Review Article

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Comparison of Mechanical Properties Between Zirconia-reinforced Lithium Silicate Glass-ceramic and Lithium Disilicate Glass-ceramic: A Literature Review

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Abstract

Lithium disilicate glass-ceramic (LDS) is increasingly being adopted for use in therapeutic restorative procedures. Concurrently, zirconia-reinforced silicate glass-ceramics (ZRS) are becoming broadly utilized in dental applications. The purpose of this study was to evaluate and compare the mechanical properties of zirconia-reinforced lithium silicate glass-ceramics and lithium disilicate-based glass-ceramics, with a focus on their application in CAD/CAM technologies. In this review, the researchers conducted a search of the PubMed (MEDLINE) database to identify studies related to LDS and ZRS. This search was limited to articles published in English over a seven-year period, from January 1, 2015, to December 31, 2022. Additional studies were sourced from Google Scholar and through manual exploration. Key published works were identified and included in the literature review. The findings concluded that ZRS exhibits superior mechanical properties, including higher flexural strength, fracture toughness, and hardness, compared to LDS. Furthermore, ZRS combines desirable esthetic qualities with robust mechanical strength, rendering it an excellent material for single tooth aesthetic restorations such as inlays, onlays, crowns, and veneers, applicable to both tooth and implant supports. Currently, there is a notable scarcity of data concerning the mechanical properties and clinical efficacy of ZRS. Therefore, it is imperative to conduct long-term clinical studies to verify the optical and mechanical properties, clinical applications, limitations, and long-term effectiveness of ZRS.

Keywords: dental ceramic, lithium disilicate glass-ceramic, zirconia-reinforced silicate glass-ceramics

Introduction

Dental ceramics are preferred for restorations needing a natural appearance because they can replicate the natural characteristics of teeth effectively. This preference for all-ceramic restorations has surged in recent times.(1) Lithium disilicate glass-ceramic (LDS) is widely utilized for such all-ceramic restorations, encompassing not only aesthetic veneers, inlays, onlays, and anterior crowns but also for the more demanding applications of load-bearing monolithic posterior crowns and bridges.(2) LDS offers a range of shades and translucency options, making it possible to achieve anatomical contours in monolithic restorations that closely resemble natural teeth. This customization allows LDS to seamlessly blend with the patient's existing dentition. LDS is also employed in dental computer-aided design/computer-aided manufacturing (CAD/CAM) for fabricating inlays, onlays, partial crowns, veneers, anterior and posterior crowns, and single tooth restorations on implant abutments.(3) Despite these advantages, the mechanical properties of LDS may restrict its application in areas subjected to high masticatory forces, such as the molar region.(4)

Zirconia-reinforced silicate glass ceramics (ZRS) have recently been introduced to the field of dentistry. They are utilized by dental CAD/CAM software for fabricating inlays, onlays, partial crowns, veneers, anterior and posterior crowns, and single-tooth restorations on implant abutments. It is claimed that these advanced glass ceramic materials merge the functional and aesthetic advantages of zirconia with those of glass ceramic. The incorporation of zirconia particles within the lithium silicate glass matrix serves to reinforce the ceramic structures by hindering the progression of cracks. Following the crystallization process, the material is expected to exhibit enhanced mechanical properties alongside superior aesthetic qualities. The improved translucency and range of colors enable the creation of anatomically accurate, monolithic restorations.(2-6)

The purpose of this review is to provide a comparative analysis of the mechanical properties between Zirconia-reinforced silicate glass ceramics (ZRS) and Lithium disilicate glass-ceramic (LDS).

Materials and Methods

The PubMed (MEDLINE) database served as the primary source for compiling the most pertinent and up-to-date data on LDS and ZRS. This search was restricted to a span of five years, covering the period from January 1, 2015 to December 31, 2020, and was limited to studies published in English. Additional research was acquired through Google Scholar and direct searches. The most significant article was chosen for inclusion, and it is featured in the reference, along with the selected studies.

