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Translucent Zirconia: Modifications and Current Classifications – A Review

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ABSTRACT

Zirconia ceramics have undergone several modifications to improve its optical properties which expanded its indication in many clinical scenarios. Newer generations of zirconia with higher translucency and multi-layer configuration combined with high strength and biocompatibility are being developed continuously in the market. Optical properties of zirconia particularly translucency can be improved through several modifications' techniques that utilise the understanding of its isotropic and polymorphism attributes. Various types of zirconia are now available in the market which can be classified into different parameters for selection and further aid clinicians in making accurate clinical decision making. The expanded clinical application of zirconia ceramics has been facilitated by advancements in their translucency. This progress stems from an enhanced comprehension of zirconia's intrinsic properties, which has enabled the development of innovative approaches to improve its transparency and aesthetic characteristics.

1. INTRODUCTION

An ideal restorative dental ceramic material should possess both excellent mechanical and optical properties to replicate the native tooth structure. However, current dental ceramics in the market often fall short of meeting all clinical needs. Therefore, the primary goal in developing dental ceramics is to create materials

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that are both highly aesthetic and durable. Aesthetic parameters commonly discussed in the literature include colour and shade, translucency, refractive index, and contrast ratio. Meanwhile, mechanical properties such as flexural strength, fracture toughness, and resistance to crack propagation under functional and parafunctional loading are equally important (Zarone et al., 2011). The most common dental ceramics available in the market are silica-, leucite-, lithium disilicate-, alumina-, and much more recently zirconia-based materials (Bona et al., 2015). Lithium disilicate has shown the best aesthetic characteristics that can mimic natural tooth structure optical properties. Unfortunately, its uses are still limited mostly in the non-load bearing region as clinically it has shown lower mechanical performance in the posterior region and in the long-span fixed dental prostheses (FDPs). This has resulted in the increased adoption of zirconia-based restorations due to their remarkable mechanical strength and fracture toughness. Nevertheless, zirconia was originally formulated as a white, opaque material, which limited its use in anterior restorations where aesthetic considerations are paramount.

Zirconia is an oxide of zirconium that has been used in gems and jewellery since early times. Its name was obtained from the Arabic term "*Zargun*", which was derived from the Persian words "*Zar*" (Gold) and "*Gun*" (Color) meaning "Golden Colour" (Piconi & Maccauro, 1999). It was first introduced in medicine in 1969 as a substitute material for titanium and alumina in hip replacement therapy (Manicone et al., 2007). The term "ceramic steel" was coined to describe this material as having excellent mechanical properties in addition to good biocompatibility, and favourable wear properties (Bona et al., 2015). Zirconia exhibits the highest strength and durability among dental ceramics, outperforming materials like lithium disilicate and alumina. Compared to lithium disilicate, which is known for its excellent aesthetics but relatively lower strength, and alumina, which offers good strength but lacks translucency, zirconia provides a unique combination of mechanical robustness and modifiable optical properties. Its superior mechanical properties include high flexural strength and fracture toughness, making it ideal for high-stress areas for dental restorations. However, its uses have always been limited to mainly at posterior region initially due to the opacity of the materials, and adhesion was also deemed as a major issue due to inertness to etching by hydrofluoric acid with concentration between 4-10% (Baldissara et al., 2010; Rinke & Fischer, 2013). Advances in zirconia technology have also improved its translucency, expanding its use to both anterior and posterior restorations, thus offering a versatile solution for various clinical scenarios**.**

In general, both optimum strength and translucency are difficult to observe in a single type of dental material. Balancing between different parameters often leads to compromises; materials with higher translucency typically have lower mechanical strength (F. Zhang et al., 2019). Dental ceramics must possess a certain degree of translucency to replicate the optical properties of natural tooth structures by allowing the transmission and reflection of light, thus providing a lifelike appearance to restorations (Carrabba et al., 2017). This optical phenomenon, perceived through human colour perception, involves a complex interaction between the light source, the object receiving the light, and the observer's characteristics (Burkinshaw, 2004). Modifying the composition of dental ceramics ultimately changes these interactions by altering the way light interacts with the materials, enhancing or diminishing their optical properties. This alteration in optical properties can also affect the material's strength and toughness, demonstrating the interconnected nature of dental ceramics' mechanical and aesthetic characteristics. A common approach in creating biomimetic prostheses involves veneering translucent ceramics, such as feldspathic porcelain and lithium disilicate, over zirconia to enhance the overall mechanical strength of the prosthesis. Frequent chipping of veneering ceramics, due to differences in thermal expansion and flexural strength between ceramic layers, has led to the development of monolithic and fully contoured ceramics, especially zirconia, along with more translucent variations of zirconia (Roscoe et al., 2020).

