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Microwave versus conventional sintering on mechanical properties of 3Y-TZP - A systematic review

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Abstract:

This systematic review evaluates the mechanical properties of yttria-stabilized zirconia (3Y-TZP) processed by microwave sintering compared to conventional sintering methods. Zirconia, known for its excellent strength and esthetics, has seen advancements in sintering techniques to enhance its properties. Conventional sintering, while effective, is time-consuming and less energy-efficient. In contrast, microwave sintering, introduced in 1999, offers rapid heating and improved control over temperature and shrinkage. This review, adhering to PRISMA guidelines, included studies from 2000 to 2023 that compared the effects of both sintering methods on relative density, flexural strength, Young's modulus, and hardness of zirconia. Results indicate that microwave sintering improves hardness and reduces processing time, whereas conventional sintering provides higher relative density, flexural strength, and Young's modulus. The findings suggest that the choice of sintering technique should align with specific material property requirements, with each method offering distinct advantages for zirconia applications.

Keywords: zirconia, microwave sintering, conventional sintering, mechanical properties

Background:

In the past 75 years, ceramics have significantly impacted Prosthodontics due to their chemical inertness, strength, and excellent esthetics [1]. However, ceramics also exhibit limitations such as brittleness, low tensile strength, and high cost [2]. To address these issues, zirconia was introduced in the 1990s for dental prostheses. It has gained prominence due to its exceptional properties, including high mechanical strength, wear resistance, biocompatibility, and corrosion resistance at high temperatures [3]. Yttria-stabilized tetragonal zirconia polycrystalline (3Y-TZP) is particularly valued for its aesthetics and adequate strength, making it suitable for a wide range of applications from single-unit crowns to multi-unit bridges, implants, and implant abutments [4]. Zirconia restorations are manufactured using CAD/CAM technology, which involves scanning, designing, milling, and sintering [5]. Sintering, a crucial step in the manufacturing process, involves heating zirconia powder to high temperatures to bond particles into a dense, solid ceramic structure [6]. Fully sintered zirconia is denser and exhibits superior mechanical properties compared to pre-sintered zirconia [7]. Conventional sintering involves heating zirconia powder in a furnace over several hours, transferring heat through conduction, radiation, and convection [8]. While effective, this method has drawbacks such as longer processing times, slower heating rates, and potential non-uniform temperature distribution [9]. To overcome these limitations, microwave sintering was introduced in 1999. This method uses electromagnetic radiation to heat materials internally, resulting in faster sintering times, reduced energy consumption, and better control over shrinkage and temperature [10]. Microwave sintering offers several advantages over conventional sintering, including speed, energy efficiency, precise temperature control, and the potential for improved material properties [11]. However, it also faces challenges like the need for specialized equipment and potential issues with

uniformity in large-scale production [12]. Recent advancements in sintering methods, such as Spark Plasma Sintering (SPS) and flash sintering, have further expanded the possibilities for zirconia processing, enhancing material properties and efficiency [13, 14]. Considering these advancements, conventional and microwave sintering methods remain prevalent in zirconia restoration manufacturing. This study aims to investigate the efficacy of microwave sintering compared to conventional sintering regarding the flexural strength, relative density, Young's modulus, and hardness of yttria-stabilized zirconia.

Materials and Methods:**Review methods:****Protocol and registration:**

The present systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the protocol was registered at PROSPERO under registration code CRD42023471421.

Eligibility criteria:**Inclusion criteria:**

- [1] **Population:** Studies including specimens or fabricated tooth crowns made up of monolithic yttria-stabilized zirconia (YSZ).
- [2] **Intervention:** Studies using microwave or speed sintering of YSZ material.
- [3] **Comparison:** Studies using conventional sintering of YSZ material.
- [4] **Outcome:** Studies providing information on mechanical properties of YSZ after sintering, such as flexural strength, fracture toughness, hardness, and Weibull modulus.
- [5] **Study Design:** Studies published in English between January 1, 2000, and June 31, 2023, including all types of

studies except for case reports/series and review articles. Only full-text articles were included.

Exclusion Criteria:

- [1] Single intervention studies without a comparative group.
- [2] Observational studies, review reports, case series, in-vitro and animal studies.
- [3] Studies providing only abstracts without full text.
- [4] Studies in languages other than English.

Focused review question:

Is there a difference in the efficacy of microwave sintering compared to conventional sintering regarding mechanical properties such as flexural strength, fracture toughness, hardness, and Weibull modulus of yttria-stabilized zirconia?

