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Original Article

EFFECT OF TWO SINTERING PROTOCOLS ON THE MARGINAL INTEGRITY OF MONOLITHIC ZIRCONIA CROWNS (IN VITRO STUDY)

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Abstract

Aim: to evaluate the marginal integrity (vertical marginal gap) of monolithic zirconia crowns with two different finish lines and sintered with two different sintering protocols.

Material and methods: Two metal dies with different finish line thicknesses (0.2 and 0.5 mm) were digitally designed and manufactured. Each metal die was scanned using an intraoral scanner (Primescan) and CEREC Software was used to design the crowns and give the milling order to the chairside milling machine (Primemill) to mill them. For each finish line, a total of sixteen zirconia crowns were obtained. Each group (n=16) was divided into two subgroups; conventional sintering protocol using (Tegra speed furnace) and high-speed sintering protocol using (CEREC SpeedFire furnace). Then, after sintering and polishing the crowns, the vertical marginal gap was measured using a stereomicroscope. The data obtained were collected, tabulated and subjected to statistical analysis.

Results : With regard to the vertical marginal gap, high-speed sintering exhibited statistically significant lower values (63.5 ± 19 um) than conventional sintering (67.3 ± 16.7 um) and there is no statistical significant difference between 0.5 and 0.2 mm finish line thicknesses.

Conclusion: 1. Monolithic zirconia crowns sintered using high-speed sintering protocol revealed lower marginal gaps than those sintered using conventional sintering protocol. While, there is no statistical significant difference between crowns with 0.2 and 0.5 mm finish line thicknesses.

2.High-speed sintering with more conservative preparation is a valid protocol for sintering zirconia crowns with more economical and time-saving attribute which complies with the chairside concept of digital dentistry.

Keywords: Zirconia; Chairside; high-speed sintering; Finish line; CAD/CAM; Marginal gap

Introduction

Nowadays, there is a great demand from the patients seeking dental treatment to esthetic ceramic restorations due to their color stability, wear resistance, biocompatibility, and excellent esthetics. **Blatz (2019)**

Gracis et al. (2015) proposed a new method to classify ceramic restorative materials into three families, based on the presence of specific characteristics in their formulation, as follows; *Glass-matrix ceramics*, *Polycrystalline ceramics* and *Resin-matrix ceramics.* Zirconia gained a lot of popularity among the clinicians and technicians due to its vast range of indications as it combines strength, biocompatibility and upgrading esthetics to be more natural-like.

Different generations of zirconia restorations were introduced into the market through the past 15 years and the ultimate aim was to develop a formula for zirconia production with the best esthetics without large compromise of its well-known strength. **Stawarczyk (2017).**

The concept of veneering zirconia frameworks to mask their opacity with porcelain veneering is minimized to avoid the risk of chipping and the goal was to develop a monolithic zirconia restoration. **Benetti (2014)**.

In September 2021, DentSply Sirona launched the new chairside material 'CEREC MTL Zirconia' blocks. The microstructure of CEREC MTL Zirconia blocks consists of two zirconia polymorphs. The tetragonal modification with an amount of about 65% provides high strength (around 860 MPa), while the cubic modification leads to an increase of the translucency. **CEREC MTL Zirconia brochure (2021).**

According to its yttria content, CEREC MTL zirconia contains around 6-8% by weight (4 mol %) Y_2O_3 in its composition (4Y-TZP) which is considered an example of the fourth generation of zirconia restoration with an improved esthetics and good range of flexural strength. **Rinke (2022)**

CEREC MTL zirconia is the very easy and fast processing workflow, which is applicable with the CEREC integrated system "CEREC Primemill milling machine and the Speed-Fire sintering furnace". Super-fast milling step for a single crown in less than 5 minutes, a complete sintering procedure in 18-20 minutes. All the aforementioned high-speed process complies with the chair-side concept in daily clinical practice. Zirconia is presented either in pre-sintered state or fully sintered state. Sintering plays a pivotal role in determining the mechanical and thermal properties of zirconia ceramics. **Cocik (2020).**

An empirical classification into three separate sintering regimes is possible through the compilation of sintering data from specific studies. "Conventional sintering" refers to a total sintering time range from 7-12 hours. The "speed sintering" protocol from 90-150 minutes. Finally, the "high-speed sintering" protocol with only 20-30 minutes. **Mirt et al. (2023)**.