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2. OVERVIEW OF ZIRCONIA

Zirconium (Zr) in its pure form is a soft, lustrous, ductile, silvery metal and mostly found in abundance in the earth's crust either in silicate or oxide form. The commonly used type of zirconium, zirconium dioxide (ZrO_2) or zirconia is derived after undergoing rigorous processing and refinement which produces white, high-fusing crystalline powder (Stawarczyk et al., 2017). The powder is then packed into a specific blank shape usually in the form of discs or blocks. It will be milled using CAD/CAM machinery into an oversized prosthesis to compensate for the expected shrinkage during the sintering process. After milling of zirconia blanks to the required prosthesis shape, it will undergo a final sintering process to reach the fully sintered stage of the ceramic before being delivered to the patients. Another type of milling process for zirconia can be done through grounding fully sintered zirconia blocks which have better initial mechanical properties with drawbacks of higher processing cost due to bur wear rate and long processing duration. (Stawarczyk et al., 2012, 2017).

Zirconia is characterized by polymorphism and allotropic features as it can exist naturally in three different principal phases at different temperatures (Zarone et al., 2019). The multi-phase configurations: monoclinic (*m*), tetragonal (*t*), and cubic (*c*), can only be fully appreciated during the manufacturing process of the zirconia. During the melting stages of the zirconia, at above 2370º C, the cubic phases of zirconia will start to crystallize first before transforming into tetragonal phases as it cools down until 1170º C, and subsequently into the monoclinic phase as it further cools down from 1052º C to room temperature (Zhang & Lawn, 2018). The transformation of the tetragonal to monoclinic phase is characterized by martensitic transformation, which is accompanied by approximately 5% volume expansion. This led to the development of high internal stress and undesirable cracks that may influence the strength of the ceramics (Stawarczyk et al., 2017). This phenomenon however can be prevented by stabilizing the zirconia in a metastable state of tetragonal or cubic phase at room temperature which otherwise can't be achieved naturally. Stabilization can be achieved primarily by the addition of doping agents most commonly yttria (Y_2O_3) or other types of metal oxide such as magnesia (MgO), calcia (CaO), and ceria (CeO) (Giordano, 2022).

Zirconia can be stabilized at room temperature using at least 3 mol% of yttria, which renders its polycrystalline structure to be made up of almost 100% tetragonal phase and known as 3 mol% yttria tetragonal zirconia polycrystal (3Y-TZP) (Ban, 2021). Due to the optical limitation of 3Y-TZP zirconia despite exhibiting high durability, zirconia can be further stabilized with a higher amount of yttria up to 6 mol% of concentration, increasing the cubic phase content in the crystal lattice, making it more translucent. The partially stabilized zirconia with higher yttria content with higher content of cubic phase is often referred to as fully stabilized zirconia (FSZ) or cubic zirconia (Baldissara et al., 2018; F. Zhang et al., 2020a). At metastable state, tetragonal zirconia is subjected to volumetric expansion of 3% which may be induced by mechanical and/or thermal stresses that still allow tetragonal-monoclinic phase conversion. This is explained by the tendency for trapped energy within the crystal to drive back the conversion of the tetragonal grain to the monoclinic phase (Bona et al., 2015). However, this increase in volume negates the crack propagation by exerting local compressive stress at the tip of the cracks which limits the crack growth and resists the catastrophic fracture of the ceramic (Darvell, 2018). The phenomenon is termed as Phase Transformation Toughening (PTT) which provides zirconia self-repairability characteristics up to a certain point if a crack already exists in the ceramic itself (Zarone et al., 2019). FSZ zirconia which contains a majority of cubic phase does not undergo PTT and may behave differently in terms of physical and mechanical properties with much lesser fracture toughness and flexural strength (Elsaka, 2019; Flinn et al., 2017; Kwon et al., 2018). Higher content of cubic phase in zirconia microstructure is translated into much higher translucency as it allows light to be emitted equally in all directions compared to zirconia with higher tetragonal phase content (Stawarczyk et al., 2017).

