintering group, speed sintering mode was selected.

The epoxy die was scanned using Primescan (Dentsply Sirona, Germany). Using CEREC software (SW 5.2.4, 2022), margin line detection was done and confirmed by an arrow pointing at the exact position of the finish line in a 3D image. The proposed design by the software was employed. Spacer thickness was set at 80 microns while minimum thickness of restoration was set at 600 microns. The next step involved the chair-side milling of zirconia blocks to fabricate monolithic zirconia crowns using Primemill.

F. Sintering of zirconia crowns:

For group 1 of milled zirconia crowns, conventional sintering was employed using Tegra speed furnace (Yenadent, Turkey) in accordance to the sintering protocol advised by the manufacturer. Sintering temperature was raised from 0 to 300 for 30 minutes followed by an increase from 300 to 950 for 120 minutes. Later on, the temperature was further increased from 950 to 1530 for 150 minutes. The sintering temperature reached 1530°C where it remained constant for 120 minutes. The crowns were then removed from the furnace and allowed to bench cool till they reached the room temperature. While for group 2 of milled crowns, speed sintering was performed using CEREC speed fire (Dentsply Sirona, Germany), **Figure (3).** Sintering of each crown was completed in 18 minutes and 48 seconds, **Figure (4).** CEREC Speed Fire reaches a maximum sintering temperature of 1600°C with a maximum heating rate of 300°C per minute.

G. Restoration verification

One crown "Pilot sample" was milled and checked for full seating on its corresponding die before proceeding in production of the total number of crowns. Leica L2 (Leica microsystems Ltd, Wetzlar, Germany) was used to check the seating of the restorations under 30X magnification, **Figure (5).**

After confirmation of full seating of the restoration, the remaining 19 crowns were produced. The Sintered crowns were polished using Eve's Diacera HP Medium polishing spiral wheels followed by Eve's Diacera HP Fine spiral polishing wheels.

H. Translucency measurement

The degree of translucency was assessed by comparing the reflectance of light passing through the test specimen against a white background with high reflectance and a black background with low reflectance or absorbance. The translucency parameter for each restoration was calculated using the following equation which quantifies the color difference between the compared colors in terms of ΔE units. The total color difference, based on the L*, a*, and b* coordinates, was calculated using the equation:

$$\Delta E* = \sqrt{(\Delta L*)2 + (\Delta a*)2 + (\Delta b*)2}$$

In this equation, L* represents the lightness of an object, ranging from 0 (black) to 100 (white). The a* value indicates redness (a > 0) or greenness (a < 0), while the b* value represents yellowness (b > 0) or blueness (b < 0).

The Cary 5000 Spectrophotometer manufactured by Agilent Technologies in the USA was utilized in conducting these measurements, **Figure (6).**

A **B** **C**

Figure (1): Finished Titanium Die;(A) Labial view (B) Occlusal view (C) Palatal View.

Figure (2): Duplicated white and black epoxy dies

Figure (3): CEREC speed fire furnace for speed sintering of zirconia

Figure (4): Sintering time for CEREC MTL Zirconia crown as shown on CEREC SpeedFire's screen.

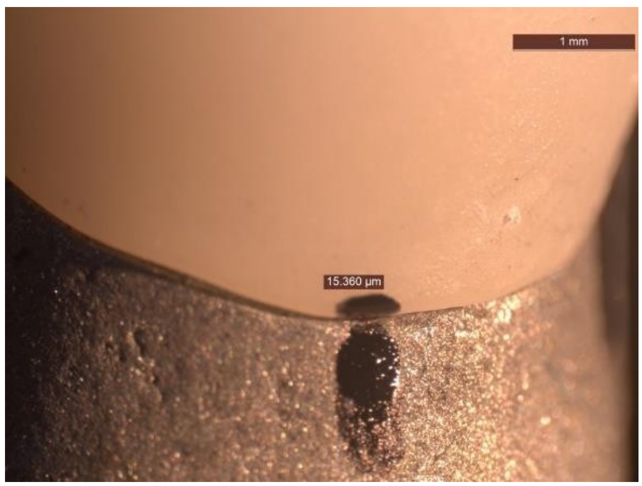

Figure (5): Margin adaptation of pilot crown under 30X magnification

Figure (6): Agilent Cary 5000 spectrophotometer

Results

Data normality was assessed using Shapiro-Wilk and

Kolmogorov-Smirnov tests. Descriptive statistics such as the mean, standard deviation (SD), mean difference and 95% confidence interval (CI) were reported. The unpaired Student's t-test was employed for analyzing quantitative data. A significance level of $P \leq 0.05$ was considered. Statistical analyses were conducted using MedCalc software, version 19 for Windows, developed by MedCalc Software Ltd in Ostend, Belgium.

