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Mechanical and Optical Properties of Contemporary Dental Zirconia Materials Used in Fixed Prosthodontics: A Systematic Review

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ABSTRACT: Background: Zirconia has evolved from an opaque veneered framework material to encompass multiple monolithic grades (3Y-TZP, 4Y-PSZ, 5Y-PSZ and strength- or color-gradient multilayer blanks for strength and translucency) for fixed prosthodontics. Unfortunately, the compromises involved and the factors that control them are scattered throughout a number of laboratory reports.

Justification: To collate the updated research (2020-2025) on mechanical and optical properties of modern dental zirconia used for crown and fixed dental prostheses (FDPs).

Methods: The systematic review adhered to the PRISMA 2020 statement. Peer-reviewed laboratory studies reporting on the following properties of zirconia indicated for fixed restorations were identified, with data extracted into a pre-arranged format: flexural strength, fracture load, fracture toughness, hardness, translucency parameter, contrast ratio, and colour change. Results were synthesized narratively and supported by a harvest plot as well as tabulated values owing to differences in specimen geometry and testing method, thickness, and ageing protocol.

Results: 10 primary in vitro studies (2021-2025) were retrieved and cross checked with 4 systematic reviews and 2 clinical syntheses. Most studies showed strength was lower with higher yttria contents; 3Y-TZP 918 MPa versus 5Y-PSZ 402 MPa (3 point bending study). Pooled data from 78 laboratory studies demonstrated strength of 4Y-PSZ (803 ± 233 MPa) and 5Y-PSZ (570 ± 116 MPa). Fatigue strength was lowest for 5Y-PSZ (377 MPa) at 0.7 mm. Yttria content was related to higher translucency; glazing, repeated firing, sintering protocol and hydrothermal ageing also affected strength, translucency and optical properties; the magnitude of ageing effects were grade dependent. Fracture load was higher for 3/4Y strength-gradient blank than for homogeneous 4Y material.

Conclusions: 3Y-TZP and gradient materials will probably still be the safer choice for loadbearing and multi-unit restorations, whereas 4Y-PSZ appears to be an intermediate choice. For 5Y-PSZ, the recommendation should be limited to single-unit or short-span anterior restorations with adequate thickness. The newest grade of zirconia (5Y-PSZ) will benefit from the definition of a standardized set of test and clinical follow-up protocols

1. INTRODUCTION

A newer trend in fixed prosthodontics is the use of CAD/CAM ceramics and yttria stabilized zirconia as the polycrystalline material of choice for crowns and FPDs. Among the first generation of dental zirconia, 3 Mol% yttria stabilized tetragonal zirconia polycrystal (3Y-TZP) has been used to produce these strong restorations with some transformation toughening. The opacity of the material led to the need for veneering porcelain, which has been reported to cause chipping problems (Yousry et al., 2024). The need for a full-arch, monolithic and fully anatomic restoration led to the abutments of all zirconia FDPs having

to forego the veneer, stimulating manufacturers to introduce multilayer blanks, after increasing the yttria content of the materials.

The evolution of Y2O3 additions can be explained by the 'new generation' classification from Yousry et al. (2024): c 2011 "monolithic" 3Y; c 2014 a 5 mol% YO 1 grade (5Y-PSZ) with higher translucency; c 2015 multilayer blank; c 2018 a 4 mol% grade (4Y-PSZ), which fills a "gap" of high strength/high translucency materials; c and since this date, 6 mol% and multilayer 6Y grades have become available. The higher phases have a greater content of cubic phase, which scatters less light but does not lead to the transformative toughening mechanism of 3Y–TZP, in which the stressed phase undergoes a monoclinic to tetragonal phase transformation, to enhance its strength. Bruhnke et al. (2023) quantified the increased cubic phase amount for 4Y (approximately 25%) and 5Y (up to approximately 53%). As confirmed by Calvache Arcila et al. (2021) from X-ray diffractometry, the cubic content progressively rises in the sequence 3Y<4Y<5Y.

Clinically, this means the new development introduces a trade-off that is simple to describe but rather complex to quantify. 3Y-TZP reported strengths often have been between 900 and 1200 MPa (Yousry et al., 2024), while highly translucent grades tend to be weaker, with much less consistent strength values, owing to possible influences of specimen preparation, test geometry, and thickness (Bernauer et al., 2025). Until now, other systematic reviews often only considered strength and translucency separately, or strictly up to 2019 (Fathy et al., 2021), or used either some exacts (translucency) (Yousry et al., 2024), or only certain properties, such as the sintering protocol (Al-Haj Husain et al., 2022), or just translucency (Yousry et al., 2024). Yousry et al. (2024) just reviewed the translucency, and Bernauer et al. (2025) concentrated mainly on flexural strength, but this meant optical results, fatigue, and the ultimate load to fracture of multi-unit prostheses had to be cited from other studies.