Conforming to the high qualities of newer generations of monolithic zirconia restorations, a more conservative preparation was advocated by many investigators (**El-Damaty (2020) and Sorrentino (2019)** to defend their ability to be a safe alternative to the aggressive preparation of all-ceramic restoration. The marginal integrity of any fixed dental restoration is an essential factor contributing to its durable success. Poorly adapted restoration margins cause detrimental effects on the prepared teeth and supporting periodontium in the form of cement dissolution, micro-leakage, secondary caries and /or gingival injuries. **Nawafleh (2013).**

For CAD/CAM restorations, the range between 50 and 100 micrometers (µm) is generally considered clinically tolerable. The vertical marginal gap can be measured using;

Direct view with a microscope (stereomicroscope, digital microscope and scanning electron microscope), cross sectioning and micro computed tomography (Micro CT).There is a lack of investigations about the effect of high-speed sintering protocol on the marginal gap. So, the aim of this study was to evaluate the marginal integrity (vertical marginal gap) of monolithic zirconia crowns with two different finish line thicknesses and sintered with two different sintering protocols (Conventional and high-speed).

The null hypothesis is that there is no effect of the different sintering protocol and finish line thicknesses on the vertical marginal gap values.

Material and Methods

A. Sample size calculation:

This power analysis used internal fit as the primary outcome. Based upon the results of Miura S and Inagaki R (2014); the mean values for internal fit were 40 and 70 microns, respectively. The effect size (d) was 1.027. Using alpha (α) level of (5%) and Beta (β) level of (20%) i.e. power = 80%; the minimum estimated sample size was 16 specimens per group. Sample size calculation was performed using G*Power Version 3.1.9.2.

B. Samples grouping:

A total of thirty two samples were divided into 2 main groups (sixteen in each group) according to the sintering protocol; **Group (CS):** (n=16) Zirconia crowns fabricated with conventional sintering protocol (control) and **Group (HSS):** (n=16) Zirconia crowns fabricated with high-speed sintering protocol.

C. Die manufacturing:

Two digitally customized maxillary central incisor titanium dies with 0.2 and 0.5 mm finish line thicknesses were designed using ExoCAD software 3.0 Galaway version, 2021 (Darmstadt, Germany). After designing, STL files were sent to a 3D printing machine (VULCANTECH VM120**,** Visakhapatnam, India) and the dies were constructed with the direct selective laser melting technique using. Following the 3D printing process, the dies were finished and polished **Figure (1)**. Two notches were done on the labial aspect and one notch was done on the palatal aspect to aid in proper tracking of the scanning process. Re-evaluation of the metal dies was done by scanning them again and re-measuring the finish line thicknesses using “2D slice” feature in ExoCAD software.

D. Restoration fabrication:

The metal dies were embedded in a putty platform with a marking on the labial aspect to be easily detected upon designing. In the administrative phase; tooth selection, design mode, type of the restorative material (CEREC MTL Zirconia, Dentsply Sirona, Germany) and milling machine were determined in the software “CEREC SW 5.2.4, 2022”. Each metal die was scanned using an intraoral scanner (Primescan, Dentsply Sirona, Germany) Figure (2) free hand in a rotational manner.

A virtual die was created. Margin line detection was done and insertion axis was adjusted. Setting the restoration parameters was done as follows; the cement gap was set at 80 µm and the minimum thickness was set at 700 µm. An anatomical design was proposed by the software using the Biogeneric individual design mode. The position, shape and contour were then manually adjusted.