Search strategy:

Studies were selected based on the PICOS criteria in the review protocol. Two reviewers independently assessed titles and

abstracts to identify potentially eligible studies, with any discrepancies discussed with a third reviewer. The primary outcomes measured were mechanical properties of YSZ. The PRISMA guidelines were followed for conducting the meta-analysis. Electronic databases searched included the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE, CINAHL, EMBASE, PsycINFO, Scopus, and ScienceDirect using controlled vocabulary and free text terms. Articles published from January 1, 2000, to June 31, 2023, were included. Keywords and MeSH terms were used in combination with Boolean operators in advanced search options.

Selection of studies:

Titles and abstracts were reviewed and critically assessed by two independent reviewers. Duplicate records were removed using RevMan software. The screening process of the articles included in the review is explained in the form of the PRISMA flowchart (Figure 1).

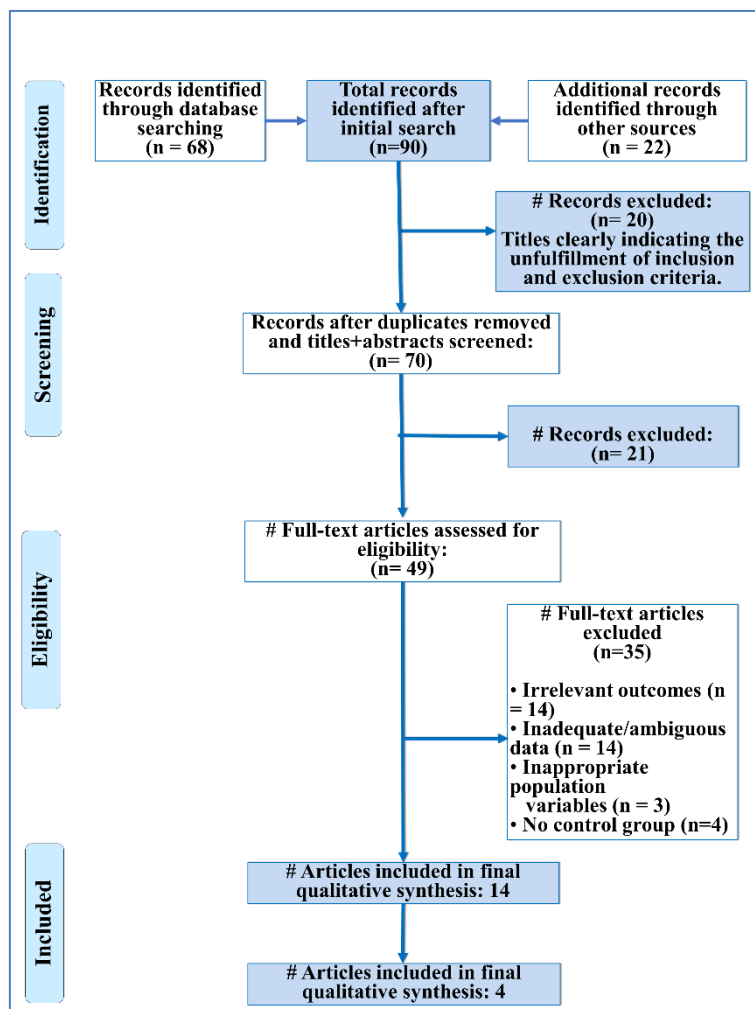


Figure 1: PRISMA flow diagram

The level of concordance between reviewers, calculated through Cohen’s kappa, was 0.92 for titles and abstracts and 0.90 for full texts. Discrepancies were resolved by a third reviewer (XYZ) through discussion.

Data extraction:

Two reviewers independently extracted data from the included studies. Disagreements were resolved through discussion. Data were gathered using a verification list of items, including: Authors, year, and title of the study, country, study design, sample size, age group of participants, gender, intervention, type and volume of YSZ material, comparators, outcomes, methods of outcome assessment, conclusions, and other relevant items. Data for all primary outcomes were recorded in Excel sheets.

Results:

Narrative synthesis:

Fourteen studies [15-28] were included in this systematic review whose general characteristics are mentioned in **Table 1**. All the

studies were conducted *in vitro*. These studies were conducted in different parts of world, with China, Spain, USA, Germany, Turkey, Belgium, and Egypt. A total of 720 specimens of zirconia were evaluated in this review of which 360 were speed sintered and remaining was conventionally sintered. Mechanical properties of Zirconia post sintering such as flexural strength, density, and fracture toughness were evaluated. The conclusions of all studies implied that microwave sintering improves the mechanical properties of YSZ, with time and energy consumption reduction.

