Evaluation of Mechanical, Biocompatibility and Cytotoxicity of Different Monolithic Hybrid and Zirconia-Added Ceramics

Farklı Monolitik Hibrit ve Zirkonya Katkılı Seramiklerin Mekanik, Biyouyumluluk ve Sitotoksitite Değerlendirmesi

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ABSTRACT

Today advances in CAD/CAM technology have enabled the production of indirect monolithic restoration materials and increased their use in prosthodontics. CAD/CAM-formed materials that can be used monolithically include composites, feldspathic glass ceramics, leucite crystals glass ceramics, glass ceramics reinforced with lithium disilicate crystals, lithium disilicate ceramics doped with zirconia, hybrid ceramics, and zirconia. The mechanical and physical properties of restorative materials must be biocompatible with the oral environment and free of toxic substances that may cause harmful local effects or systemic reactions. Some of the expected properties of dental materials include aesthetics, ease of use, long clinical lifespan, durability, and biocompatibility. Cytotoxic substances can cause harmful tissue reactions ranging from postoperative sensitivity to irreversible pulp damage in both the short and long term. These materials should be tested in vivo or in vitro before use. This article aims to present the results of the mechanical and biological studies of monolithic hybrid and zirconia-doped ceramic materials and the biocompatibility and cytotoxicity values obtained in the materials.

Keywords: *Prosthodontics, hybrid ceramic, glass ceramic, biocompatibility, cytotoxicity*

ÖZ

Günümüz CAD/CAM teknolojisinde indirekt monolitik restorasyon materyallerinin üretimi arttırılmış ve protetik diş hekimliğinde kullanımı sağlanmıştır. Monolitik olarak kullanılan CAD/CAM ile şekillendirilen materyaller; kompozit, feldspatik cam seramik, lösit kristal cam seramikler ve lityum disilikat kristalleri ile güçlendirilen cam seramikler, zirkonya katkılı lityum disilikat seramik, hibrit seramik ve zirkonya gelmektedir. Restoratif materyallerin mekanik ve fiziksel özellikleri, ağız ortamında biyouyumlu olmalı, zararlı lokal etkilere veya sistemik reaksiyona neden olabilecek toksik maddeler içermemelidir. Dental materyallerin sahip olması beklenen bazı özellikleri; estetik, kullanımı kolay, klinik ömrü uzun, dayanıklı ve biyouyumlu olmasıdır. Sitotoksik maddeler, postoperatif hassasiyetten geri dönüşümsüz pulpa hasarına kadar uzanan kısa ve uzun vadeli zararlı doku reaksiyonlarına neden olabilir. Bu nedenle dental materyallerin kullanımından önce in vivo veya in vitro olarak test edilmesi gerekmektedir. Bu makalenin amacı, monolitik hibrit ve zirkonya katkılı seramik materyallerine uygulanan mekanik ve biyolojik özellik çalışmalarının sonuçlarına ait bulguların ve materyallerden elde edilen biyouyumluluk ve sitotoksititeye ait değerlerinin incelenerek sunulmasıdır.

Anahtar Kelimeler: *Protez, hibrit seramik, cam seramik, biyouyumluluk, sitotoksitite*

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INTRODUCTION

Due to increasing expectations of dentists and patients in restorative dentistry, ceramic materials are seen as an alternative to traditional restorative materials due to their aesthetic, mechanical, and biological properties.[1] High-quality materials have been produced and developed with the rapid development of Computer Aided Design-Computer Aided Manufacturing (CAD/CAM) technology.

With developments in CAD/CAM technology, monolithic restorations have become possible in dentistry.[2,3] CAD/CAM-shaped materials that can be used monolithically: Glass ceramics, zirconia-doped lithium disilicate ceramics, hybrid ceramics, and zirconia.[4] Newly developed hybrid and zirconia-doped ceramics are also among monolithic materials shaped with CAD/CAM.

Many metal, all-ceramic, or polymer materials have been used in dentistry. It is necessary to test the mechanical performance of materials in randomized controlled clinical trials. Therefore, preclinical testing helps to evaluate materials physically and mechanically and to determine the indications for clinical use (Table 1).

Table 1. Comparison of the mechanical and biological properties of the materials tested in this study.