The degree of color difference was obtained for each crown. The mean ΔE values of each group was calculated. The mean ΔE for Group I was 6.19 ± 0.55 and for Group II was 5.69 ± 0.61 as illustrated in **Figure (7)** and mentioned in **Table (1)**. One-way analysis of variance showed no significant difference in the translucency of the two groups. Unpaired Student's t-test performed for the color coordinates ΔL, Δa and Δb showed a significant difference in Δb, but there was no significant difference in ΔL and Δa as shown in **Table (1).**

Table (1): Results of unpaired student's t-test comparing colour measurements (mean ±SD) between speed sintering and conventional sintering.

	Speed sintering	Conventional sintering	Mean difference [95% CI]	P-value
Translucency	5.69 ± 0.61	6.19 ± 0.55	-0.50 [-1.05, 0.05]	0.07
ΔL	4.74 ± 0.60	5.17 ± 0.56	-0.43 [-0.98, 0.12]	0.11
Δa	0.39 ± 0.08	0.42 ± 0.04	-0.03 [-0.09, 0.03]	0.29
Δb	3.12 ± 0.25	3.37 ± 0.25	-0.25 [-0.49, -0.02]	0.04*

Statistically significant at P ≤ 0.05

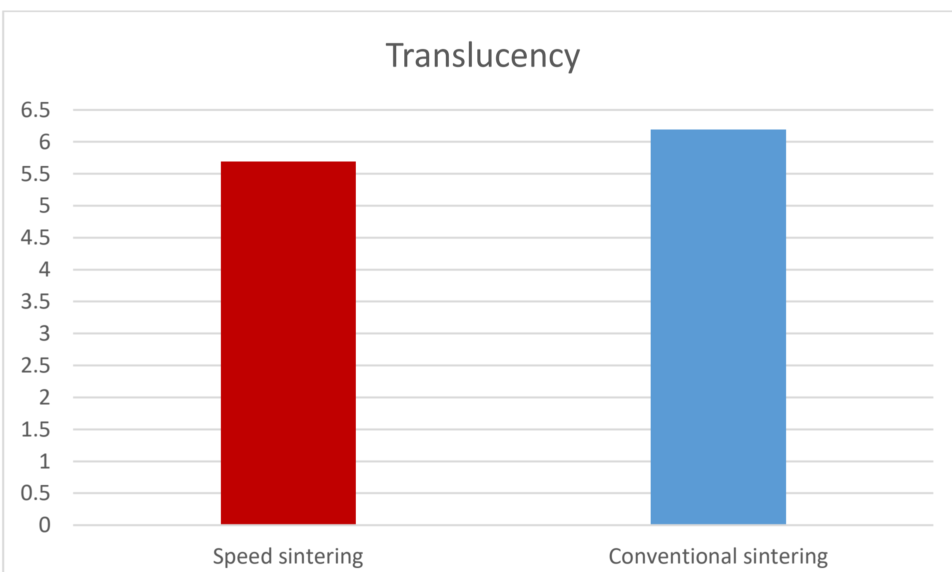

Figure (7): Bar chart showing translucency between speed sintering and conventional sintering.

Discussion

Soft milled zirconia restorations could not be considered as a single visit treatment option because of the need for a conventional post-milling sintering procedure lasting several hours and requiring a furnace reaching 1500 ◦C. Recently, Chairside Zirconia restorations have been developed using fast milling mode of Primemill in conjunction with CEREC Speed Fire novel induction furnaces allowing the clinician to design and manufacture the dental prosthesis in the dental practice for single-visit restorative treatment. **Al-Haj Husain et al. (2022)**

The control group for this study was the conventional sintering protocol, which was chosen because it represents the most commonly used method for sintering zirconia. In this method, traditional furnaces are employed, which typically operate at temperatures ranging from 1350 °C to 1400 °C, with holding times lasting between two to four hours. These conventional furnaces are equipped with heating resistance elements, specifically molybdenum disilicate, which generate heat by passing an electric current through the resistor, thus surrounding air is heated. The presence of resistance elements restricts the rate of heating of the furnace to a range of 40 to 70 °C per min. **Ahmed, W. M. (2019)**

In the sintering process, the pores between particles within the granular material are decreased by atomic diffusion. Thus, Altering the sintering process in terms of sintering temperature and time can alter the optical properties of zirconia. **Al-Haj Husain et al. (2022)**

For a dental prosthesis to be clinically successful, it must achieve the masticatory, phonetic and aesthetic requirements. The aesthetic requirements depend on the translucency and shade of the material. **Sravanthi et al. (2015)**

In this study, *CEREC MTL Zirconia* was the material of choice as it provides high aesthetics owing to the natural multi transitional layer and high shade match while still maintaining high Strength of more than 850 MPa enabling minimal tooth reduction. **CEREC MTL Zirconia Dentsply Sirona (2021)**