Clinical decision making therefore requires that both elements of this balancing act be considered simultaneously. For the clinician choosing a material for the many applications of dentistry such as a 3-unit posterior bridge, anterior crown with a thin preparation, or a full arch prosthesis, it is necessary to find out how much strength must be compromised in order to increase translucency. The effects of glazing, sintering, and aging, as well as the correlation between laboratory evidence and clinical survivability is also critical. The purpose of this systematic review therefore was to review recent laboratory findings concerning the mechanical and optical properties of modern dental zirconia in use in fixed prosthodontics in relation to clinical indications.

2. MATERIALS AND METHODS

2.1 Protocol and Reporting Guideline

This review was structured and reported following the PRISMA 2020 statement (Page et al., 2021). The review question was framed with a population-intervention-comparison-outcome (PICO) table adapted for laboratory research: zirconia specimens or restorations (population) representing materials used for fixed prosthodontics was targeted; a certain yttria grade, multilayer structure, or processing condition (intervention) was proposed; a different yttria grade, multilayer structure, or processing condition, or lithium disilicate was used as comparison; and mechanical or optical properties were set as outcomes. Protocol registration details can be found at [registry and number, if any].

2.2 Eligibility Criteria

Articles were included if they were (a) published in English, between 01/2020 and 12/2025, in a peer-reviewed journal; (b) related to dental zirconia, for crown and fixed dental prostheses, including 3Y-TZP, 4Y-PSZ, 5Y-PSZ, and multilayer; (c) reported at least 1 outcome, i.e., flexural strength, fracture load, fracture toughness, hardness, fatigue strength, transmittance, translucency parameter (TP), contrast ratio (CR), light transmittance, and color difference (ΔE). Systematic reviews and clinical syntheses were kept as secondary references for cross-referencing and cross-checking the clinical findings; however, these references were not considered for data extraction. Studies related to implant components, orthodontic/non-dental zirconia,

bonding-only studies without reporting strength or optical outcome, conferences abstracts, and studies without an extractable outcome were excluded.

2.3 Information Sources and Search Strategy

Comprehensive electronic searches of the Pub Med/MEDLINE, Scopus, Web of Science and Google Scholar databases were conducted and the bibliographies of relevant reviews were hand searched. The primary search strategy is listed in Table 1 and was adapted to the syntax of individual databases.

Table 1 Search strategy (PubMed/MEDLINE syntax, adapted for other databases)

Concept	Search terms
Material	zirconia OR "yttria-stabilized zirconia" OR "translucent zirconia" OR "monolithic zirconia" OR "multilayer zirconia" OR 3Y-TZP OR 4Y-PSZ OR 5Y-PSZ OR "strength-gradient zirconia"
Property	"flexural strength" OR "fracture load" OR "fracture toughness" OR hardness OR "fatigue" OR translucency OR "translucency parameter" OR "contrast ratio" OR "optical properties" OR "colour change"
Application	"fixed prosthodontics" OR crown OR "fixed dental prosthesis" OR bridge OR CAD/CAM
Limits	Publication years 2020–2025; English language; peer-reviewed journals

Concepts were combined with AND; terms within a concept were combined with OR.

2.4 Study selection and data extraction

Screening of titles and abstracts and then full text paper was performed independently by two authors. Discrepancies in decision to include or exclude publications were resolved by discussion. Data were extracted using a standardized sheet of data including author and year, materials and grades, study design and size, test standard and method, aging or processing conditions, outcome value and main conclusion. Numerical values were used when reported in the article or abstract; if values were not presented as a group mean, they were not estimated.

2.5 Methods for Appraisal and Synthesis

Methodological aspects that could affect validity in studies in vitro (sample size per group, compliance with ISO 6872, specimen thickness, duration of ageing, statistical analysis) were summed up in a table, and not combined into one score. To visualize variation and heterogeneity in specimen geometry (disc, bar, 3-unit bridge), method of testing (biaxial, three-point, four-point bending), thickness, and ageing conditions, a quantitative pooled estimate was not feasible; so a synthesis was achieved in a narrative manner. The direction of effect was depicted in a harvest plot, and individual study results are shown in a graph, with no quantitative pooling.