HYBRID CERAMIC MATERIALS	**CONTENT**	**MANUFACTURER**
Paradigm Mz100 (PM)	85% Zirconia-silica ceramic, bis-GMA, TEDGMA	3M ESPE, Minnesota, USA
Lava Ultimate (LU)	Bis-GMA, Bis-EMA, UDMA, TEGDMA 80% ZrO□/SiO□ clusters SiO□ (20 nm) and ZrO□ (4-11 nm)	3M ESPE, Minnesota, USA
Vita Enamic (VE)	86% Feldspathic ceramic network, UDMA, TEDGMA	Vita Zahnfabrik, Bad Säckingen, Germany
Cerasmart, (CS)	71% Silica and barium, 2,2-Bis propane, UDMA, DMA	GC Dental, Tokyo, Japan
Shofu Block (SB)	61% Silica powder, zirconium silicate, and micro-clustered silica components	Shofu Dental, Ratingen, Germany
Katana Avencia (KA)	Fillers containing colloidal silica and aluminum oxide, UDMA	Kuraray Noritake, Kurashiki, Japan
Grandio Block (GB)	Bis-GMA, TEGDMA, Barium boron alumino silicate glass (0.1-2.5 µm), silica (20-60 nm)	Voco Dental, Cuxhaven, Germany
ZIRCONIA-REINFORCED LITHIUM SILICATE MATERIALS	**CONTENT**	**MANUFACTURER**
Vita Suprinity (VS)	8–12% Zirconia, 56–64% Silicon Dioxide, 15–21% Lithium Oxide	Vita Zahnfabrik, Bad Säckingen, Germany
Celtra Duo (CD)	%58 Silicon Dioxide, %5 Phosphorus Pentoxide, %1.9 Alumina, %18.5 Lithium Oxide , %10 Zirconium Dioxide	Dentsply Sirona, Erlangen, Germany

Ceramics and resin-containing composites constitute two main groups of dental prosthetic materials.[5,6] Dental ceramics are inorganic materials with a crystalline phase and/or glass matrix composition.[6] Ceramic materials have been widely used in dentistry due to their high tissue compatibility, durability, abrasion resistance, low plaque accumulation, color stability, and aesthetics.[7,8] Ceramic materials have high bending strength and elastic modulus. However, due to this property, dental ceramics do not absorb the incoming load and are less flexible and more brittle.[9]

Lithium silicate-reinforced glassceramics have been produced to develop a higher strength and fracture resistance material. This system has a much higher crystal content than leucite glass ceramics to strengthen substrate ceramic. Lithium disilicate crystals are used in 70% of material content.[10]

Zirconia-reinforced Lithium Silicate glass ceramics (ZLS) were obtained by enriching glass ceramics with approximately 10 wt% zirconia. This newly developed ceramic material, which has a homogeneous microstructure and small particle size, shows superior mechanical resistance to other glass-ceramic materials. The fracture resistance of these ceramics containing 8-12% ZrO_2 is 210 MPa after milling and increases to 420 MPa after crystallization.[11]

New alternative materials have been introduced to market that combine the favorable properties of ceramics and composites and are shaped by CAD/CAM. In 2013, ADA defined ceramics as 'pressed, fired, polished or milled materials containing many inorganic refractories such as porcelain, glass, ceramic and/or glass-ceramic'. These newly developed materials are categorized as ceramic-like materials because they contain more than 50% by weight of inorganic content and a small amount of organic phase.[12]

Resin composites are a polymer matrix reinforced with inorganic fillers (ceramic, vitreous ceramic, or glass), organic, or composite. Composite materials cause minimal abrasion to opposing tooth and are easy to handle.

Advantages of newly developed monolithic hybrid ceramic materials include less abrasion of opposing tooth tissue, less preparation, ease of repair with similar resin composites, and chemical compatibility with adhesive resin cement. It also has the same anisotropy as dentin.[13] Hybrid ceramic materials are much more durable, less brittle, and less porous than ceramics. This new generation of polymer-containing ceramics shows better bending and lower fracture resistance due to their elastic modulus being close to dentin.[14] These materials have been named under various names: Resin nanoceramics, hybrid ceramics, resin-matrix ceramics, and double-meshed materials.[12] Using hybrid ceramics in prosthodontics has increased gradually.

Mechanical and Biological Properties of Hybrid Ceramic Materials

Hybrid ceramic materials and Zirconia-reinforced Lithium Silicate glass ceramic (ZLS) materials are frequently used in prosthodontics (Table 2).

Table 2. Summary of studies included in this review.