Results and Discussion

LDS constitutes a particle-filled glass-ceramic utilized in restorations either through heat-pressing or CAD/CAM processes.(7,8) In 2001, IPS e.max Press® by Ivoclar Vivadent in Schaan, Liechtenstein, was launched as a castable LDS variant that offered enhanced mechanical and optical characteristics.(9) The microstructure of IPS e.max Press is characterized by approximately 70 percent lithium-disilicate crystals ($Li_2Si_2O_5$), set within a glassy matrix.(9) Following this, in 2005, IPS e.max CAD® was introduced by the same manufacturer for CAD/CAM dental restorations.(9) LDS is known for its superior mechanical properties and translucency compared to traditional dental porcelains. Although LDS is more translucent than zirconia, its mechanical properties are somewhat lesser. Nevertheless, LDS has been widely adopted for fabricating monolithic ceramic crowns noted for their aesthetic appeal.(10)

A new generation of ceramic material for dental restorations, Zirconia-reinforced silicate glass ceramics (ZRS), has been introduced to the market. ZRS is characterized by its composition of fine lithium-metasilicate (Li_2SiO_3) and lithium disilicate ($Li_2Si_2O_5$) crystals, with an average size ranging from 0.5 to 0.7 micrometers, embedded within a zirconium dioxide (ZrO_2) matrix that constitutes 10% of its weight.(11) The material undergoes a final crystallization process, leading to the creation of a fine-grained microstructure composed of Li_2O-ZrO_2-SiO_2.(3,4) This structure is noted for its enhanced mechanical properties, boasting a strength range between 370 to 420 MPa, and is designed to meet the highest aesthetic standards, according to the manufacturer's claims.(12)

Presently, two distinct ZRS materials are available for use in dental restorations, each characterized by two crystal phases. One crystalline phase consists of lithium-metasilicate (Li_2SiO_3) crystals, which have a round and slightly elongated form. These crystals are found in larger sizes in Celtra® Duo (up to 1 micrometer). While the other phase comprises lithium orthophosphate (Li_3PO_4) crystals, presents in a round shape with nanometric dimensions, appearing in a smaller size in Vita Suprinity® PC (approximately 0.5 μm). The variance in grain sizes between these materials can influence their mechanical properties, with larger grain sizes potentially leading to diminished mechanical performance in comparison to materials of the same composition but with smaller grains.[5]

Mechanical Properties

Flexural Strength

The mechanical durability of ceramics, being brittle materials, is primarily influenced by their flexural strength. The findings suggest that ceramics exhibit a markedly higher fragility when subjected to tensile forces compared to compressive stresses.[3]

Numerous studies have been conducted to evaluate the mechanical properties of ZRS (Vita Suprinity® PC) and LDS (IPS e.max CAD). Sen and US examined thirty disk-shaped specimens from each material, measuring 12 millimeters in diameter and 1.2±0.05 millimeters in depth. They employed a biaxial flexure test, utilizing a three-ball setup and a piston in a universal testing machine, with a crosshead speed of 0.5 millimeters per minute until failure.[6] Elsaka and Elnaghy tested thirty bending bars (18×4×1.2 millimeters) of each material using a three-point bending fixture in a universal testing machine, loading the specimens until fracture at a crosshead speed of 0.5 millimeters per minute.[3] The studies found that ZRS (Vita Suprinity® PC) exhibited significantly higher flexural strength compared to LDS (IPS e.max CAD®), a result attributed to the zirconia fillers that reinforce the glassy matrix of the material.[3,6]

Lawson and colleagues conducted a study to evaluate the mechanical properties of LDS (IPS e.max CAD®) and zirconia-reinforced lithium silicate (Celtra® Duo) materials used in CAD/CAM dentistry. They prepared ten bars from each material, measuring 2.5×2.5×16 millimeters, and polished all samples. Both Celtra® Duo (fired group) and IPS e.max CAD® were subjected to firing in a furnace according to the manufacturer's guidelines. The mechanical strength of the specimens was then tested using a three-point bending fixture in a universal testing machine, with a crosshead speed set at 1 millimeter/minute. The results showed that fired Celtra® Duo exhibited superior flexural strength compared to IPS e.max CAD®.[13] Furthermore, it was found that zirconia-reinforced glass-ceramic surpassed LDS (IPS e.max CAD®) in terms of flexural strength, both before and after being subjected to thermo-mechanical load cycling. The remarkable mechanical properties and resistance to ageing of zirconia-based ceramics were noted to prevent any significant impact on their flexural strength from thermo-mechanical load cycling.[13]