3. RESULTS

3.1 Study Selection

Study selection process is shown on the flow chart (Figure 1). After exclusion of duplicates and screening, 10 primary papers were enrolled from 2021 to 2025 publications for the data extraction table and 4 systematic reviews (Al-Haj Husain et al., 2022;

Bernauer et al., 2025; Fathy et al., 2021; Yousry et al., 2024) and 2 clinical syntheses (Kim et al., 2022; Shihabi & Chrcanovic, 2023) were selected and used as secondary evidence.

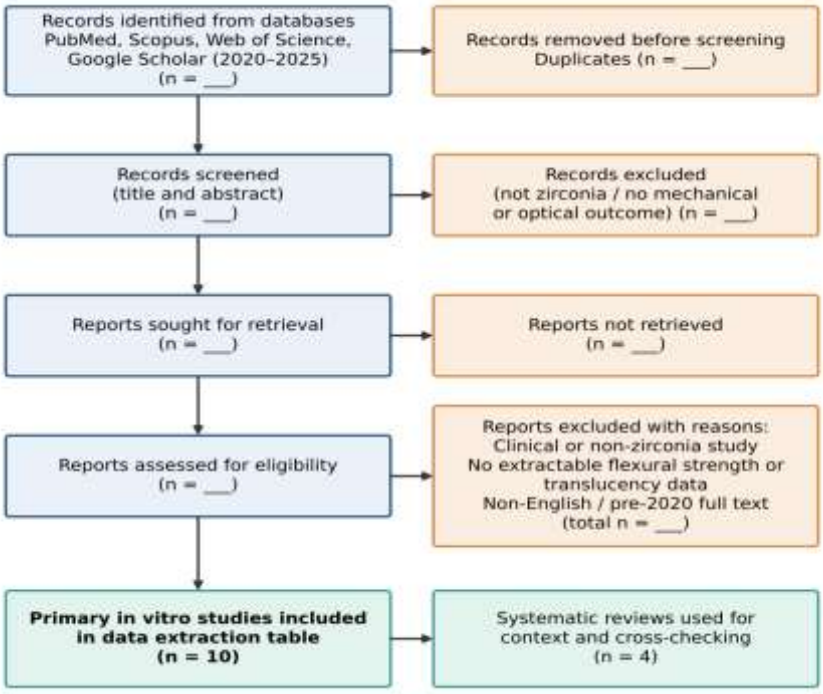

Figure 1. PRISMA 2020 flow diagram of study identification, screening, eligibility and inclusion (Page et al., 2021).

3.2 Characteristics of included studies

The 10 focused studies are shown in the data-extraction sheet (Table 2). Study and sample sizes, where reported, ranged from 30 to 320 specimens. For each study, one or more tests, limited to biaxial flexural strength testing in 5 studies, three-point bending in 3 studies, testing fracture load of three-unit FDPs after thermomechanical aging in 1 study, and only optical results in 1 study, were shown. Nine studies involved comparison of two or more yttria grades/multilayer design; two studies used lithium di-silicate as a reference glass-ceramic (Figure 2). The number of publications peaked in 2021 and 2024 which probably coincides with the commercial availability of 4Y and strength-gradient materials.

Table 2 Data-extraction sheet of the ten included primary studies

Study (year)	Materials / grades	Design, sample size and test	Outcomes	Key findings
Calvache Arcila et al. (2021)	Vita YZ HT (3Y-TZP), ST (4Y-PSZ), XT (5Y-PSZ); 0.7 and 1.2 mm	N = 318 discs; ISO 6872 biaxial and step-stress fatigue; SEM, XRD, EDX	BFS, fatigue, hardness, IFR	5Y-PSZ had the lowest fatigue strength and cycles to failure; 3Y and 4Y behaved similarly. Cubic phase 5Y > 4Y > 3Y. 4Y showed the highest quasi-static BFS.
Jerman et al. (2021)	Opaque, translucent, extra-translucent and high-translucent 3Y/4Y/5Y blanks	N = 320; biaxial testing, thermomechanical ageing, chevron-notch toughness	TP, Martens hardness, BFS, *KIC*, grain size	Translucency of ET and HT increased with thermomechanical ageing; ET gave the highest flexural strength; hardness unaffected by material or ageing.