Quality assessment of included studies:

Among the included studies, one showed medium risk while the remaining studies showed low risk of bias. In the study by Ai 2015, details of sample size were not mentioned hence the total score of this study was higher as compared to other studies. (Table 2)

Table 1: Characteristics of included studies

Study ID	Place of study	Sample size	Intervention	Comparison	Material	Cycle		Outcomes measured	Authors conclusions
						Speed sintering	Conventional		
Ai 2015	China	IG/CG	two step microwave sintering, one step microwave sintering	two step conventional sintering		900°C, 30min + 1350°C 30min	900°C 2h + 1350°C, 2h	density, hardness, fracture toughness, bending strength	No significant variation in density and mechanical properties between one-step and two-step microwave sintering. Microwave sintering superior to conventional sintering.
Presenda 2015	Spain	10/10	Microwave sintering	conventional sintering	LAVA	1200°C 10min + 1300°C 10min	1300°C 120min + 1400°C 120min	density, young's modulus	Microwave sintering enhances mechanical properties, reduces time and energy consumption.
					VITA	1200°C 10min + 1300°C 10min	1300°C 120min + 1400°C 120min		
					TOSOH	1200°C 10min + 1300°C 10min	1300°C 120min + 1400°C 120min		
Presenda 2015 A	Spain	25/25	one step microwave sintering	one step conventional sintering	LAVA	1200°C 10min	1400°C 2h	relative density, hardness, young's modulus, surface topography	Significant influence on microstructure and hydrothermal degradation susceptibility. Comparable wear resistance with lower sintering temperatures and shorter processing times.
					TOSOH (LAB)	1200°C 10min	1400°C 2h		
Presenda 2017	Spain	10-Oct	one step microwave sintering	one step conventional sintering	LAVA	1200°C 10min	1400°C 2h	relative density, hardness, young's modulus	Comparable wear resistance with lower sintering temperatures and shorter processing times.
					TOSOH (LAB)	1200°C 10min	1400°C 2h		
Presenda 2017 A	Spain	05-May	microwave sintering at 2 different temperatures - 1200C and	one step conventional sintering	10ZTA	1300°C 10min + 1400°C 10mon	1400°C 120min	density, hardness, fracture toughness	Reduces processing times and temperatures, increases
					5ZTA	1300°C 10min + 1400°C 10mon	1400°C 120min		
					5ATZ	1300°C 10min +	1400°C 120min		

Author	Country	Sample Size	Sintering Method	Conventional Sintering	Material	Temperature/Time	Temperature/Time	Properties	Notes
Kaizer 2017	USA	10-Oct	1300C	speed sintering	conventional sintering	3Y-TZP	1400°C 10mon	1400°C 120min	resistance to LTD.
			inCoris TZI			1300°C 10min + 1400°C 10mon			
Kauling 2019	Germany	48 24/24	speed sintering	conventional sintering	cerec zirconia medi	N/A	N/A	fit and fracture strength	Speed-sintered FPDs show equal/better fit and fracture load than conventional sintering.
Ozturk 2019	Turkey	340 16 groups n=10	speed sintering	sintered according to manufacturer's instructions	inCoris TZI, Upcera	Temperature 1400-1600°C, holding time - 30-240 min	According to manufacturer's instructions	surface roughness, flexural strength	No effect on surface phase transformation, roughness, and strength.
Moratal 2021	Spain	06-Jun	Microwave sintering at 2 different temperatures - 1200C and 1300C	conventional sintering	NK00 NK04 NK08 NK10	1. 1200°C, 10min 2. 1300°C, 10min	1400°C, 60 min	relative density,	Microwave technology increases sintering activity due to dielectric properties.
Cokic 2020	Belgium	20/20	speed sintered 1. Katana STML 2. CEREC zirconia	conventional sintered 1. Katana STML 2. inCoris TZI	Katana STML, inCoris TZI, CEREC zirconia	Total thermal cycle/sintering time/dwell temperature: 30 min/16 min/1560 °C	Total sintering time 6.8h, dwell time 2h at 1550°C	density, flexural strength	Speed sintering suitable for clinical use but requires translucency and reliability improvements.
Yang 2020	China	15/15	rapid sintering	conventional sintering	Corpan zirconia system, Cercon HT, Cercon XT	Corpan: 50-1100°C, dwell time 30min Cercon: 70-1540°C, dwell time 35min	Corpan: 10-950°C, dwell time 90min Cercon: 22-880°C, dwell time 130min	flexural strength	Rapid sintering affects optical properties depending on the material.
Albayrak 2023	Turkey	40 20/20	speed sintering	conventional sintering	monolithic zirconia	Total time 105min, 1515°C, dwell time 30min	Time: 7hrs, 1500°C, dwell time 120min	translucency values, opalescence, fluorescence	Speed sintering increases translucency but causes minor changes in chemical composition.
Lubauer 2023	Germany	30/30	speed sintering	conventional sintering	IPS emax CAD MO IPS emax CAD MT Lava Plus Lava Esthetic Cercon ht cercon xt Katana ML Katana STML Prettau Prettau Anterior	Max temp:1500-1600°C dwell time: 120-145 mins	Max temp:1540°C dwell time: 35 mins	flexural strength, youngs modulus	No significant compromise in mechanical properties with speed sintering.
Rezeika 2023	Egypt	45 15/15/15	speed sintering according to manufacturer instructions	conventional sintering	inCoris TZI, IPS e-max	According to manufacturer's instructions	According to manufacturer's instructions	flexural strength, translucency parameter	Zirconia suitable for chairside use in non-aesthetic zones with superspeed sintering.