Milling preview was shown on the software after completion of the designing process. Fine milling mode was selected in the milling preview. CEREC Primemill (Dentsply Sirona, Germany) 4-axis milling machine was used to mill zirconia monolithic crowns. Block registration was done by scanning the QR code imprinted on the bottom of the block. Milling was done using the dry milling mode. The milling burs used were bur 2.5 ZrO_2 CS (B): bur 1.0 CS (C): bur 0.5 CS.

E. Sintering of zirconia crowns:

Milled zirconia crowns were assigned into two main groups (Conventional sintering protocol group and high-speed sintering protocol group).

1. Conventional sintering protocol: Milled crowns were sintered using Tegra speed (Yenadent, Turkey) sintering furnace. The milled crowns were placed on the palatal surface away from the margins in a tray full of zirconium oxide beads.

The sintering program is illustrated in **Figure (3)**. It takes 7 hours to finalize the sintering procedure then the door of the furnace opens for natural cooling.

1. High-speed sintering protocol: Milled crowns were sintered using the SpeedFire furnace **(**Dentsply Sirona, Germany). The CEREC software sent an order with all necessary information to the furnace. High-speed sintering was performed at a heating rate of 300 °C/min and a dwell time of 2 min at 1500 °C. The sintering process for CEREC MTL zirconia single crown takes around *18 minutes* **Figure (4)**.

F. Restoration verification

All crowns were placed on the respective master titanium dies to confirm their full seating before proceeding. The margins of each crown were initially checked with a dental explorer (EXD 11/12, Hu-Friedy, Chicago, US). Magnifying loupes were used to check the seating of the restorations under 3X magnification. The Sintered crowns were polished using Eve Diacera Twist (Eve Inc, Keltern, Germany) HP Medium polishing spiral wheels followed by Fine spiral polishing wheels.

G. Vertical marginal gap measurement

Zirconia crowns were seated on the corresponding master dies and held in place using special tacking platform under the microscope. The vertical marginal gaps were assessed according to Holmes's definition of vertical marginal gap, using a Leica L2 stereomicroscope (Leica microsystems Ltd, Wetzlar, Germany) at 25X magnification. According to **Kale et al. (2016)**, vertical marginal gaps were measured using 8 predetermined points in each die (mid-buccal, mid-palatal, mid-mesial, mid-distal) and 4 line angles (mesio-buccal [MB], mesio-palatal [MP], disto-buccal [DB], disto-palatal [DP]). Microscope was connected to a compatible personal computer. A digital image analysis software (Leica Application Suite, LAS Core, Germany) was used for vertical marginal gap measurement. All measurements were made perpendicular to the crown along the margins **Figure (5).**

H. Statistical analysis

Numerical data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. Repeated measures ANOVA test was used to study the effect of sintering technique, finish line thickness, surface and their interactions on mean marginal gap distances. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

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

A

B

Figure (2): (A) Primescan Intraoral scanner, (B) Scanned metal die

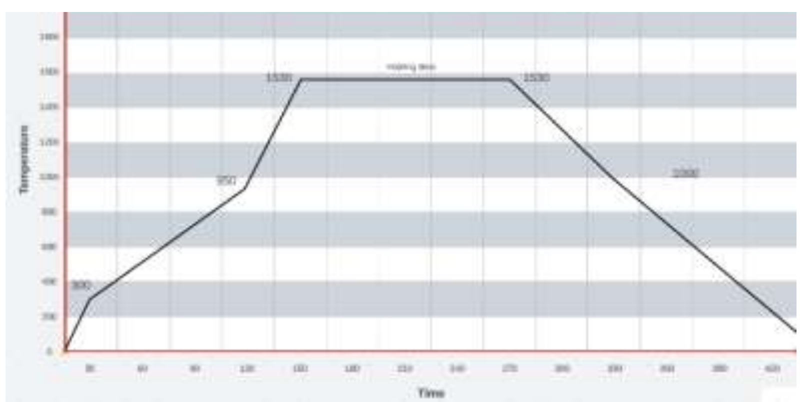


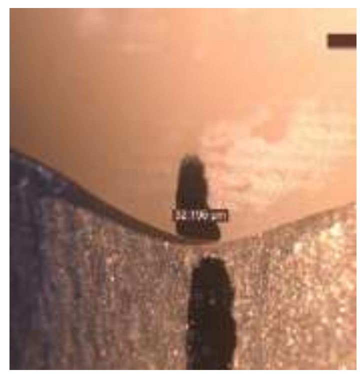
Figure (3): A diagrammatic chart showing the conventional sintering program