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Zirconia ceramics undergoes an ageing process spontaneously and gradually from a metastable tetragonal phase to a monoclinic phase, but this transformation, however, occurs in the absence of initial local stress at the tip of the advancing crack (Lughi & Sergo, 2010). This phenomenon is known as low-temperature degradation (LTD) and may be exacerbated by high humidity and warm environment in addition to the presence of stress which can be commonly found in challenging environments of the oral cavity (Chevalier et al., 2009). The process initiated on the surface of zirconia, progressively extends deeper into the bulk of the ceramics and at the same time is infiltrated with water molecules (Chevalier et al., 1999). The existence of water later causes lattice contractions, leading to the accumulation of tensile stress on the surface of zirconia grains, thereby resulting in the transformation of tetragonal zirconia into the monoclinic state. This transformation involves grain pull-out and surface elevations, which leads to the formation of microcracks which in turn, facilitate the diffusion of water, causing the entire process to gradually spread throughout the bulk of the material (Deville et al., 2006). Microcracks, surface roughening and reduction in mechanical strength can be observed due to the LTD mechanism (Muñoz-Tabares et al., 2011; Nakamura et al., 2015; Roy et al., 2007). Zirconia resistance against LTD can be influenced by the alumina and silicate content, grain size, yttria concentration, cubic phase content and residual stress (Deville et al., 2006; Hallmann et al., 2012; Inokoshi et al., 2014; Samodurova et al., 2015).

3. IMPROVING ZIRCONIA OPTICAL PROPERTIES

The opaque appearance of zirconia ceramics remains a major obstacle for it to be used in aesthetic zones in the mouth, particularly in the anterior region. The optical property is attributed to the interactions between the grain in the zirconia crystal lattice and the light wavelength which lead to a differential refractive index (Ghodsi & Jafarian, 2018). Zirconia translucency is highly dependent on the composition and concentration of additives, grain size, sintering parameters, and amount of porosity inside the microstructure of zirconia crystal (Fathy et al., 2021). Many endeavours have been made to improve the aesthetic appearance of zirconia by matching its optical property closer to the natural teeth or at least to lithium disilicate ceramics.

One of the most common methods to improve translucency is by increasing the concentration of yttria as a doping agent which results in the increase of cubic phase content in zirconia. 3Y-TZP zirconia with 3% mole of yttria or 5.18%wt, contains 90% or more tetragonal phase which contributes to its opaqueness. Tetragonal grains exhibit birefringent optical behaviours or anisotropic in which it has different crystallographic orientations for light to pass through (Klimke et al., 2011). This is reflected in higher values of refractive index as light propagation shows discontinuity in grain boundaries resulting in less transmission of light therefore the opaqueness of 3Y-TZP zirconia. By increasing cubic phase content through the addition of 4-5% and up to 8% of yttria concentration, the translucency of zirconia shows marked improvement. In contrast to tetragonal grain, cubic grain is optically isotropic in which there are no light scattering effects contributing to higher translucency as light can be transmitted through it (Harada et al., 2016; Putra et al., 2017; F. Zhang et al., 2016). Zirconia is fully stabilized in the single-phase cubic form at 8% yttria content, while at 4-5% yttria, it becomes partially stabilized with both tetragonal and cubic phases, predominantly cubic at over 50% (Zhang, 2014a).

Modification of impurities particularly alumina is also part of the modalities in increasing the translucency of zirconia. Alumina was originally added during the manufacturing process of the green state of zirconia aiming to co-stabilize tetragonal zirconia along with yttria and to reduce pore formation (Kwon et al., 2018). Oxygen spaces between zirconia grain contribute to the pore formation and reduce the translucency by increasing light scattering especially when its size is equal to the spectral light wavelength (~0.4 µm to 0.7 µm) (Anselmi-Tamburini et al., 2007; Shahmiri et al., 2018). Amplification of light scattering due to the porosity also occurred due to the stark difference in refractive index between air and zirconia with ($n=1$) and ($n=2.1$-2.2) respectively (Vagkopoulou et al., 2009). However, alumina also

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inadvertently reduced the translucency by amplifying the light scattering effect that occurred at alumina-zirconia grain boundaries. (Zhang et al., 2012).

The reduction of alumina content with the addition of co-stabilizing agents such as lanthanum oxide allows for more translucent zirconia without compromising the mechanical properties of the ceramics (Harada et al., 2016). Duration and number of sintering cycles can also be adjusted to reduce the unwanted side effect of reducing alumina content in the zirconia (Catramby et al., 2021a; Stawarczyk et al., 2013a, 2014).