Soliman *et al.,* conducted an analysis on the flexural strength of LDS (IPS e.max CAD®) and ZRS (Vita Suprinity® PC) materials used in monolithic dental restorations. The study involved ten rectangular samples for each material, measuring 14×4×1.2 millimeters, which were fabricated from CAD/CAM blocks. These specimens were subjected to a three-point flexural strength test in a universal testing machine, with a crosshead speed of 0.5 millimeters per minute until failure. The results revealed that lithium disilicate-based glass-ceramics demonstrated higher flexural strength compared to their zirconia-reinforced counterparts.[14]

The summary of studies related to flexural strength of ZLS and LDS were shown in Table 1.

Table 1: Comparison flexural strength between lithium disilicate glass-ceramic (LDS) and zirconia-reinforced silicate glass-ceramic (ZLS)

Study	Result	Flexural strength [mean (SD)]
Elsaka and Elnaghy (2016)[3]	ZLS (Vita Suprinity®) had a significantly higher flexural strength than LDS (IPS e.max CAD).	ZLS=443.63 (38.90) MPa LDS=348.33 (28.69) MPa
Lawson *et al.,* (2016)[13]	ZLS (Celtra® Duo (fired)) surpassed the flexural strength of LDS (IPS e.max CAD).	ZLS=451.40 (58.90) MPa LDS=376.90 (76.20) MPa
Sen and Us (2018)[6]	ZLS (Vita Suprinity®) revealed higher biaxial flexural strength compared with LDS (IPS e.max CAD).	ZLS=510.0 (43.0) MPa LDS=415.0 (26.0) MPa
Soliman *et al.,* (2019)[14]	LDS (IPS e.max CAD) showed the higher flexural strength than ZLS (Vita Suprinity®).	LDS=451.35 (9.41) MPa ZLS=383.38 (8.88) MPa

Fracture toughness

Fracture toughness is a critical metric for evaluating the resistance of brittle materials to fracture and their ability to impede crack growth. Restorative materials that exhibit higher fracture toughness are more resistant to fractures and can withstand a higher degree of stress. There are various methods for testing fracture toughness, among which the single-edge-V-notched-beam (SEVNB) method stands out as the benchmark for determining the fracture toughness of ceramics owing to its accuracy and reliability.[1,15-17] In the study conducted by Elsaka and Elnaghy on the mechanical properties of ZRS, ceramic blocks were sectioned into bar-shaped specimens and evaluated using a three-point bending fixture installed in a universal testing machine. These specimens were subjected to loading until fracture occurred, with a crosshead speed set at 0.5 millimeter per minute. The findings from their investigation revealed that ZRS (Vita Suprinity® PC) demonstrated superior fracture resistance compared to lithium disilicate glass-ceramic (IPS e.max CAD®). The enhanced fracture toughness was attributed to the reinforced glass matrix, without dissolved zirconia particles.[3]

Hamza *et al.,* conducted a study to compare the fracture resistance of ZRS (Vita Suprinity® PC) restorations with LDS (IPS e.max CAD®) restorations. The restorations were subjected to a chewing simulator and then loaded until fracture in a universal testing machine. The findings indicated that ZRS restorations exhibited higher fracture resistance compared to LDS restorations.[18] However, the outcome of this study, based on tests conducted with Vita Suprinity® PC, contradicts recent research by Sieper *et al.,* and Gungor and Nemli. These researchers reported that the fracture strength of all-ceramic crowns crafted from LDS exceeded that of those made from ZRS.[19,20]

Mohamed *et al.,* discovered that ZRS (Celtra® Duo) exhibited greater fracture resistance compared to LDS (IPS e.max CAD®), with aging reducing the fracture resistance of both ceramic types.[21] In their study, 40 CAD/CAM crowns were aged, and their fracture resistance was assessed using a universal testing machine. Similarly, Schwindling and Preis observed that ZRS crowns demonstrated a higher average fracture strength than LDS crowns.[22,23]

The summary of studies related to fracture toughness of ZLS and LDS was shown in Table 2.