A

B

Figure (4): (A) SpeedFire furnace, (B) The screen shows a total of 18 minutes of sintering

A



B

Figure (5): Microscopic photos "under 25x magnification" showing the vertical marginal gap (A: mid-buccal, B: mid-palatal points)

Results

Conventional sintering showed statistically significantly higher mean vertical marginal gap distance than high speed sintering (*P*-value = 0.014, Effect size = 0.199). The results are shown in **Table (1).**

Regardless of sintering technique and surface, there was no statistically significant difference between the two finish line thicknesses (*P*-value = 0.097, Effect size = 0.096). The results are shown in **Table (2).**

The interaction between the different variables (sintering protocol, finish line thickness and surface) is shown in **Figure (6)**

Table (1): The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between vertical marginal gaps (µm) of the two sintering techniques

Conventional sintering		High speed sintering		*P*-value	*Effect size (Partial Eta squared)*
Mean	SD	Mean	SD		
67.3	16.7	63.5	19	0.014*	0.199

***Statistically significant at P ≤ 0.05**

Table (2): The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between vertical marginal gap distance (µm) of the two finish line thicknesses regardless of sintering technique and surface

0.2 mm		0.5 mm		*P*-value	*Effect size (Partial Eta squared)*
Mean	SD	Mean	SD		
66.6	17.3	64.2	18.5	0.097	0.096

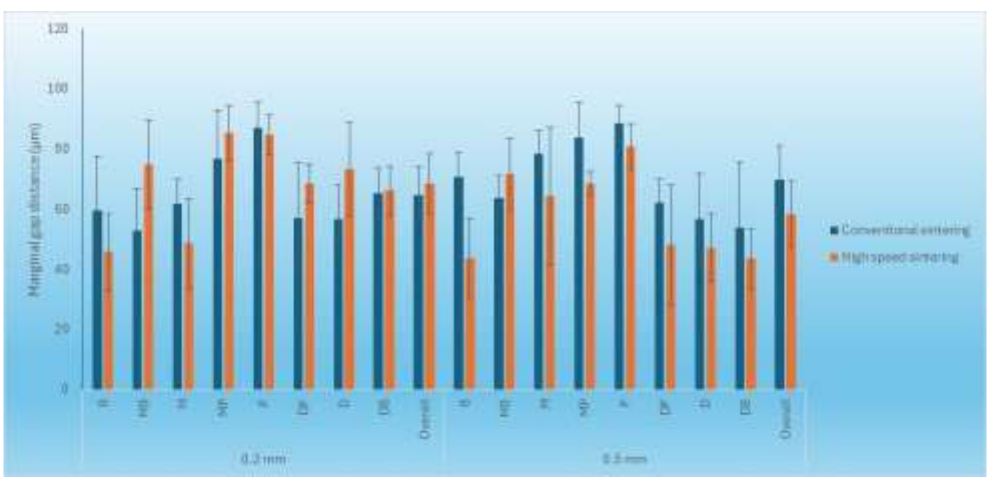


Figure (6): Bar chart representing mean and standard deviation values for vertical marginal gap distance with different interactions of variables