Study (year)	Materials / grades	Design, sample size and test	Outcomes	Key findings
Lümkemann & Stawarczyk (2021)	3Y-TZP (two variants), 4Y, speed-sintered 4Y, 5Y; lithium disilicate	Manually coloured specimens; hydrothermal ageing 0–160 h (134 °C, 0.2 MPa); biaxial test	Light transmittance, BFS	Lithium disilicate most translucent, then 5Y, 4Y, 3Y. Ageing raised BFS of 3Y but lowered it for 5Y (P = .005) and speed-sintered 4Y (P < .001).
Kongkiatkamon & Peampring (2022)	Katana STML (5Y-TZP) block and disc	Regular vs speed sintering, with or without low-temperature degradation; biaxial test	Phase, TP, BFS	TP differed significantly among groups except speed sintering vs speed sintering + LTD.
Bruhnke et al. (2023)	Katana HTML, STML, UTML; four layers; 0.4, 0.8, 1.2 mm	15 specimens per group; three-point bending (ISO 6872)	Flexural strength, hardness, Weibull modulus, K*IC*	FS: HTML 652.85–887.64 MPa; STML 280.17–435.95 MPa; UTML 258.25–331.26 MPa; HTML significantly higher than STML and UTML.
Bakitian (2024)	IPS e.max ZirCAD Prime vs Katana HTML	80 bars (n = 10/group); three-point bending	Flexural strength	HTML higher than ZirCAD Prime overall (P < .001) but similar to its dentin layer; HTML layers 763–816 MPa without layer differences.
Mayinger et al. (2024)	3/4Y-TZP gradient, 4Y-TZP, 3Y-TZP	High-speed, speed and conventional sintering; four layers; three-unit FDPs after thermomechanical ageing	Grain size, phases, T, BFS, fracture load	3/4Y gave the highest fracture load, then 3Y, then 4Y; 4Y mechanics largely unaffected by sintering; all FDPs exceeded maximum bite force.
Elzoughary et al. (2024)	ZirCAD Prime (3Y/5Y), Katana UTML (5Y), IPS e.max CAD	N = 30 (n = 10/group); autoclave 1, 3, 5 h; XRD	ΔE00, TP00, CR	Lithium disilicate highest TP00; UTML highest CR; translucency of all samples increased with ageing.
Alshali et al. (2025)	3Y-TZP, 4Y-PSZ, 5Y-PSZ	N = 120; polish, glaze, one and two glaze firings; three-point bending	FS, TP, ΔE*ab	3Y: 918.46 MPa, TP 4.32; 5Y: 401.58 MPa. Firing lowered 5Y strength (P = .002) and 3Y (P = .04); 4Y most stable; 5Y ΔE*ab 1.49–9.6.
Gupta et al. (2025)	3Y-TZP vs 5Y-PSZ	40 discs; biaxial test; SEM	FS, roughness, TP, CR	3Y had significantly higher flexural strength; 5Y higher translucency; surface roughness comparable.

BFS = biaxial flexural strength; FS = flexural strength; IFR = indentation fracture resistance; K*IC* = fracture toughness; TP = translucency parameter; CR = contrast ratio; T = translucency; LTD = low-temperature degradation; FDP = fixed dental prosthesis; ET/HT = extra-/high-translucent. Values are as reported by the authors.

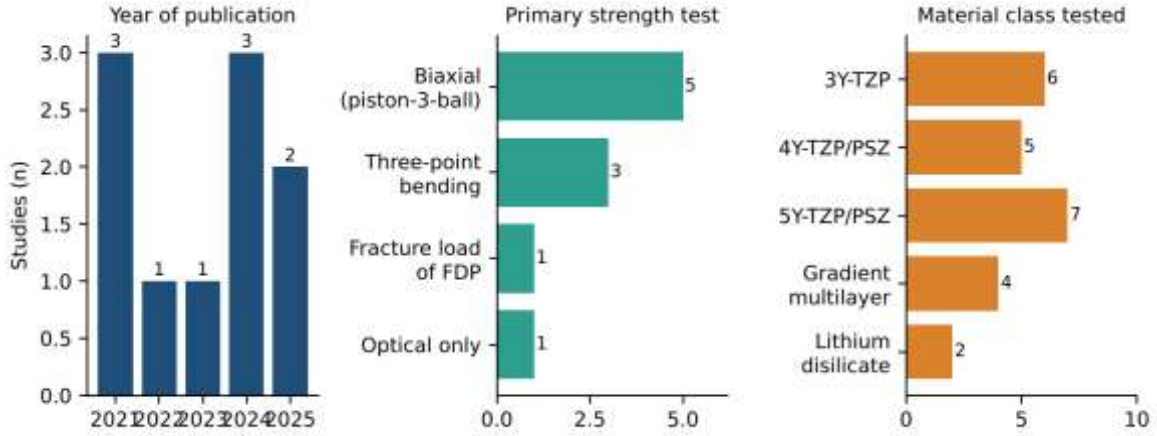

Figure 2. Characteristics of the ten included primary studies by publication year, principal strength test and material class evaluated

Methodological features. Table 3 describes the characteristics affecting the validity of the laboratory comparisons. It should be borne in mind that the sample sizes in all cases were small, from 10-15 specimens if stated. The thickness, test standards, and ageing procedures differed between the studies and this may account for the numbers in the tables following being given in the two columns rather than combined.