Longer sintering required for high translucency restorations

Table 2: Quality assessment according to MINORS tool

Study ID	Sample size	Random	Sintering	Sample preparation	Statistical analysis	Measuring procedures	Operator	Total	Risk of bias
Ai 2015	2	2	0	1	0	0	2	7	Medium
Presenda 2015	0	1	0	0	0	0	1	2	Low
Presenda 2015 A	0	2	0	0	0	0	1	3	Low
Presenda 2017	0	2	0	0	0	0	1	3	Low
Presenda 2017 A	0	2	0	0	0	0	1	3	Low
Kaizer 2017	0	1	0	0	0	0	1	2	Low
Kauling 2019	0	2	0	0	0	0	1	3	Low
Ozturk 2019	0	2	0	1	0	0	1	4	Low
Cokic 2020	0	2	0	0	0	0	1	3	Low
Yang 2020	0	2	0	0	0	0	1	3	Low
Moratal 2021	0	2	0	0	0	0	1	3	Low
Albayrak 2023	0	2	0	0	0	0	1	3	Low
Lubauer 2023	0	2	0	0	0	0	1	3	Low
Rezeika 2023	0	1	0	0	0	0	1	2	Low

Meta-analysis:

Meta-analysis was conducted on studies providing data on similar outcomes irrespective of the type of zirconia material used in the studies.

Relative density:

Two studies were included in the assessment. The pooled value obtained was -0.05[-0.95, 0.84] indicating that the density values were less with speed sintered zirconia as compared to conventionally sintered. Overall, the results were **not statistically significant (p>0.05), with 88% heterogeneity**. Due to high heterogeneity, a random effects model was used for assessment (Figure 2).

Flexural strength:

Two studies were included in the assessment. The pooled value obtained was -0.36[-0.87, 0.16] indicating that the flexural strength values were less with speed sintered zirconia as compared to conventionally sintered. Overall, the results were **not statistically significant (p>0.05), with 91% heterogeneity**. Due to high

heterogeneity, a random effects model was used for assessment (Figure 3).

Youngs Modulus:

Three studies were included in the assessment. The pooled value obtained was -0.63[-1.20, -0.07] indicating that the Young's modulus values were less with speed sintered zirconia as compared to conventionally sintered. Overall, the results were **statistically significant (p<0.05), with 92% heterogeneity**. Due to high heterogeneity, a random effects model was used for assessment (Figure 4).

Hardness:

Two studies were included in the assessment. The pooled value obtained was 0.72[-0.38, 1.82] indicating that the hardness values were greater with speed sintered zirconia as compared to conventionally sintered. Overall, the results were **not statistically significant (p>0.05), with 88% heterogeneity**. Due to high heterogeneity, random effects model was used for assessment (Figure 5).