Manipulation of grain size of zirconia ceramics is also able to affect the translucency of the ceramics. The relationship between grain size and light wavelength size is well established in terms of the light scattering effect as the closer the size of the grain to the light wavelength, the more the light scattering effect will be observed impacting the translucency (Pekkan et al., 2020). The change in the grain size of the polycrystalline structure of zirconia beyond this continuum will influence the behaviour of light transmission (Y. Zhang, 2014b). In addition, the critical grain size of 0.6 µm is required in stabilizing tetragonal zirconia to its ideal surface energy requirement, with size ranging between 0.9 µm to 1.4 µm has shown high mechanical strength from 650 MPa to 1000 MPa (Anusavice, 2021; Shahmiri et al., 2018). Initially, the preferred method to improve the translucency was by increasing the grain size which reduces the interaction between propagated light with the grain boundaries and promotes more light diffuse transmission (Apetz & Van Bruggen, 2003). However, this modification results in spontaneous conversion of tetragonal to monoclinic phase resulting in decreased resistance towards LTD and lower fracture strength. The more effective method then is by reducing the grain size which allows for higher in-line light transmission and, therefore, higher translucency (Xiong et al., 2014). Reducing the grain size down to 0.082 µm produces translucency close to feldspathic porcelain although this is dependent on the thickness of the material (Zhang et al., 2012).

Another possible method that has been proposed to improve the translucency and overall aesthetic and strength of zirconia is through modifications of the sintering parameters. Different zirconia ceramics are unique in their composition; therefore, each manufacturer may have different instructions for the sintering process. The sintering temperature may be increased up to a certain level to improve the translucency by increasing the grain size of zirconia consequently reducing the light reflection and scattering effect at the grain boundaries (Denry & Kelly, 2014; Zhang, 2014b). A critical temperature of 1550º C has been suggested and corroborated by a few studies which confirmed that increasing the temperature beyond 1660º C may have a detrimental effect on flexural strength and final translucency (Catramby et al., 2021b; Jiang et al., 2011; Zhang, 2014b). Above this temperature, any increase in grain size will result in the formation of pores within the zirconia microstructure, which will impact its final translucency (Stawarczyk et al., 2013b). Additionally, exceeding the grain size threshold for spontaneous phase transformation of tetragonal to monoclinic phase will result in the reduction of strength and compromised hydrothermal stability (Bravo-Leon et al., 2002). The temperature and holding time of the sintering cycle can also be extended without any adverse effects on the strength, phase transformations, or surface roughness of the materials (Ebeid et al., 2014). Kim and colleagues found that a shorter duration of sintering from 40 hours to 20 minutes in the speed sintering technique reduces the zirconia grain size which increases the amount of visible light to be transmitted through the zirconia (Kim et al., 2013). Nonetheless, this could potentially influence the tribological characteristic of the materials, resulting in increased volume loss compared to its conventional counterpart, which can, in turn, have an impact on the eventual translucency of the material over time (Kaizer et al., 2017).

Fabrication of multi-layered zirconia blanks by layering zirconia with different translucency is one of the more recent ways to optimize both the optical and mechanical strength of newer translucent zirconia (Ueda et al., 2015). This can be achieved either through the incorporation of additional dye pigment and

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co-doping agents into one single blank or layering it with a mixture of different generations of zirconia. This layering effect is aimed to mimic the natural gradient of tooth structure based on its translucency: where the highest translucency is observed in the incisal region and further decreased down to the cervical region with increased chroma at the same time. The high cubic fraction in the enamel layer contributes to higher translucency compared to that in the dentine layer and is dependent on the yttria content on each layer.

A single blank of zirconia can be incorporated with colouring pigments as a co-doping agent using metal oxides such as Erbium (III) oxide (Er_2O_3), Cerium (IV) oxide (CeO_2), Ferric oxide (Fe_2O_3), Manganese dioxide (MnO_2), and Praseodymium oxide (P_6O_{11}).(Huang et al., 2007; Shah et al., 2008) The addition of these metal oxides affects its optical characteristic in terms of translucency in hue and brightness at different layers producing different shades to mimic the effect of tooth structure and layered ceramics.(Elsaka, 2019; Kaya, 2013; Pecho et al., 2012; Wen et al., 2007; Yi et al., 2008) Polychromatic zirconia also can be fabricated with layering using zirconia with different amount percentages of yttria. This is to capitalize the advantages of both generations, by layering zirconia of higher yttria content at the incisal level for higher translucency and lower amount of yttria at dentinal layer with higher mechanical properties. (Inokoshi et al., 2023; Kolakarnprasert et al., 2019) Fully stabilized multi-layered block zirconia has shown higher translucency parameters and lower contrast ratio compared to monolithic monolayer zirconia block (Elsaka, 2019). Nevertheless, an in-vitro study has shown that in a partially stabilized 5Y-PSZ multilayered block, its translucency may be no different from the 4Y-PSZ multilayered blocks (Kolakarnprasert et al., 2019).