Arthur Furtado et al. (2019).[25]	-IPS e.max CAD (IEX) -Vita Suprinity (VS) -Cerasmart (CS) -Vita Enamic (VE)	To evaluate the fracture strength of one lithium disilicate, one zirconia-doped lithium silicate, and two hybrid ceramic materials.	IPS e.max CAD (4100 N, IEX) and Vita Suprinity (3659 N, VS) materials have significantly higher fracture toughness values compared to Vita Enamic (2003 N, VE) and Cerasmart (1562 N, CS) materials.
Frank A. Spitznagel et al. (2021).[26]	-3Y-TZP -4Y-TZP -5Y-TZP -Vita Enamic (VE)	To evaluate the thermo-mechanical fatigue behavior and failure modes of three different zirconia and one hybrid ceramic material.	All tested materials showed higher failure loads (>1750 N) than normal physiological occlusal loads in the posterior region (200-900 N) and can be recommended for posterior clinical use.
N. Juntavee et al. (2020).[33]	-IPS e.max CAD (IEX) -Vita Suprinity (VS) -Y-TZP	To evaluate the influence of different tempering processes on the flexural strength of one zirconia-reinforced lithium silicate glass ceramic, one lithium disilicate ceramic and one monolithic zirconia materials.	Y-TZP indicated significantly higher flexural strength upon slow tempering (1,183.98 ± 204.26 MPa) than Vita Suprinity (VS, slow tempering: 267.15 ± 32.71 MPa) and, IPS e.max Cad (IEX, slow tempering: 392.09 ± 37.91 MPa)
T. Srichumpong et al. (2019).[34]	-IPS e.max CAD (IEX) -IPS Empress CAD (IES) -Vita Suprinity (VS) -Celtra Duo (CD)	To evaluate the fracture strength of one lithium disilicate, two zirconia-reinforced lithium silicate, and one leucite-reinforced glass-ceramic materials.	The fracture toughness of IPS e.max CAD (2.64 MPa, IEX) was the highest, and IPS Empress CAD (1.09 MPa, IES) had the lowest fracture toughness.
J.B. Monteiro et al. (2018).[35]	-Vita Suprinity (VS) -Celtra Duo (CD)	To evaluate the effect of ceramic thickness on the fatigue failure load of two zirconia-reinforced lithium silicate ceramic materials.	The ceramic thickness influenced the fatigue failure load for both zirconia-reinforced lithium silicate ceramic materials: Vita Suprinity (VS, 716 N up to 1119 N) and Celtra Duo (CD, 404 N up to 1126 N).

The Microstructure of first hybrid ceramic shaped by CAD/CAM (Paradigm Mz100, PM, 3M ESPE, Minnesota, USA) consists of 85% weight of zirconia-silica ceramic particles. Polymer matrix contains bisphenol A glycidyl methacrylate (bisGMA), triethylene glycol dimethacrylate (TEDGMA), and an initiator system.[12,15,16] This material is used in inlay, onlay, crown, and veneer restorations.[17]

Hybrid ceramic called “resin nanoceramic” by manufacturer (Lava Ultimate, LU, 3M ESPE, Minnesota, USA) consists of 80% of the weight of nanoceramic particles in a resin matrix.[12,17] This material has a modulus of elasticity equivalent to dentin and is less brittle than glass ceramics. Since they are flexible, they resist chipping and cracking during grinding.[17] Thanks to their low elastic modulus, they absorb masticatory forces better. Indications for this material are inlay, onlay, and veneer restorations.[17,18]

In the production of one of new hybrid ceramic materials currently used in prosthodontics (Vita Enamic, VE, Vita Zahnfabrik, Bad Säckingen, Germany), a pre-sintered porous feldspar ceramic is first produced. Resin is then infiltrated into this porous ceramic network by capillary action. By applying polymerization with heat, polymer forms polymer network that enables the formation of a polymer-infiltrated ceramic mesh.[19] Feldspathic ceramic network constitutes 86% of its weight. Thanks to this double network structure, crack propagation is stopped. Polymer network contains UDMA (Urethane Dimethacrylate) and TEGDMA.[12,17] The advantages of this material are low brittleness, the ability to be milled in thin areas without cracks/fractures, higher modulus of elasticity compared to conventional ceramics, the ability to mill restorations with diamond burs, and less milling time. It is used in the crown, inlay, onlay, and veneer restorations and is contraindicated in bridges and parafunctional cases.[17]

Another hybrid ceramic used (Cerasmart, CS, GC Dental, Tokyo, Japan) consists of 71% filler particles by weight and is called nano ceramic by manufacturer. Filler particles contain silica and barium, and resin matrix contains 2,2-Bis propane, UDMA, and DMA (dimethacrylate).[20] Indications are inlay, onlay, veneer, crown, and implant-supported crown restorations.