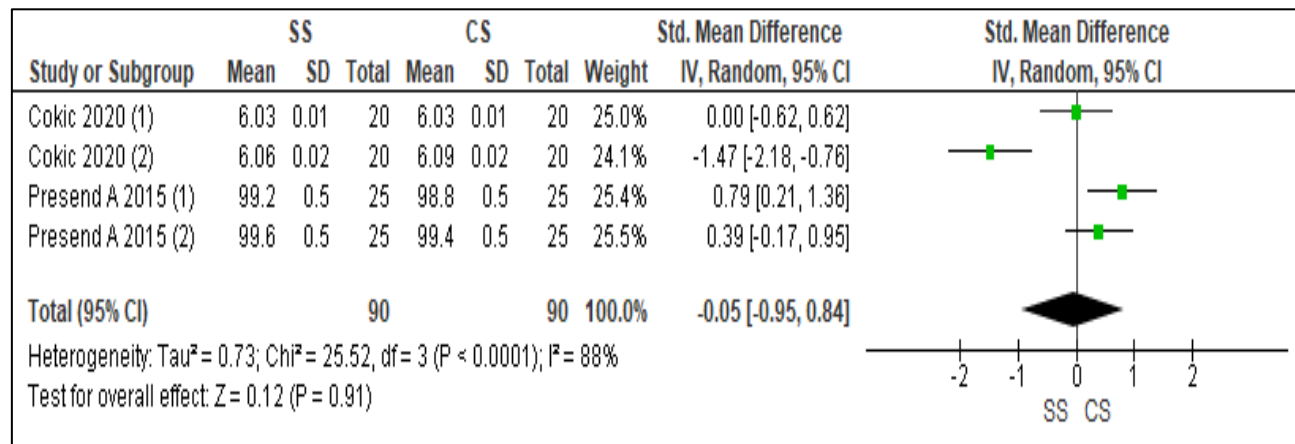


Figure 2: Forest plot for relative density

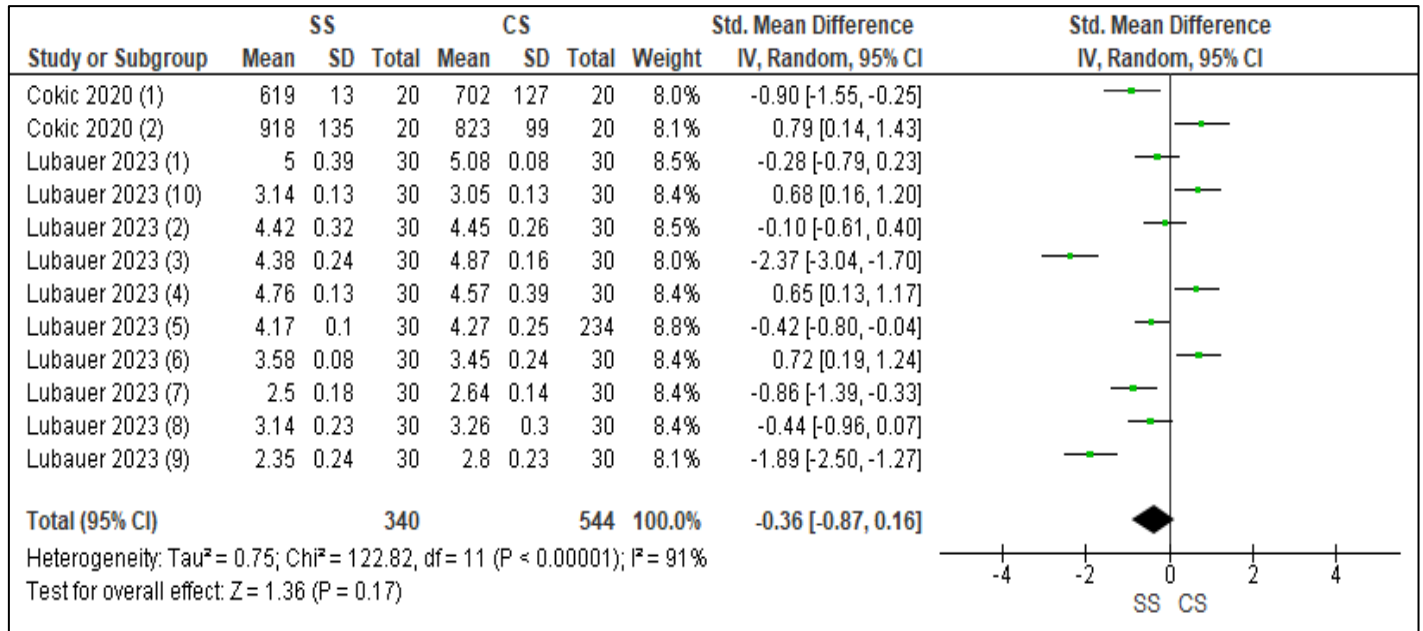


Figure 3: Forest plot for flexural strength

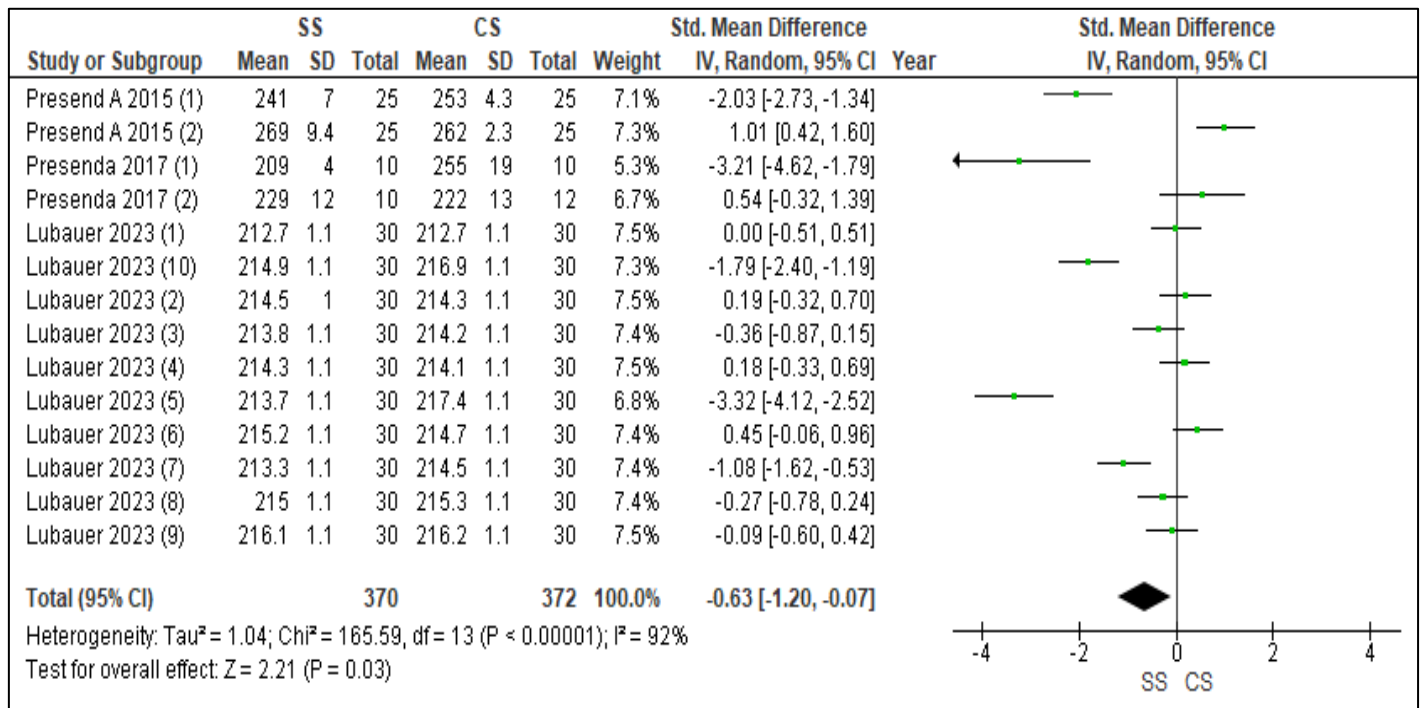


Figure 4: Forest plot for Young's modulus

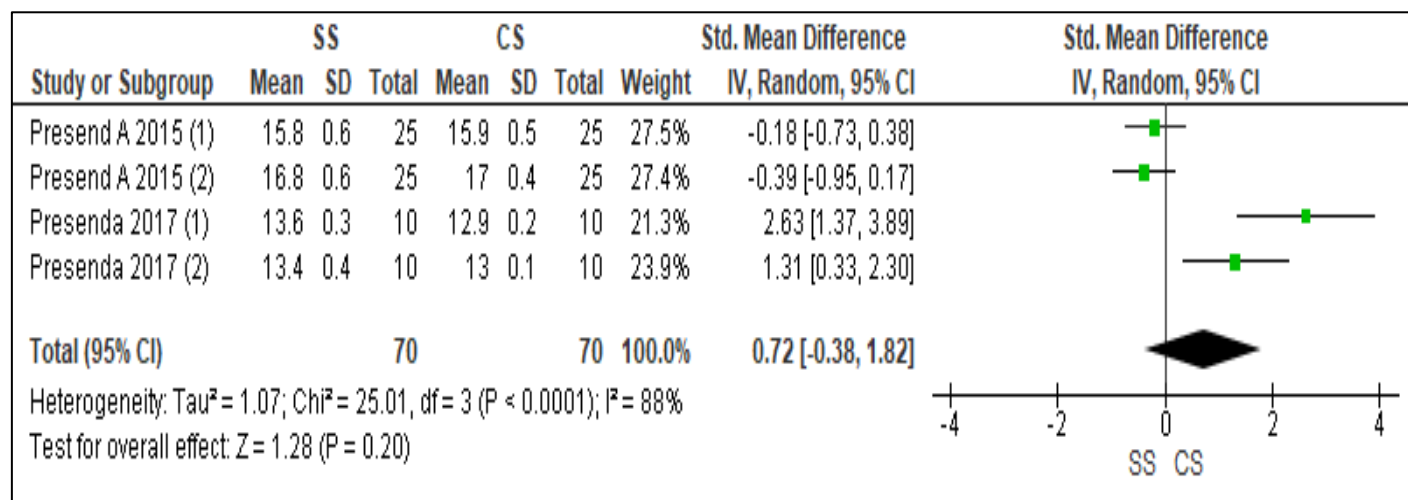


Figure 5: Forest plot for Hardness

Discussion:

The present systematic review evaluated the influence of microwave sintering and conventional sintering on the mechanical properties of yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) material. Y-TZP demonstrates distinctive polymorphic properties, including monoclinic, tetragonal, and cubic phases. This polymorphism imparts remarkable mechanical properties to zirconia, such as resistance to crack propagation and impressive fracture toughness [29]. The transformation toughening mechanism, associated with reversible phase transformations, contributes to zirconia's exceptional strength and durability. Yttrium oxide is added to pure zirconia to stabilize the tetragonal phase at room temperature and reduce volume expansion [18]. Conventional sintering, a well-established method uses electrical-resistance or gas-fired furnaces to heat zirconia powder gradually, typically over extended periods [24]. This traditional method, involving controlled temperature ramping, dwell times, and cooling rates, has been a cornerstone in ceramic processing for many years. The extended sintering durations contribute to enhanced grain growth, influencing the final properties of the material. These furnaces use resistance heating elements such as molybdenum disilicide