4. OPTICAL & MECHANICAL TRADE-OFF IN TRANSLUCENT ZIRCONIA

Optical improvement of zirconia ceramics changes the overall microstructure and composition that influence other material properties such as flexural strength, fracture toughness, and hydrothermal stability (Inokoshi et al., 2018; Kolakarnprasert et al., 2019; Zhang et al., 2020b). These factors, in turn, can significantly affect the clinical performance of zirconia in an oral environment (Inokoshi et al., 2018). There is a trade-off between mechanical and optical characteristics in zirconia as yttria concentration increases. 4Y and 5Y-PSZ zirconia contain higher cubic-phase content and exhibit more translucency compared to 3Y-TZP zirconia but with much-reduced strength due to the absence of the PTT process that is evident in tetragonal zirconia (Zhang et al., 2019). Without this process, the lack of volume expansion that typically occurs during the initial transformation of the tetragonal to monoclinic phase, leads to a decreased level of compressive stress at the tip of the inner crack site which is important in preventing the progression of the inner crack growth mechanism.(Pereira et al., 2018) Various lab studies have shown zirconia with higher cubic phase content possess lower mechanical strength and do not benefit from the conversion of tetragonal to monoclinic in PTT that provides the increase in strength and toughness when subjected to air particle abrasion surface conditioning.

Increasing the concentration of yttria content to produce more translucent zirconia introduces more cubic phase in its microstructure with a lesser amount of tetragonal phase. This brings changes to overall physical and mechanical properties compared to 3Y-TZP zirconia as cubic phase zirconia is optically isotropic and resistant towards low thermal degradation (Camposilvan et al., 2018). The tetragonal phase in the high translucent zirconia loses its tetragonality in higher yttria concentration to match the cubic phase in unimodal microstructure therefore exhibiting higher translucency and resistance towards hydrothermal aging (Zhang et al., 2020a). However, some studies found a possible relationship between high cubic phase content and a reduction in the resistance of zirconia towards low thermal degradation (Chevalier et al., 2004, 2009). The group suggested that it may be contributed by the conversion of the less stable tetragonal grain in the boundaries to the monoclinic phase that occurs during the typical hydrothermal ageing process instead of during the sintering procedure.

Another technique in improving the appearance of zirconia is the application of glazing liquid prior to the sintering process to ensure a smooth surface and to mimic the surface texture of a natural tooth. It has been shown in laboratory studies that glazing reduces the flexural strength of ceramics even though it provides resistance towards low thermal degradation (Hjerppe et al., 2010; Lai et al., 2017; Salihoglu Yener et al., 2015). The presence of the pigments in the layering of zirconia also may have different impacts on the mechanical and physical properties of the zirconia ceramics (Inokoshi et al., 2018). Several studies suggest no effect on the overall strength of the pigment-coloured zirconia compared to non-colored specimens in addition to no significant effect on the thermal stability of the zirconia (Kaya, 2013; Nakamura et al., 2016; Sedda et al., 2015). However, Shah and colleagues found that the increasing concentration of metallic salts as a co-doping agent may reduce the flexural strength of zirconia contributed by the possible presence of porosity at the grain boundaries (Shah et al., 2008). Combining zirconia with varying yttria concentrations and types into a single puck or disc may also create interfacial defects that could weaken the interfaces between the chromatic layer (Kaizer et al., 2020). In multi-layered zirconia with different concentrations of yttria configuration, there is also a risk of crack propagation that originates from the layer with lower yttria concentration which is associated with lower fracture strength, usually in the incisal or occlusal area (Badr et al., 2022).