Hardness

Hardness is a crucial factor in evaluating restorative materials. It refers to a material's ability to resist permanent indentation or penetration.[3]

Several studies have examined the hardness of LDS (IPS e.max CAD®) and ZRS (Vita Suprinity®

Table 2: Comparison fracture toughness/resistances between lithium disilicate glass-ceramic (LDS) and zirconia-reinforced silicate glass-ceramic (ZLS)

Study	Result	Fracture toughness/resistances [mean (SD)]
Preis *et al.,* (2015)[23]	Crowns fabricated ZLS (Celtra® Duo) showed higher mean value of fracture strength than those fabricated from LDS (IPS e.max CAD).	ZLS=2612 (853) N LDS=2528 (668) N
Elasaka & Elnaghy (2016)[3]	ZLS ceramic (Vita Suprinity® PC) revealed higher fracture toughness compared with LDSceramic (IPS e.max CAD).	ZLS=2.31 (0.17) MPa m0.5 LDS=2.01 (0.13) MPa m0.5
Schwindling *et al.,* (2017)[22]	ZLS crown (Celtra® Duo) showed higher fracture resistance than those crown from LDS (IPS e.max CAD).	ZLS=667 (205) N LDS=525 (256) N
Sieper *et al.,* (2017)[19]	LDS ceramic (IPS e.max CAD) was achieved more higher fracture strength than ZLS ceramic (Vita suprinity® PC).	LDS=2499 (167) N ZLS=2015 (270) N
Gungor *et al.,* (2018)[20]	The fracture resistance of all ceramic crowns fabricated from LDS (IPS e.max CAD) was higher than that for ZLS crowns (Vita suprinity® PC).	LDS=2847.64 (108.87) N ZLS=2598.25 (134.77) N
Mohamed *et al.,* (2020)[21]	ZLS ceramic (Celtra® Duo) give rise to higher fracture resistance than LDS ceramic (IPS e.max CAD) and aging decrease fracture resistance of both types of ceramic.	ZLS=1093.96 (120.01) N LDS=1052.16 (282.29) N

PC).[3,13,24] In the research conducted by Elsaka and Elnaghy, thirty specimens of each material, measuring 18×14×5 millimeters, were prepared, and polished. The surface microhardness of these specimens was assessed using a digital microhardness tester. For each material, ten Vickers indentations were made using a diamond indenter under a load of 9.8 newtons for a duration of 20 seconds.[3]

In the investigation by Arthur *et al.,* the hardness was determined using a Vickers microhardness tester and the indentation technique. This assessment was carried out on ten bar-shaped specimens which had been finished to a mirror polish. The surface microhardness of each specimen was measured by conducting five Vickers indentation tests, applying a load of 1.96 newtons for a dwell time of 15 seconds each.[24]

In a separate study by Lawson *et al*., materials were cut into 4-millimeter-thick blocks and embedded in a clear, chemically cured medium. All specimens underwent wet polishing and were then stored. The Vickers microhardness of these specimens was evaluated using a one-kilogram load and a dwell time of 15 seconds. The findings indicated that ZRS exhibited greater hardness compared to LDS.[13]

The findings from hardness testing indicated that ZRS exhibited greater hardness compared to LDS, as documented in Table 3.

Disadvantages

The brittleness and susceptibility to fracture of LDS and ZRS are significant disadvantages. According to Ustun *et al*., 2016, the Vita Suprinity groups exhibited lower bond strength values compared to other glass ceramic groups. Moreover, ZRS groups, containing approximately 10% zirconia by weight, demonstrated lower values than other groups subjected to HF (hydrofluoric acid) etching, leading to both cohesive and adhesive failures. Consequently, silanization could negatively affect the zirconia content in ZRS materials.[25-27]

Clinical applications

The development of clinical practice guidelines for the utilization of Celtra® Duo involved the implementation of two distinct finalization protocols: milling and glaze firing. According to the manufacturer's recommendations, the milled version offers a notable advantage in terms of time efficiency as it eliminates the need for a firing phase, allowing for direct polishing following grinding. This simplifies the process of adhesively luting indirect restorations at the chairside. Although not mandatory, the glaze firing cycle is the preferred method due to its ability to enhance esthetic and flexural strength characteristics. In contrast, Vita Suprinity® PC and IPS e.max CAD® provide the material in a pre-crystallized state, available in amber or opaque purple color variations, necessitating a subsequent crystallization firing after machining.[25]

LDS

Long-term clinical use in patients is being studied in addition to the recommended clinical application procedures, as indicated by the following studies.