and silicon carbide and are equipped with gas control systems to create controlled atmospheres, preventing undesired reactions [13]. Microwave sintering, a relatively modern technique, utilizes microwave radiation for rapid heating within the zirconia powder. It involves electromagnetic waves to directly heat the material, resulting in rapid and uniform temperature distribution. This technique offers advantages such as reduced processing time, energy efficiency, and improved uniform heating [23-25]. The rapid and uniform heating can lead to specific changes in the microstructure and properties of zirconia, resulting in enhanced mechanical properties. This review compared the performance of microwave sintering and conventional sintering from 2000 to 2023, focusing on relative density, Young's modulus, flexural strength, and hardness of zirconia [15-28]. The results suggest that some mechanical

properties, such as hardness, are superior with microwave sintering, while properties like relative density, Young's modulus, and flexural strength are greater with conventional sintering.

The findings indicate that conventional sintering results in higher relative density due to slower heating and longer dwell times, facilitating greater particle rearrangement, sintering neck formation, and densification. This leads to a more compact zirconia with less porosity. However, the differences were not statistically significant (88% heterogeneity). Conventional sintering also yields higher values of flexural strength and Young's modulus due to controlled heating and longer sintering times, allowing for improved crystal growth and better inter particle bonding. The results for Young's modulus were statistically significant (92% heterogeneity). In contrast, microwave sintering enhances hardness through rapid and uniform heating, forming a fine-grained microstructure with minimized grain boundaries, reducing defects and increasing overall hardness. Microwave sintering also presents certain challenges, such as sluggish grain growth during the final stage of sintering and slightly reduced fracture toughness due to shorter dwelling times (10-15 minutes). However, this technique is significantly faster than conventional sintering, saving time and energy in producing zirconia materials with adequate mechanical properties [24, 26]. Microwave sintering results in increased hardness by increasing the density (above 98%) of zirconia particles compared to conventional sintering. The field of zirconia sintering is marked by continuous innovation and refinement [15-21]. Recent advancements in both microwave and conventional techniques underscore the commitment to pushing the boundaries of what can be achieved with this versatile ceramic material [28, 29]. Researchers weigh various technical parameters and specific application requirements when selecting the most appropriate sintering technique for a given application in fields such as dentistry and advanced ceramics manufacturing. As researchers delve deeper into the intricacies

of the sintering process, the future holds the promise of even more tailored and efficient methods for realizing the full potential of zirconia across a spectrum of applications.