5. CLASSIFICATION OF ZIRCONIA

Continuous development and improvement of zirconia materials contribute to numerous options available in the market and it is hard to keep up with what type of zirconia ceramics clinicians may end up using in clinical practice. Classifying zirconia therefore may help to guide in choosing the correct zirconia in the right clinical situation and improving communication among clinicians and dental laboratory. Zirconia can be categorized based on the translucency of the zirconia, the concentration of yttria incorporated into the ceramics or the type of modifications done to improve the optical or mechanical properties of zirconia (Alqutaibi et al., 2022; Güth et al., 2019; Rondoni, 2016).

5.1 Generation-based

The generation-based classification was described by Güth and colleagues to differentiate zirconia according to the type of modifications subjected to improve its optical and mechanical properties in chronological order (Table 1). In each generation, several additional modifications were made to improve the appearance of zirconia by configuring the blanks into multi-layered or shade-graded forms to imitate the natural gradient of tooth colour (Kolakarnprasert et al., 2019). It is important to note that despite the introduction of the newer generation of zirconia, earlier renditions are still in the market, with their usage depending on clinical scenarios.

5.2 Translucency

Zirconia ceramics can be classified based on their translucency; traditional opaque zirconia, high-translucency (HT) zirconia, and cubic ultra-translucent (UT) zirconia (Rondoni, 2016). Rondoni described opaque zirconia as being associated with high mechanical strength ranging from 900 to 1200 mPa. It is usually used as a veneering ceramic in the crown of fixed dental prostheses (FDPs), supported by either teeth or implants in extensive restoration or masking unwanted discolouration. HT zirconia presented with the same mechanical strength as previous opaque zirconia but with much-improved translucency. This class of zirconia can be stained and may exist in monolithic blocks or disks, either in monochromatic or multi-layered versions which allows more aesthetic prostheses to be made. In the third group, UT zirconia exhibits a much lower mechanical strength of 500 to 800 mPa but with a higher cubic phase content making its translucency as close to lithium disilicate ceramics. However, this type of classification generally groups different types of translucent zirconia with different types of fabrication methods that may create confusion

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between clinicians and laboratories (Ghodsi & Jafarian, 2018). The term "translucent zirconia" can be quite broad, encompassing a wide array of parameters that can be adjusted, and modifying just one aspect may not achieve the maximum level of translucency (Darvell, 2018; Elsaka, 2019).

5.3 Yttria concentration

Another most common ways to classify zirconia is also by grouping it according to the amount of mol % concentration of yttria incorporated in stabilising the zirconia. The mechanical and physical attributes of zirconia are substantially influenced by the concentration of yttria, which may have implications for its clinical applications. Alqutaibi and colleagues categorize dental zirconia as: Type 1 with 3 mol % of yttria tetragonal zirconia polycrystalline (3Y-TZP), Type 2 with 4 mol % of yttria (4Y-TZP) and Type 3 containing 5 mol % of yttria (5Y-TZP) (Alqutaibi et al., 2022). Type 1 has the highest strength and the lowest translucency whereas Type 3 has the lowest strength and maximum translucency. Type 2 exhibits both optical and mechanical properties that are in between Type 1 and 3 which makes it an attractive solution in rehabilitation of aesthetic zones that require optimum translucency without heavy compromise on mechanical strength (Zhang & Lawn, 2018).

Table 1. Generations of dental zirconia.

Generation	Features
1st Generation (3Y-TZP)	1. Introduced in 1994 2. High opacity 3. Excellent mechanical reliability and clinical performance (Heintze & Rousson, 2010)
2nd Generation (3Y-TZP) & reduced alumina content	1. Introduced in 2013 2. Molecular level adjustment a. Reducing the number and size of alumina grain (Al_2O_3) b. Placing alumina at the boundaries of zirconia crystals 3. Increased translucency with high flexural strength and clinical stability (Stawarczyk et al., 2016)
3rd Generation (5Y-PSZ)	1. Introduced in 2015 2. Increase the mole percentage of yttria up to 5% 3. Fully stabilised zirconia with high cubic phase content reaching 50% 4. Highest translucency amongst all generations with reduced mechanical strength 5. A viable alternative to high-strength glass ceramics
4th Generation (4Y-PSZ)	1. Introduced in 2017 2. Lessen the amount of yttria to 4% 3. Better mechanical strength than the previous generation with compromised optical properties

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Table 2. Different types of zirconia with different compositions and configurations exhibit different mechanical and optical properties. (Alqutaibi et al., 2022; Kongkiatkamon et al., 2023; Sulaiman et al., 2024).