The microstructure of one of new generation hybrid ceramic restorative materials (Shofu Block, SB, Shofu Dental, Bad Ratingen, Germany) contains silica powder, zirconium silicate, and micro-clustered silica, with inorganic component constituting more than 61% by weight.[12,20] The advantages of this material are high-stress absorption due to its high elasticity and flexural strength. The flexural strength of material is more than 190 MPa. In the system of this material, two-layer blocks are available for anterior restorations, it has good light transmission and fluorescence properties, as well as easy and sustainable polishing. Due to its tooth-like light transmission and good mechanical properties, it is used in anterior and posterior restorations, implant-supported restorations, inlay, onlay, and veneer restorations.

Currently used hybrid ceramic material (Katana Avencia, KA, Kuraray Noritake, Kurashiki, Japan) is produced by compressing nano-sized fillers in a block and then impregnating with a resin monomer, polymerized by heat. Main components are fillers containing colloidal silica and aluminum oxide, polymerized resins, methacrylate monomers (urethane dimethacrylate copolymers and other methacrylate monomers), and pigments. It is used to prepare inlay, onlay, veneer, and full crown restorations.[21]

Hybrid ceramic material (Grandio Block, GB, Voco Dental, Cuxhaven, Germany), new to market, has a polymerization shrinkage of 1.57% due to its 87% nanofiller content. In this way, nanoparticles act as a network within matrix, increasing abrasion and tensile strength. Surface finishing processes are faster than other CAD/CAM materials. It does not require baking during restoration construction phase. Milling, matching, and polishing processes are more accessible. Intraoral adaptations, additions, and repairs can be applied with light polymerized restorative materials. Cementation with adhesive cement is recommended.[22]

Nowadays, using zirconia-reinforced lithium silicate glass ceramics in prosthodontics has gradually increased.

Mechanical and Biological Properties of Zirconia-Reinforced Lithium Silicate Glass Ceramic Materials

Hybrid ceramics are frequently used in prosthodontics and Zirconia-reinforced Lithium Silicate glass-ceramics (ZLS) (Table 2).

One of these materials, Vita Suprinity (VS, Vita Zahnfabrik, Bad Sackingen, Germany), is fully crystalline and in pre-crystallized form. Due to the homogeneous distribution of crystals of approximately 0.5µm in size, even fully crystallized form can be easily milled and polished. There are varieties with different degrees of translucency, including High Translucent (HT) and Translucent (T). Anterior and posterior crowns, implant crowns, veneers, inlay, and onlay restorations can be produced with these blocks.[23]

Zirconia-reinforced Lithium Silicate glass ceramic ZLS (Celtra Duo, CD, Dentsply Sirona, Erlangen, Germany) is obtained by adding 10% ZrO_2 to lithium silicate. It has properties similar to natural tooth enamel as its lithium silicate crystals correspond to the wavelength range of natural daylight, which is responsible for opalescence. This provides a significant advantage, especially for inlay and onlay restorations produced chairside.[23]

The mechanical properties of hybrid ceramics were investigated by Abdallah Awada[24] and Arthur Furtado[25], Frank A. Spitznagel[26].

Abdallah Awada et al.[24] investigated the mechanical flexural strength of four different hybrid ceramic materials (Vita Enamic, VE, Lava Ultimate, LU, Cerasmart, CS, and Paradigm MZ100 Block, PM), one feldspathic ceramic (Vitablock Mark II, VM2, Vita Zahnfabrik, Bad Säckingen, Germany) and one one leucite-reinforced glass ceramic (IPS Empress Cad, IES, Ivoclar Vivadent, Liechtenstein, Germany). Cerasmart (219 MPa, CS) and Lava Ultimate (178 MPa, LU) exhibited higher mechanical flexural strength than the other materials. As a result, it was found that newly developed hybrid ceramics exhibited high mechanical bending strength and modulus of resistance values.

Arthur Furtado et al.[25] investigated the fracture toughness of one lithium disilicate (IPS e.max CAD, IEX, Ivoclar Vivadent, Liechtenstein, Germany), one zirconia doped lithium silicate (Vita Suprinity, VS), and two hybrid ceramic (Cerasmart, CS, Vita Enamic, VE) materials. As a result, IPS e.max CAD (4100 N, IEX) and Vita Suprinity (3659 N, VS) materials were found to have significantly higher fracture toughness values compared to Vita Enamic (2003 N, VE) and Cerasmart (1562 N, CS) materials.