In the current study, a titanium die resembling a prepared central incisor was designed and additively manufactured by direct laser melting (DLM) to allow for a controlled and reproducible manufacturing technique for the production of a complex-shaped 3D metallic component. Thus, ensuring a reliable and standardized platform for the subsequent laboratory procedures. **Hato Sharon Tshephe et al. (2022)**

The titanium die was duplicated into 2 colored (Black and white) epoxy resin dies using a silicon index so that white and black backgrounds were formed to allow for reflectance measurements of crowns. **Sravanthi et al. (2015)**

An intraoral scanner (*Primescan, Dentsply Sirona, Germany*) was utilized to scan the epoxy dies to simulate a complete chairside digital workflow. Primescan has the advantage of 20 mm depth of scan. Moreover, it showed the highest trueness and precision when compared to other intraoral scanners and conventional impression techniques. **DENTSPLY Sirona / Primescan (2021)**

A four-axis milling machine (*Primemill, Dentsply Sirona, Germany*) was used for milling CEREC MTL monolithic zirconia crowns in accordance with the manufacturer's recommendations allowing milling the zirconia restorations in around 5 minutes using 'Super-Fast' milling mode. **DENTSPLY Sirona / Primemill (2021)**

Regarding the findings of our investigation**,** the null hypothesis was accepted since there was no statistically significant difference in the translucency observed between both groups. The mean ΔE for Group I was 6.19 ± 0.55 and for Group II was 5.69 ± 0.61.

These findings were in alignment with **Cokic et al. (2020)** who conducted an investigation on the performance of zirconia ceramics sintered using a speed sintering induction furnace. They compared the mechanical and optical properties of that speed sintered ceramics with conventionally sintered zirconia. The study found that speed sintered zirconia exhibited similar microstructure, density, average strength and hydrothermal aging stability compared to conventionally sintered zirconia. According to these findings, it was concluded that the speed sintering of 3Y-TZP and 5Y-PSZ using high speed sintering induction furnace is suitable for clinical applications.

This was in a partial agreement with **Jansen et al. (2019)** who conducted a study to examine the impact of high-speed sintering on translucency and biaxial strength of 450 specimens of three different zirconia materials. The materials investigated were two types of 3Y-TZPs (3 mol% yttria)- Ceramill ZI and Zolid (ZD), and a 4Y-TZP (4mol% yttria) - Zolid HT+. Additionally, the specimens had varying thicknesses og 1.0, 1.5, 2.0, 2.5, and 3.0 mm. Two protocols of high-speed sintering were employed with final temperature of 1570 °C and 1590 °C, respectively, and a reference sintering protocol at 1450 °C. The findings of this study indicated that for ZI, the sintering protocols had nonsignificant effect on translucency or biaxial flexural strength. However, the other two materials showed significant reduction in translucency for high-speed sintering protocols.

Also, **Lawson et al. (2020)** compared the strength and translucency of three commercially available 5Y zirconia blocks, used in dental computer aided design and manufacturing (CAD/CAM) systems, with both traditional and high-speed sintering methods, to lithium disilicate. The study revealed that zirconia materials responded differently when subjected to high-speed sintering protocols. Specifically, two out of the three tested materials namely Zpex Smile and Prettau Anterior, reduced translucency. Additionally, these materials experienced significant grain growth from 1.24 to 4.11 μm and porosities formation, resulting in lower translucency. On the other side, Katana STL remained unchanged. The changes in the grain size were attributed to higher temperatures and heating rates employed in high-speed sintering.

On the contrary, results were inconsistent with **Michailova et al. (2020)** who studied the Translucency of both strength-gradient and color-gradient multi layered zirconia sintered using conventional compared to high-speed protocols. The high-speed sintered color gradient multi layered zirconia exhibited minimal reduction in transmission of light in its enamel layer (35%) than conventionally sintered color gradient multi layered zirconia.

This was also in disagreement with **Nonaka et al. (2022)** who conducted a study on the impact of super speed sintering on translucency of 5Y zirconia sintered bodies using various tests as X-ray diffraction (XRD), density measurements, fracture toughness and three-point flexural tests, translucency measurements and scanning electron microscopy (SEM). According to their research, the high-speed sintering protocol led to reduction in translucency and mechanical properties of 5Y zirconia. The results from XRD and SEM observations revealed that these reductions were attributed to changes in composition of crystal phases and increase in residual pores.

Conclusion:

Within the limitations of this study, it was concluded that speed sintering protocol is an acceptable alternative to conventional sintering for chairside use of monolithic zirconia.

Acknowledgement

The authors would like to thank **Dr. Noha Ayman Ghallab -** Professor of Periodontology and Oral Medicine, Faculty of Dentistry, Cairo University - for the generous guidance, patience and support she willingly offered in the statistical analysis of our research results.