Type of zirconia	**Yttria concentration**	**Strength (MPa)**	**Fracture toughness (MPa $m^{1/2}$)**	**Elastic modulus (GPa)**	**Translucency Parameter**	**Contrast Ratio**	**Brands/ Manufacturer**
3Y-TZP	3 mol%	900-1300	3.5-4.5	200-210	12-14	0.90-0.93	Ceramill Zi (Amann Girrbach AG, Austria) Katana HT (Kuraray Noritake, Japan) IPS emax Zir CAD LT (Ivoclar Vivadent, Liechtenstein) Superfectzir (Aidite, China) Lava Frame, Lava Plus (3M ESPE, USA) Cercon HT (Dentsply Sirona, Germany)
4Y-PSZ	4 mol%	600-800	2.5-3.5	200-210	15-18	0.80-0.85	Ceramill Zolid HT+ (Amann Girrbach AG, Austria) Katana ST (Kuraray Noritake, Japan) IPS emax ZirCAD MT (Ivoclar Vivadent, Liechenstein) Zpex 4 (Tosoh, Japan) Vita YZ ST (Vita Zahnfabrik, Germany)
5Y-TZP	5 mol%	300-600	2.2-2.7	200-210	18-25	0.72-0.78	Ceramill Zolid FX (Amann Girrbach AG, Austria) Katana UT (Kuraray Noritake, Japan) Lava Esthetic (3M ESPE, USA) Bruxzir Anterior (Glidewell Laboratories, USA) Cercon xt, Cercon xt ML (Dentsply Sirona, Germany)
5Y/3Y-PSZ/TZP	3-5 mol%	300-1200	2.2-4.5	200-210	12-25	0.72-0.93	Katana YML (Kuraray Noritake, Japan) Emax Zir CAD MT Multi (Ivoclar Vivadent, Liechenstein) NexxZr Multi: High Translucent (Sagemax, USA)

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5Y/4Y-PSZ	4-5 mol%	300-600	2.2-3.5	200-210	15-25	0.72-0.85	Katana YML (Kuraray Noritake, Japan) Emax Zir CAD MT Multi (Ivoclar Vivadent, Liechenstein) NexxZr Multi: High Translucent (Sagemax, USA)

Table 3. Proposed classification of zirconia in regards of type of prosthesis, chromaticity, yttria concentration, and suggested clinical indications.

Type of Prosthesis	Chromaticity	Yttria concentration	Clinical Indications
Veneered	Monochrome (Stained/Glazed)	3Y-TZP	1. Substructure for single crown or post/core restoration 2. Custom implant abutment 3. Framework for tooth or implant supported FDPs up to 14 units in the anterior or posterior area
Monolithic	Monochrome (Stained/Glazed)	4Y-PSZ	1. Inlay, onlay, vonlay 2. Single crown prosthesis in anterior or posterior area 3. Long-span FDPs up to 14 units on tooth or screw-retained implant restorations
		5Y-PSZ	1. Veneer 2. Single unit full contour crown in anterior and posterior region. 3. FDPs less than 3 units extending up to second premolar area
	Polychrome	5Y/3Y- PSZ/TZP	1. Veneer 2. Single unit full contour crown and short span FDPs in anterior and posterior region
		5Y/4Y-PSZ	

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6. CONCLUSIONS

Enhancing the optical characteristics of zirconia ceramics, especially in terms of translucency, has broadened the scope of their clinical applications. This progress is attainable by continuously improving our understanding of zirconia's properties and behaviour, leading to the development of newer methods that render zirconia more translucent and aesthetically appealing compared to earlier generations of zirconia ceramics. However, it is crucial for proper and thorough clinical assessment, in addition to incorporating scientifically proven preparation and adhesive techniques to ensure long-term clinical success. Clinicians also need to know the limitations of translucent zirconia when making clinical judgements. With the rapid evolution of dental materials technology, practitioners must stay abreast of the latest advancements to uphold a successful clinical practice.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Muhammad Nur Izham Khairuddin carried out the research, wrote and revised the article. **Mohamed Ibrahim Abu Hassan** conceptualised the central research idea and provided the theoretical framework. **Mohamed Ibrahim Abu Hassan and Aini Hayati Abdul Rahim** designed the research, supervised research progress; **Mohamed Ibrahim Abu Hassan** anchored the review, revisions and approved the article submission.

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7. APPENDIX

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