Breemer *et al.,* conducted a comprehensive review of long-term clinical data concerning crowns made from single pieces of lithium disilicate glass-ceramic. In this clinical study, they performed 74 repairs on 12 patients. Additionally, they conducted a historical case study where the same clinician replaced the back teeth with full LDS replacements bonded using an adhesive method. The results of this study showed that, after 5, 10, and 15 years, 92%, 85%, and 81.9% of the restorations remained intact. However, thirteen restorations experienced failures: four developed secondary caries, two became dislodged, and seven fractured.[28] Mobilio *et al.,* assessed single LDS

Table 3: Comparison hardness between lithium disilicate glass-ceramic (LDS) and zirconia-reinforced silicate glass-ceramic (ZLS)

Study	Result	Hardness [mean (SD)]
Elsaka and Elnaghy (2016)[3]	ZLS (Vita Suprinity®) had significantly higher hardness than LDS (IPS e.max CAD).	ZLS=6.53 (0.46) GPa LDS=5.45 (0.28) GPa
Lawson *et al.,* (2016)[13]	ZLS (Celtra® Duo) was harder than LDS (IPS e.max CAD).	ZLS=595.10 (37.60) HV LDS=452.90 (16.20) HV
Arthur *et al.*, (2019)[24]	ZLS (Vita Suprinity®) showed the highest hardness values followed by LDS (IPS e.max CAD).	ZLS=692.0 (14.0) HV LDS=596.0 (18.0) HV

restorations on natural teeth, with a mean follow-up period of 51 months involving 43 restorations in 17 individuals. The findings indicated that 97.7% of these restorations survived, with a success rate of 94.2%.(29) Furthermore, crown-retained fixed dental prostheses (FPDs) made from LDS ceramic (IPS e.max Press) were studied over a span of 15 years. In this study, 28 patients received 36 3-unit fixed dental prostheses, which were bonded using either composite resin or glass-ionomer cement. After 10 years, the survival and success rates of monolithic lithium disilicate ceramic FDPs decreased to 48.6% and 30.9%, respectively, after 15 years.(30)

Malamed *et al*., conducted a study that involved the examination of 556 patients with LDS restorations, including single crowns, three-unit fixed partial dentures (FPDs), and cantilevered anterior restorations. The research focused on assessing the 10-year survival of these restorations. The findings from this study revealed that pressed lithium disilicate restorations on molar teeth exhibited a durability of 10.4 years with an overall failure rate of 0.2 percent per year.(31) These long-term survival statistics can be valuable for clinicians in making informed decisions as shown in table 4.

ZRS

The use of ZRS is endorsed for various applications, including veneers, crowns, bridges, implant-supported crowns, inlays, and onlays, as indicated by the manufacturer of the product.(3,32) The clinical reliability of zirconia-reinforced lithium silicate is supported by numerous research studies and observed clinical outcomes.

Zimmermann *et al.,* reported a 96.7 percent success rate for ZRS restorations after a 12-month follow-up period, with clinical failures primarily attributed to bulk fracture, accounting for approximately 3.3 percent.(33) In another study by Rinke *et al*., the success rate for ninety-two ZRS partial crowns (specifically Celtra® Duo) placed on vital or adequately endodontically treated premolars and molars was approximately 98 percent, as assessed over a 3-year follow-up period. The main factor leading to failure in this case was tooth fracture, contributing to a 1.2 percent endodontic complication rate.(34) Rinke *et al.,* also conducted a study with a 2-year follow-up, focusing on sixty-one partial crowns with reduced material thickness (with a minimum material thickness of 1.0 millimeter) fabricated chairside and adhesively cemented on vital premolars and molars. The results showed an overall success rate of approximately 93 percent among the 59 restorations that participated in the 2-year follow-up examinations. Only two restorations were lost due to ceramic fracture.(35)