Ethics: This study protocol was approved by the ethical committee of the Scientific Research, Faculty of Dentistry, Cairo University. The approval date was (16-12-21).

Funding: The research received no specific grant or fund.

Conflict of interest: No conflict of interest,

References

1. **Abdulazeez, M. I., & Majeed, M. A.** (2021). Fracture Strength of Monolithic Zirconia Crowns with Modified Vertical Preparation: A Comparative In Vitro Study. Eur. J. Dent. https://doi.org/10.1055/s-0041-1735427
2. **Abdulla MA., Ali H Kh. & Jamel RS.** (2020). CAD-CAM Technology: A literature Review. Al–Rafidain Dent J, 20 (1): 95-113.
3. **Ahmed, W. M.** (2019). Evaluation of distortion of monolithic zirconia crowns under the influence of different preparation designs and sintering techniques. University of British Columbia, (November), 1–181
4. **Al-Haj Husain, N., Özcan, M., Dydyk, N., & Joda, T.** (2022). Conventional, Speed Sintering and High-Speed Sintering of Zirconia: A Systematic Review of the Current Status of Applications in Dentistry with a Focus on Precision, Mechanical and Optical Parameters. Journal of clinical medicine, 11(16), 4892. https://doi.org/10.3390/jcm11164892
5. CEREC MTL™ Zirconia – Block for CEREC. Multi Transitional Layer Zirconia. VITA Zahnfabrik/Dentsply Sirona. Accessed June 30, 2021.
6. **Cokic, Jef Vleugels, Bart Van Meerbeek, Bernardo Camargo, Evita Willems, Maoyin Li, Fei Zhang.** (2020). Mechanical properties, aging stability and translucency of speed-sintered zirconia for chairside restorations. *Dental Materials*, *36*(7), 959-972. https://doi.org/10.1016/j.dental.2020.04.026.
7. **Coskun, Mehmet & Sari, Fatih**. (2019). Effects of Speed Sintering on Multilayered Monolithic Zirconia. Cumhuriyet Dental Journal. 22. 31-36. 10.7126/cumudj.510393
8. **Hato Sharon Tshephe, Samuel Olukayode Akinwamide, Eugene Olevsky, Peter Apata Olubambi.** (2022). Additive manufacturing of titanium-based alloys- A review of methods, properties, challenges, and prospects, Heliyon, 8 (3),2405-8440, https://doi.org/10.1016/j.heliyon.2022.e09041.
9. **Jansen, J.U.; Lümkemann, N.; Letz, I.; Pfefferle, R.; Sener, B.; Stawarczyk.** (2019). Impact of high-speed sintering on translucency, phase content, grain sizes, and flexural strength of 3Y-TZP and 4Y-TZP zirconia materials. J. Prosthet. Dent. 2019, 122, 396–40
10. **Kontonasaki, E., Rigos, A. E., Ilia, C. and Istantsos, T.** (2019). Monolithic Zirconia: An Update to Current Knowledge. Optical Properties, Wear, and Clinical Performance'. **Dent. J.**; 7(3), 90. doi:10.3390/dj7030090
11. **Lawson, NC, Maharishi, A.** (2020). Strength and translucency of zirconia after high-speed sintering. J Esthet Restor Dent.; 32: 219– 225. https://doi.org/10.1111/jerd.12524

12. **Lee Y. K.** (2015) Translucency of human teeth and dental restorative materials and its clinical relevance. Journal of biomedical optics, 20(4), 045002. https://doi.org/10.1117/1.JBO.20.4.045002

13. **Michailova, M., Elsayed, A., Fabel, G., Edelhoff, D., Zylla, I. M., & Stawarczyk, B.** (2020). Comparison between novel strength-gradient and color-gradient multilayered zirconia using conventional and high-speed sintering. Journal of the mechanical behavior of biomedical materials, 111, 103977. https://doi.org/10.1016/j.jmbbm.2020.103977

14. **Nonaka, K., Teramae, M., & Pezzotti, G**. (2022). Evaluation of the Effect of High-Speed Sintering and Specimen Thickness on the Properties of 5 mol% Yttria-Stabilized Dental Zirconia Sintered Bodies. Materials (Basel, Switzerland), 15(16), 5685. https://doi.org/10.3390/ma15165685

15. Primescan. Intra oral scanner. Dentsply Sirona. Accessed March, 2019

16. **Sravanthi, Y., Ramani, Y. V., Rathod, A. M., Ram, S. M., & Turakhia, H**. (2015). The comparative evaluation of the translucency of crowns fabricated with three different all-ceramic materials: an in vitro study. *Journal of clinical and diagnostic research: JCDR*, *9*(2), ZC30–ZC34. https://doi.org/10.7860/JCDR/2015/12069.5559