Discussion

Since sintering procedure is the longest step in zirconia manufacturing, recent furnaces were introduced into the market to shorten the time period of this step and favors the zirconia restorations more "chair-sided". There is usually an irreparable loss of tooth hard tissue during the intrusive process of preparing teeth for a full coverage restoration. There have been numerous attempts to prepare teeth so that more tooth structure is preserved during the process and an acceptable marginal fit and emergence profile are achieved. In prosthetic restorations, vertical preparation was advised as a more conservative option to horizontal preparation (shoulder or chamfer), particularly when monolithic zirconium oxide crowns are planned and the finish line may be quite thin. **Łabno & Drobnik (2020)**

Therefore, the aim of the present study was to evaluate the effect of two different sintering protocols: The "High-speed Sintering" protocol, and the "Conventional sintering" protocol, on the marginal integrity (vertical marginal gap) of monolithic translucent zirconia crowns with 0.2 and 0.5 mm finish line thicknesses.

In the current study, a metal die was used rather than natural teeth, as natural teeth represent great variations among each extracted tooth due to difference in anatomy, age and storage time after extraction so that standardization is too difficult. **Alghazzawi et al. (2012)**

The metal die prevent any wearing off with repeated removal and insertion of various specimens on the die during measurements. Moreover, measuring the marginal gap between the metal die and a specimen is the only verified method provided by the ISO standard of dimensional accuracy for CAM milled crowns. **Al-Mussawi et al. (2021)**

Full digital designing and manufacturing of prepared metal dies was performed for the purpose of standardization to eliminate any human variations. The metal dies were 3D-printed using the direct laser selective melting technique instead of milling as there is no "drill compensation" required in such a technique especially with the thin margins. **Örtorp et al. (2011)**.

An intraoral scanner (Primescan) was used to scan the preparations, to simulate a completely clinically digital workflow for acquisition. Primescan was selected as it has the highest trueness and precision when compared to other intraoral scanners. **Le Texier et al. (2024)**

The metal dies were embedded in a putty platform with a marking on the labial aspect of the putty. Also, two notches were made on the labial side and one notch was made on the palatal aspect of the dies. During scanning, the markings served as geometrically recognized references to help with stitching and alignment. **Rong Li et al. (2020)**. To increase surface roughness and make scanning easier, the dies were sandblasted. **Ferrini et al. (2019)**

CEREC MTL Zirconia was selected to be the material of the research as it complies with the concept of chairside dentistry that was the motive behind the development of high-speed sintering furnaces. **Rinke et al. (2022)**

In accordance with the manufacturer's guidelines, the cement gap was established at 80 μm and the minimum thickness at 700 μm **CEREC MTL Zirconia brochure (2021)**

Fine milling mode was selected in the milling preview as recommended by the manufacturer's instructions especially in case of feather edge margins. **Rinke et al. (2022)**.

The adoption of the Speedfire furnace was justified by its unique very short sintering time (around 18 minutes) which is compatible with chairside concept and being an integral part of the CEREC workflow recommended from the manufacturer of CEREC MTL Zirconia. Sintering procedure for conventional and high-speed protocols followed the parameters recommended for both furnaces. Polishing only of the sintered zirconia crowns rather than glazing is preferred as it results in less wear to the opposing teeth. **Janyavula et al. (2013)**

Marginal fit was evaluated in our study as it is one of the most crucial factors determining the clinical quality and efficacy of any ceramic crown. A crown that exhibits a higher marginal disparity is more favorable to the cement dissolution rate. Inflammation of the vital pulp and secondary caries can arise from micro-leakage from the oral cavity. **Bindl & Mörmann (2005)**

The vertical marginal gap measurement was chosen as the most popular technique to evaluate the marginal accuracy of the restorations. While some intraoral adjustments can be made to horizontal disparities, including crown overhangs, fixing the vertical marginal gap requires the use of luting cement, which dissolves easily. Because of this, the vertical marginal gap is the most clinically significant when evaluating crown margins. **El-Damaty et al. (2020)**

Vertical marginal gap can be measured with different methods; direct view using stereomicroscope or scanning electron microscope, cross sectioning and micro computed tomography (Micro CT). In the current study, measuring the marginal adaptation of the crowns was done using a stereomicroscope with magnification of 25X. It's the most commonly used method for its simplicity, non-invasive feature and time-saving. **Euán et al. (2012)**