Frank A. Spitznagel et al.[26] investigated the thermo-mechanical fatigue behavior of three monolithic zirconia (3Y-TZP, 4Y-TZP, 5Y-TZP, Dentsply Sirona, Erlangen, Germany) and one hybrid ceramic (Vita Enamic, VE) materials. All tested materials showed failure loads (200-900 N) higher than normal physiological occlusal loads (>1750 N) in posterior region and were considered suitable for clinical use.

Biological Properties of Hybrid Ceramic Materials

The biological properties of hybrid ceramics were analyzed by Soho. A. Hassan[27], Numan Aydin[28], MA Bottino[29], Kyoung K. Him[30], and Miriam Zaccaro Scelzan[31] (Table 3).

Table 3. Summary of studies included in this review.

AUTHORS (Year)	MATERIALS	OBJECTIVE	CONCLUSION
Soho. A. Hassan et al. (2022).[27]	-Brilliant Crios (BC) -Cerasmart (CS) -Vita Enamic (VE)	To investigate the biocompatibility of three different hybrid ceramic materials.	Brilliant Crios (278.1 CFU/ml, BC) showed the highest value, followed by Cerasmart (105.1 CFU/ml, CS) and Vita Enamic (102 CFU/ml, VE).
Numan Aydin et al. (2020).[28]	-Brilliant Crios (BC) -Cerasmart (CS) -Vita Enamic (VE) -Celtra Duo (CD) -Grandio Block (GB)	To investigate the cytotoxic effect of four different hybrid and zirconia-reinforced lithium silicate ceramic materials on human gingival keratinocyte cells.	Vita Enamic (102%, VE) provided the highest cell viability; Brilliant Crios (71.3%, BC) and Celtra Duo (73.5%, CD) exhibited minimal cell viability.
MA Bottino et al. (2019).[29]	-Vita Enamic (VE) -Y-TZP	To investigate the biofilm formation and cell viability of one hybrid and one Yttrium-stabilized Tetragonal Zirconia ceramic materials.	Vita Enamic (95.06%, VE) and Y-TZP (90.53%) exhibited similar biofilm formation.
Kyoung K. Him et al. (2017).[30]	-Vita Enamic (VE) -Lava Ultimate (LU) -VitaBlock Mark II (VM2) -Wieland-Reflex (WF)	To investigate the effect of surface treatment of two different hybrids, one leucite-reinforced glass and one nano-leucite-reinforced glass ceramic material, on biofilm formation.	Surface treatment promoted significantly more biofilm formation in Lava Ultimate (216.5, LU), Vita Enamic (168, VE), and Wieland Reflex (183.5, WF), while Vitablock Mark II (92.5, VM2) did not affect biofilm formation.
Miriam Zaccaro Scelzan et al. (2018).[31]	-Vita Enamic (VE) -Lava Ultimate (LU) -Vita AC-12 (VA12) -InSync (ISC)	To investigate the cytotoxicity of two different hybrids and two different glass ceramic materials.	Vita Enamic (VE) and Lava Ultimate (LU) materials showed better biocompatibility than Vita AC-12 (VA12) and InSync (ISC) materials at the 24-hour extraction time points.
De Luca Pedro et al. (2018).[38]	-Vita Suprinity (VS) -Y-TZP	To investigate the biocompatibility of two different zirconia-reinforced lithium silicate ceramic materials.	Only crystallized Vita Suprinity (4.00 cells/cm², VS) showed significantly higher proliferation compared to Y-TZP (2.5 cells/cm²).
Mohamed Mahmoud Abdalla et al. (2021).[39]	-Vitablocks TriLuxe Forte (VTF) -IPS e.max Press (IEP) -Vita Suprinity (VS)	To investigate the effect of polishing on surface roughness and biofilm formation on one feldspathic ceramic, one lithium disilicate glass-ceramic and one zirconia-doped lithium silicate ceramic materials.	The polished samples of Vita Suprinity (VE, 9.24%) had a significantly lower percentage of biofilm coating than Vitablocks TriLuxe Forte (68.27%, VTF) and IPS e.max Press (30.83%, IEP).
Rizo-Gorrita et al. (2018).[40]	-Y-TZP -Celtra Duo (CD)	To investigate the biofilm formation of one Y-TZP and one zirconia-reinforced lithium silicate ceramic materials.	Y-TZP (68.90 ± 49.02 cells/cm²) exhibited better cellular proliferation than Celtra Duo (CD, 34.55±17.52 cells/cm²).