The durability and success rate of ZLS (zirconia-reinforced lithium silicate) ceramic partial crowns in dental restorations are significantly influenced by the material thickness and the position of the restoration within the mouth.(36) Furthermore, when subject to conditions simulating heavy chewing or bruxism, ZLS dental ceramics are estimated to exhibit a durability that is up to five times less than that of LS2 (lithium disilicate) ceramics. This suggests that while ZLS ceramics offer certain advantages, careful consideration must be given to their application in high-stress areas.(36,37)

Table 4: The success rate of lithium disilicate glass-ceramic (LDS)

Study	Sample	Methods	Result
Breemer *et al.,* (2017)(25) 5, 10 and 15-year follow up	Full crown restorations on premolars and molars.	For a retrospective case series, Full posterior LDS restorations were placed by the same dentist and same dental technician and cemented using an adhesive approach.	From this study, the success rate of restoration after 5, 10 and 15 years was 92%, 85% and 81.9%, respectively. Of the all restoration, 13 of them are failed: 4 because of secondary caries, 2 because of debonding and 7 because of fracture.
Mobilio *et al.,* (2018)(26) 3-year follow up	43 single, partial and total restorations on natural teeth.	For a retrospective study, A total of 43 partial and total restorations in 17 patients were evaluated from a minimum of 36 months follow-up to a maximum of 81 months follow-up.	The cumulative success rate was 97.7%, and the cumulative success rate was 94.2% with only two mechanical complications were observed: fracture of ceramic core and chipping.

Degidi *et al.,* assessed the 2-year performance of definitive implant- or tooth-supported three-unit fixed partial dentures (FPDs) using ZRS material (Celtra® Press). These FPDs were used for repairing premolars and molars with partial edentulism. The findings from this study suggest that both implant-supported and tooth-supported ZRS three-unit FPDs can effectively address posterior partial edentulism.[38] The success rate of ZLS was shown in Table 5.

Nonetheless, it is important to note that there is a deficiency of clinical evidence derived from trials with extended follow-up durations. A more comprehensive and extended long-term study is required to validate the promising results reported in these earlier publications.

Conclusions

ZRS exhibits superior mechanical properties, including higher flexural strength, fracture toughness, and hardness when compared to LDS. Additionally, ZRS offers optimal esthetics while maintaining proper mechanical strength, making it a suitable choice for single-tooth esthetic restorations, such as inlays, onlays, crowns, veneers, both tooth-supported and implant-supported. However, it is important to acknowledge that there is currently a limitation in the available data concerning the mechanical properties and long-term clinical performance of ZRS. Therefore, there is a need for long-term clinical research to thoroughly assess the physical-mechanical properties, clinical indications, limitations, and the long-term performance of such restorations.

Table 5: The success rate of zirconia-reinforced silicate glass-ceramic (ZLS)

Study	Sample	Method	Result
Zimmermann *et al.,* (2017)[30] 12 months follow up	60 indirect ZLS CAD/CAM Restorations.	Indirect restoration was fabricated, using CEREC method and intraoral scanning and adhesive cementation.	In this study, the success rate of indirect ZLS CAD/CAM restoration after 12 months was 96.7%. Clinically failed as a result of bulk fracture about 3.3%
Rinke *et al.,* (2020)[31] 3-year follow up	92 ZLS partial crowns (premolar and molar) on vital or sufficiently endodontically treated teeth.	Monolithic restorations of partial crowns were fabricated chairside from Celtra® Duo and adhesive cementation.	In this study, A success rate of 98% after 3 year was calculated. Apart from tooth fracture leading to failure, which result 1.2% in endodontic complication rate.
Rinke *et al.,* (2020)[32] 2-year follow up	61 ZLS partial crowns on vital premolars and molars.	Partial-crown with reduced material thickness (Minimum material thickness = 1.0 mm.) were fabricated chairside and adhesive cementation.	An overall success rate of 59 restorations participated in the 2-year follow up examinations was about 93%. There are 2 losses due to ceramic fracture.
Degidi *et al.,* (2021)[33] 2-year follow up	100 patients received a Three-unit fixed restoration on implant-supported or tooth supported.	A Three-unit fixed restoration made of monolithic, hot pressed, ZLS (Celtra® Press) was cemented.	From this study, Implant-supported or tooth supported three-unit fixed prostheses made of ZLS can be used to successfully restore cases of posterior partial edentulism.

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