Concerning the vertical marginal gap, according to the sintering protocol, our study revealed that zirconia crowns sintered using the high-speed sintering showed statistically significant lower mean vertical marginal gap values (63.5 ± 19 um) than conventional sintering (67.3 ± 16.7 um). These finding agreed with the results of a study performed by **Murat et al. (2021)** as higher values of vertical marginal gap were noticed with the conventional sintering protocol due to the longer sintering time and more resultant shrinkage with more dimensional changes and greater marginal discrepancy. While, there was no statistically significant difference (*P*-value= 0.097) between the two finish line thicknesses (0.2 mm and 0.5 mm). Worth to note that the maximum value of marginal discrepancy was at palatal surface (87.2 ± 10 µm) and this is maybe attributed to the placement of the crown on its palatal surface in the sintering tray. These finding match those of **Ahmed et al. (2019)** and **Ashmawi et al. (2020)**

All the mean values for the tested groups were within the clinically accepted range (below 120 µm) stated by **Holmes et al. (1989)**

Addressing the limitation of our study, it is an in-vitro study and clinical studies will be needed to verify the findings of this in-vitro study.

Conclusion:

1. Regarding the vertical marginal gap, high-speed sintering gives lower vertical marginal gap values than conventionally sintered crowns.
2. High-speed sintering with more conservative preparation is a valid protocol for sintering zirconia crowns with more economical and time-saving attribute which complies with the chairside concept of digital dentistry.

Ethics: This study protocol was approved by the ethical committee of the Scientific Research, Faculty of Dentistry, Cairo University. The approval date was (3-12-21).

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Conflict of interest: No conflict of interest.

References

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

Ahmed, W. M., Abdallah, M. N., McCullagh, A. P., Wyatt, C. C. L., Troczynski, T., & Carvalho, R. M. (2019). Marginal Discrepancies of Monolithic Zirconia Crowns: The Influence of Preparation Designs and Sintering Techniques. **Journal of Prosthodontics**, 28(3), 288–298. https://doi.org/10.1111/jopr.13021

Alghazzawi, T. F. :(2016): Advancements in CAD/CAM technology: Options for practical implementation.', **J Prosthodont Res.**, 60(2), pp. 72–84. doi: 10.1016/j.jpor.2016.01.003.

Al-Mussawi, R. M., Farid, F., & Haider, J. (2021). Effect of Die Materials on Marginal and Internal Adaptation of Zirconia Copings: An In Vitro Study. **The Open Dentistry Journal**, 15(1), 708–716. https://doi.org/10.2174/1874210602115010708

Benetti, P., Kelly, J. R., Sanchez, M., & della Bona, A. (2014). Influence of thermal gradients on stress state of veneered restorations. **Dental Materials**, 30(5), 554–563. https://doi.org/10.1016/j.dental.2014.02.020

Bindl A, Mörmann WH. (2005) Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. **J Oral Rehabil**. Jun;32(6):441-7. doi: 10.1111/j.1365-2842.2005.01446.x. PMID: 15899023.

Blatz, M. B., & Conejo, J. (2019). The Current State of Chairside Digital Dentistry and Materials. **In Dental Clinics of North America** (Vol. 63, Issue 2, pp. 175–197). W.B. Saunders. https://doi.org/10.1016/j.cden.2018.11.002

CEREC MTL zirconia brochure, Dentsply Sirona (2021). https://www.dentsplysirona.com/en-ca/categories/restorative/cerec-mtl-zirconia.html

Cokic, S. M., Vleugels, J., van Meerbeek, B., Camargo, B., Willems, E., Li, M., & Zhang, F. (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

El-Damaty, M. F., Abdel-Aziz, M. H., El-Kouedi, A. M. Y., & Hamza, T. A. (2020). Effect of finish line design and cement space thickness on the marginal accuracy of monolithic zirconia crowns. **Brazilian Dental Science**, 23(3), 1–8. https://doi.org/10.14295/bds.2020.v23i3.1908