Soho A. Hassan et al.[27] examined surface roughness, biofilm formation, cytotoxicity, and genotoxicity of three different hybrid ceramic materials (Brilliant Crios, BC, Cerasmart, CS, and Vita Enamic, VE). They performed an MTT test for cytotoxicity evaluation. It was reported that materials showed different values in terms of cytotoxicity. Brilliant Crios (278.1 CFU/ml, BC) showed the highest value, followed by Cerasmart (105.1 CFU/ml, CS) and Vita Enamic (102 CFU/ml, VE). Therefore, Vita Enamic was considered the most biocompatible material among tested materials.

Numan Aydın et al.[28] aimed to investigate the cytotoxic effect of four different hybrid (Brilliant Crios, BC, Cerasmart, CS, Vita Enamic, VE, Grandio Blocks, GB, and Zirconia reinforced lithium silicate containing (Celtra Duo, CD) ceramics on human gingival keratinocyte cells in vitro and incubated prepared samples for 1, 3 and 7 days. The cell viability of samples was analyzed by MTT assay. As a result, materials showed 100% cell viability at the end of the first day. On day 3, cell viability decreased, but no significant difference was found. Vita Enamic showed 100% cell viability at all time points. Brilliant Crios (71.3%, BC) and Celtra Duo (73.5%, CD) showed a statistically significant difference in cell viability on day 7. Among materials, Vita Enamic (102%, VE) provided the highest cell viability, while Brilliant Crios (71.3%, BC) and Celtra Duo (73.5%, CD) exhibited minimal cell viability.

Bottino et al.[29] aimed to investigate the biofilm formation of one hybrid ceramic (Vita Enamic, VE) and one Yttrium-stabilized Tetragonal Zirconia Polycrystalline (Y-TZP) material and found that Vita Enamic (95.06%, VE) and Y-TZP (90.53%) exhibited similar biofilm formation. Both Vita Enamic and Y-TZP are recommended materials for indirect dental restorations and were found to be non-cytotoxic.

Kyoung K. Him et al.[30] aimed to investigate the effect of surface treatment of two different hybrid ceramic materials (Vita Enamic, VE and Lava Ultimate, LU), one leucite-reinforced glass ceramic (VitaBlock Mark II, VM2) and one nano-leucite-reinforced glass ceramic (Wieland Reflex, WF, Wieland Dental, Pforzheim, Germany) on biofilm formation. There were two groups in total; the first group was surface-treated with disks of different sizes, while the second group did not receive any surface treatment. Results showed that surface treatment promoted significantly more biofilm formation (Lava Ultimate = 216.5, LU, Vita Enamic = 168, VE, and Wieland Reflex = 183.5, WF), while Vitablock Mark II (92.5, VM2) did not affect biofilm formation. As a result of surface treatment, the highest biofilm formation was found in Lava Ultimate (LU).

Miriam Zaccaro Scelza et al.[31] compared the cytotoxicity of two different hybrids (Vita Enamic, VE and Lava Ultimate, LU) and two different glass ceramic (Vita AC-12, VA12, Vita Zahnfabrik, Bad Säckingen, Germany and InSync, ISC, Jensen Dental, North Haven, USA) materials. Samples of each material were prepared by incubation for 1, 7, and 40 days. Human gingival fibroblasts were exposed to these samples, and cell viability was assessed by mitochondrial activity (XTT) assay. In XTT test, Vita Enamic (VE) and Lava Ultimate (LU) materials showed better biocompatibility than Vita AC-12 (VA12) and InSync (ISC) materials at 24-hour extraction time points, and the clinical use of these restorative materials was evaluated positively.

Mechanical properties of zirconia-reinforced lithium silicate glass-ceramics have been studied by C. Liu[32], N. Juntavee[33], T. Srichumpong[34], J.B. Monteiro[35], R. Ottoni[36], and Fernando Zarone[37].