Conclusion:

The present systematic review highlights the distinct advantages and limitations of both microwave and conventional sintering techniques for yttria-stabilized zirconia (Y-TZP). While microwave sintering offers superior hardness due to its rapid and uniform heating process, conventional sintering yields higher relative density, Young's modulus, and flexural strength through controlled, extended heating. The choice between these methods should be guided by the specific mechanical property requirements of the intended application, with microwave sintering proving beneficial for energy efficiency and expedited processing, and conventional sintering ensuring optimal material density and strength. Future advancements in sintering technology are anticipated to further enhance the performance and application range of zirconia ceramics, promoting innovation in fields such as dentistry and advanced material manufacturing.

References:

- [1] Kelly JR & Denry I. *Dent Mater.* 2008 **24**:289. [PMID: 17624420]
- [2] Denry I & Kelly JR. *Dent Mater.* 2008 **24**:299. [PMID: 17659331]
- [3] Conrad HJ, et al. *J Prosthet Dent.* 2007 **98**:389. [PMID: 18021828]
- [4] Manicone PF, et al. *J Dent.* 2007 **35**:819. [PMID: 17825465]
- [5] Piconi C & Maccauro G. *Biomaterials.* 1999 **20**:1. [PMID: 9916767]
- [6] Miyazaki T & Hotta Y. *Aust Dent J.* 2011 **56**:97. [PMID: 21564120]
- [7] Tinschert J, et al. *J Dent.* 2000 **28**:529. [PMID: 10960757]
- [8] Komine F, et al. *J Oral Sci.* 2010 **52**:531. [PMID: 21206154]
- [9] Denry I & Kelly JR. *J Dent Res.* 2014 **93**:1235. [PMID: 25274751]
- [10] Guazzato M, et al. *Biomaterials.* 2004 **25**:5045. [PMID: 15109867]
- [11] Kang S-JL. *Materials (Basel).* 2020 **13**:3578. [PMID: 32823630]
- [12] Chen IW & Wang XH. *Nature.* 2000 **404**:168. [PMID: 10724165]
- [13] Mansour FA et al. *Dent Mater.* 2015 **31**:e226. [PMID: 26211698]
- [14] Indurkar A et al. *Materials (Basel).* 2021 **14**:6133. [PMID: 34683723]
- [15] Ai Y et al. *Mater Des.* 2015 **65**: 1021. [DOI: <https://doi.org/10.1016/j.matdes.2014.10.054>]
- [16] Presenda Á et al. *J Am Ceram Soc.* 2015 **98**:3680 [DOI: <https://doi.org/10.1111/jace.13810>]
- [17] Presenda Á et al. *Ceram Int.* 2015 **41**:7125. [DOI: <https://doi.org/10.1016/j.ceramint.2015.02.025>]
- [18] Presenda Á et al. *J Am Ceram Soc.* 2017 **100**:1842 [DOI: <https://doi.org/10.1111/jace.14769>]
- [19] Presenda Á et al. *Chem Eng Process.* 2017 **122**:404. [DOI: <https://doi.org/10.1016/j.cep.2017.03.002>]
- [20] Kaizer MR et al. *Ceram Int.* 2017 **43**:10999. [PMID: 29097830]
- [21] Öztürk C et al. *J Dent Res Dent Clin Dent Prospects.* 2019 **13**:247. [PMID: 32190207]
- [22] Elisa Kauling A et al. *J Prosthet Dent.* 2020 **124**:380. [PMID: 31780110]
- [23] Cokic SM et al. *Dent Mater.* 2020 **36**:959. [PMID: 32493658]
- [24] Yang CC et al. *Ceram Int.* 2020 **46**:26668. [DOI: <https://doi.org/10.1016/j.ceramint.2020.07.137>]
- [25] Moratal S et al. *J Asian Ceram Soc.* 2021 **9**:188. [DOI: <https://doi.org/10.1080/21870764.2020.1860433>]
- [26] Albayrak H et al. *J Indian Prosthodont Soc.* 2023 **23**:57. [PMID: 36588376]
- [27] Lubauer J et al. *Odontology.* 2023 **111**:883. [PMID: 34961642]
- [28] Rezeika Y et al. *Alexandria Dent J.* 2022 **48**:170 [DOI: <https://dx.doi.org/10.21608/adjalexu.2022.106257.1229>]
- [29] Rexhepi I et al. *J Funct Biomater.* 2023 **14**:431. [PMID: 37623675]