Ferrini, F., Sannino, G., Chiola, C., Capparé, P., Gastaldi, G., & Gherlone, E. F. (2019). Influence of intra-oral scanner (I.O.S.) on the marginal accuracy of CAD/CAM single crowns. **International Journal of Environmental Research and Public Health**, 16(4). https://doi.org/10.3390/ijerph16040544

Gracis, S., Thompson, V., Ferencz, J., Silva, N., & Bonfante, E. (2016). A New Classification System for All-Ceramic and Ceramic-like Restorative Materials. **The International Journal of Prosthodontics**, 28(3), 227–235. https://doi.org/10.11607/ijp.4244

Janyavula, S., Lawson, N., Cakir, D., Beck, P., Ramp, L. C., & Burgess, J. O. (2013). The wear of polished and glazed zirconia against enamel. **Journal of Prosthetic Dentistry**, 109(1), 22–29. https://doi.org/10.1016/S0022-3913(13)60005-0

Kale, E., Seker, E., Yilmaz, B., & Özcelik, T. B. (2016). Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns.

Journal of Prosthetic Dentistry, 116(6), 890–895. https://doi.org/10.1016/j.prosdent.2016.05.006

Labno P & Drobnik K.: (2020): Comparison of horizontal and vertical methods of teeth preparation for a prosthetic crown. **J Pre-Clin Clin Res.**, 14(1): 25–28. doi: 10.26444/jpccr/116672

Le Texier, L., Nicolas, E., & Batisse, C. (2024). Evaluation and comparison of the accuracy of three intraoral scanners for replicating a complete denture. **Journal of Prosthetic Dentistry**, 131(4), 706.e1-706.e8. https://doi.org/10.1016/j.prosdent.2024.01.011

Mirt, T., Bhootpur, N., Malgaj, T., Özcan, M., Jevnikar, P., & Kocjan, A. (2023). Sintering Strategies for Dental Zirconia Ceramics: Slow Versus Rapid? In Current Oral Health Reports (Vol. 10, Issue 4, pp. 233–242). **Springer Science and Business Media** B.V. https://doi.org/10.1007/s40496-023-00355-y

Murat A. & ESKİTAŞÇIOĞLU, M. (2021). A Study on Dimensional and Marginal Gap Changes Through Application of Different Sintering Methods and Veneer Firings on Zirconia Crowns. **Selcuk Dental Journal**, 8(2), 522–529. https://doi.org/10.15311/selcukdentj.837186

Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: a literature review. J Prosthodont. 2013;22:419-28.

Örtorp, A., Jönsson, D., Mouhsen, A., & Vult Von Steyern, P. (2011). The fit of cobalt-chromium three-unit fixed dental prostheses fabricated with four different techniques: A comparative in vitro study. **Dental Materials**, 27(4), 356–363. https://doi.org/10.1016/j.dental.2010.11.015

Rinke, S., Metzger, A., & Ziebolz, H. (2022). Multilayer Super-Translucent Zirconia for Chairside Fabrication of a Monolithic Posterior Crown. **Case Reports in Dentistry**, 2022. https://doi.org/10.1155/2022/4474227

Sorrentino, R., Navarra, C. O., Lenarda, R. di, Breschi, L., Zarone, F., Cadenaro, M., & Spagnuolo, G. (2019). Effects of finish line design and fatigue cyclic loading on phase transformation of zirconia dental ceramics: A qualitative micro-raman spectroscopic analysis. **Materials,** 12(6). https://doi.org/10.3390/ma12060863

Stawarczyk, B., Keul, C., Eichberger, M., Figge, D., Edelhoff, D., & Lümkemann, N. (2017a). Three generations of zirconia: From veneered to monolithic. Part I. **Quintessence International** (Berlin, Germany: 1985), 48(5), 369–380. https://doi.org/10.3290/j.qi.a38057