N. Juntavee et al.[33] evaluated the effect of thermal tempering procedures on the mechanical flexural strength of a Yttrium-stabilized Tetragonal Zirconia Polycrystalline (Y-TZP), a zirconia-reinforced lithium silicate glass ceramic (Vita Suprinity, VS) and a lithium disilicate ceramic (IPS e.max Cad, IE) material. As a result of the study, it was found that while slow thermal tempering of monolithic Y-TZP (slow tempering: 1,183.98 ± 204.26 MPa, normal tempering: 1,084.43 ± 204.79 MPa, fast tempering: 777.19 ± 99.77 MPa) increased the mechanical flexural strength, the strengthening of Vita Suprinity (VS) (slow tempering: 267.15 ± 32.71 MPa, normal tempering: 218.43 ± 38. 46 MPa, fast tempering: 252.67 ± 37.58 MPa) and IPS e.max Cad (slow tempering: 392.09 ± 37.91 MPa, normal tempering: 378.88 ± 55.38, fast tempering: 390.94 ± 25.34 MPa) cannot be achieved by tempering process; therefore, slow, normal, or fast tempering procedures can be applied.

T. Srichumpong et al.[34] investigated the fracture toughness of one lithium disilicate ceramic (IPS e.max Cad, IEX), one leucite-reinforced glass-ceramic (IPS Empress Cad, IES), and two zirconia reinforced lithium silicate glass ceramic (Vita Suprinity, VS and Celtra Duo, CD) materials. As a result, the fracture toughness of IPS e.max CAD (2.64 MPa, IEX) was significantly higher than other materials, and IPS Empress CAD (1.09 MPa, IES) had the lowest fracture toughness. Based on the data obtained, tested restorative dental materials were found to be suitable for clinical use.

J.B. Monteiro et al.[35] evaluated the fatigue strength of two zirconia-reinforced lithium silicate glass ceramic materials (Vita Suprinity, VS and Celtra Duo, CD) at different thicknesses. Vita Suprinity (1 mm: 716.5 ± 95.5 N, 1.5 mm: 907.5 ± 34.5 N, 2 mm: 959.5 ± 81.8 N, 2.5 mm: 1119.6 ± 241.7 N, VS) and Celtra Duo (1 mm: 404.0 ± 43.3 N, 1.5 mm: 628.1 ± 79.6 N, 2 mm: 764.5 ± 43.9 N, 2.5 mm: 1126.8 ± 80.2 N, CD) exhibited higher fatigue strength compared to CD. In conclusion, it was found that different microstructures of zirconia-reinforced lithium silicate glass ceramics can affect the fatigue behavior of restorations.

Biological Properties of Zirconia-Reinforced Lithium Silicate Glass Ceramic Materials

The biological properties of zirconia-reinforced lithium silicate glass ceramics were investigated by P.G. De Luca[38], Numan Aydın[28], Mohamed Mahmoud Abdalla[39], and M. Rizo-Gorrita[40] (Table 3).

De Luca Pedro et al.[38] evaluated the biocompatibility of zirconia-containing lithium silicate (Vita Suprinity, VS) polished at different stages with human gingival fibroblasts in vitro, and the results were tested using cell proliferation and viability of Yttrium-stabilized Tetragonal Zirconia Polycrystalline (Y-TZP). Polishing the surface of Vita Suprinity before crystallization was found to promote cell proliferation. Only crystallized Vita Suprinity (4.00 cells/cm², VS) showed significantly higher proliferation compared to Y-TZP (2.5 cells/cm²).

Mohamed Mahmoud Abdalla et al.[39] investigated the effect of polishing on surface roughness and biofilm formation on feldspathic ceramic (Vitablocks TriLuxe Forte, VTF, Vita Zahnfabrik, Bad Sackingen, Germany), lithium disilicate glass-ceramic (IPS e.max Press, IEP), and zirconia doped lithium silicate (Vita Suprinity, VS) ceramic blocks. They found that for Vitablocks TriLuxe Forte (roughened: 81.55%, polished: 68.27%, VTF), IPS e.max Press (roughened: 68.27%, polished: 30.83%, IEP), and Vita Suprinity (roughened: 31.25%, polished: 9.24%, VS), the mean percentage of living bacteria and biofilm coverage of substrate was significantly higher for roughened ceramic blocks than for polished blocks. The polished samples of Vita Suprinity (9.24%) were reported to have a considerably lower percentage of biofilm coating than the other groups.

In their study, Rizo-Gorrita et al.[40] evaluated morphology, biofilm formation, and fibroblast viability using MTT assay of human gingival fibroblasts in contact with Yttria-stabilized Tetragonal Zirconia Polycrystal (Y-TZP, Vita YZ® T) and lithium silicate reinforced with zirconium (Celtra Duo, CD) treated with two different finishing techniques, either polishing or glazing. The study results revealed that Y-TZP (68.90 ± 49.02 cells/cm²) exhibited better cellular proliferation than Celtra Duo (34.55 ± 17.52 cells/cm²).

Restorative materials' mechanical and physical properties must be biocompatible in both hard and soft oral environments. These restorative materials should not contain toxic substances that can cause harmful local effects or systemic reactions. Cytotoxic substances can lead to short- and long-term adverse tissue reactions, ranging from postoperative sensitivity to irreversible pulp damage. Therefore, these materials must be tested before use in vivo or in vitro.

Biocompatibility is condition that a material in direct or indirect contact with living tissues has inert (non-reactive) properties that do not cause local or systemic toxicity, allergic reaction, and mutagenic or carcinogenic effects, thus can create an appropriate biological response in applied area. Non-biocompatible materials develop adverse tissue reactions, considered 'toxicity'.[41,42]

The components released from the material's structure and their effects at cellular level allow us to evaluate biocompatibility. For a material to be considered biocompatible, there must be compatibility between the host, material, and the function of material. Biological response can change over time depending on the interaction among these three factors. Therefore, biocompatibility is a dynamic process.[43]

Variation in biological response is related to whether material is in direct contact with blood, saliva, gingival crevicular fluid, or the distance between the pulp and enamel-dentin thickness.[42,44] Potential side effects a dental material might cause in the body are monitored before and after it is released to market. Before being released, it is evaluated for local and systemic side effects. Local side effects may include mucosal and pulpal toxicity, while systemic side effects may include allergic, mutagenic, estrogenic, and toxic reactions. Materials that are evaluated and deemed biocompatible regarding local and systemic side effects continue to be assessed for long-term side effects even after being introduced to market.[45]

Some expected characteristics of dental materials include aesthetic, biocompatible, easy to use, durable, and extended clinical lifespan. The biocompatibility of materials depends on several factors, such as surface properties, the structure and amount of monomers released from material, the chemical and physical properties of its components, the type and location of tissues that will contact material, and the duration of exposure. As a result of contact between dental materials and intraoral tissues, such as enamel, dentin, pulp, gingiva, tongue, cheeks, and lips, cytotoxic, genotoxic, allergic, or inflammatory reactions can develop.

In determining biocompatibility, a test method that is simple, standardized, and provides quick results should be preferred.[42] Sequentially, in vitro (primary) tests, animal experiments (secondary tests), and clinical trials in humans (usage tests) are conducted.[43,46,47]

CONCLUSION

Data on mechanical and biological studies of hybrid and zirconia-doped lithium silicate ceramic materials are presented below.

1. In the mechanical bending strength studies, Cerasmart (CS) and Lava Ultimate (LU), hybrid ceramic materials, and in the other study, YTZP, lithium disilicate ceramic materials were found to have higher bending strength.

2. Fracture toughness values of IPS e.max CAD (IEX) were higher than hybrid ceramic materials, and IPS e.max CAD (IEX) was higher than glass and zirconia-doped lithium silicate materials in the other study.
3. In fatigue failure load studies, YTZP and hybrid ceramic Vita Enamic (VE) showed similar results, while in the other study, Celtra Duo (CD) showed higher fatigue failure load values than Vita Suprinity (VS).
4. In biocompatibility studies, the Brilliont Crios (BC) material was compared with hybrid ceramic materials. It showed better biocompatibility than Vita Enamic (VE) and Cerasmart (CS), while in another study, Vita Enamic (VE) was compared with different ceramic materials and showed higher biocompatibility than Cerasmart (CS) Grandio Block (GB), Brilliont Crios (BC) and Celtra Duo (CD). Vita Enamic (VE) and Lava Ultimate (LU) was compared with glass ceramic materials and showed better biocompatibility values than Vita AC-12 (VA12) and InSync (ISC). In another study, Vita Suprinity (VS) material was compared with YTZP, and a higher biocompatibility value was determined than YTZP. Another biocompatibility study reported better biocompatibility values for YTZP material than Celtra Duo (CD) zirconia-doped lithium silicate ceramic material.
5. In biofilm formation studies, Vita Enamic (VE) and YTZP showed similar biofilm formation values. In contrast, Lava Ultimate (LU) showed higher biofilm formation values than Vita Enamic (VE), VitaBlock Mark II (VM2), and Wieland-Reflex (WF) when compared to hybrid and glass ceramic materials. In another study, Vitablock Triluxe Forte (VTF) showed higher biofilm formation than IPS e.max Press (IEP) glass and Vita Suprinity (VS) zirconia doped lithium silicate ceramic materials.

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