Table 3 Methodological features of the included primary studies

Study (year)	Specimens	Test standard / method	Thickness	Ageing / processing
Calvache Arcila et al. (2021)	N = 318 discs; n = 10 BFS, n = 15 fatigue per subgroup	ISO 6872:2015 piston-on-three-balls; step-stress fatigue, 20 Hz	0.7 and 1.2 mm	Speed-oven sintering; fatigue in water
Jerman et al. (2021)	N = 320	Biaxial test; Weibull analysis; chevron-notch beam	Not stated in abstract	Thermo mechanical ageing
Lümkemann & Stawarczyk (2021)	Not stated in abstract	Biaxial test	Not stated in abstract	Autoclave 134 °C, 0.2 MPa, up to 160 h; manual colouring; conventional vs high-speed sintering
Kongkiatkamon & Peampring (2022)	Not stated in abstract	Biaxial test	Not stated in abstract	Regular vs speed sintering ± LTD
Bruhnke et al. (2023)	15 per group	Three-point bending, ISO 6872:2015	0.4, 0.8, 1.2 mm	Four blank layers

Study (year)	Specimens	Test standard / method	Thickness	Ageing / processing
Bakitian (2024)	80 bars; n = 10 per group	Three-point bending	Bar specimens	Layer-wise comparison
Mayinger et al. (2024)	Discs from four layers; three-unit FDPs	Biaxial test; fracture load	Not stated in abstract	High-speed, speed, conventional sintering; thermo mechanical ageing
Elzoughary et al. (2024)	N = 30; n = 10 per group	Spectrophotometry; XRD	1 mm (12 × 14 mm plates)	Autoclave 1, 3, 5 h
Alshali et al. (2025)	N = 120	Three-point bending; spectrophotometry	Not stated in abstract	Glazing and up to two glaze firings
Gupta et al. (2025)	40 discs	Biaxial test; SEM	Not stated in abstract	None reported

Note. BFS = biaxial flexural strength; LTD = low-temperature degradation; FDP = fixed dental prosthesis. Entries marked "not stated in abstract" should be completed from the full text.

3.3 Mechanical properties

Flexural strength by yttria grade. In most studies that compared grades directly, 5Y-PSZ reached the lowest strength (Figure 3, Table 4). Alshali et al. (2025) reported 918.46 MPa for 3Y-TZP and 401.58 MPa for 5Y-PSZ in three-point bending, a difference of more than 500 MPa. In biaxial testing, Calvache Arcila et al. (2021) found 5Y-PSZ at 702.6 ± 133.6 MPa (0.7 mm) and 750.7 ± 127.2 MPa (1.2 mm), below 4Y-PSZ (930.9 ± 326.0 and 889.1 ± 202.7 MPa), while 3Y-TZP was 741.3 ± 78.2 MPa at 0.7 mm and 975.7 ± 132.7 MPa at 1.2 mm. The 3Y–4Y ordering therefore varied with thickness and test, which agrees with the statement of Bernauer et al. (2025) that comparing translucent zirconia values is difficult because of differences in processing parameters. Their pooled analysis of 78 laboratory studies produced 803 ± 233 MPa for 4Y-PSZ and 570 ± 116 MPa for 5Y-PSZ (P = .005), and the effect of specimen processing, surface treatment and test method was significant for 5Y-PSZ but not for 4Y-PSZ (Figure 5A).

Multilayer and Gradient Materials

Bruhnke et al. (2023) confirmed the high variation of three Katana multilayer blanks with values up to two-to-three times greater than that for UTML (Figure 4A). No differences could be identified among the 4 layers of a Katana HTML, which had strengths ranging from 763-816 MPa and it was generally stronger than the gradient blank IPS e.max ZirCAD Prime (Bakitian, 2024; Figure 4B). Bakitian (2024) reported that multilayer materials fabricated with different yttria contents per layer may have lower strength than a gradient shade technology with a constant yttria content. For fixed restorations, Mayinger et al. (2024) found that a 3/4Y strength-gradient blank had the highest fracture load in 3-unit FDPs, 3Y-TZP was intermediate, and 4Y-TZP had the lowest, but all exceeded maximum bite forces after thermo mechanical aging.

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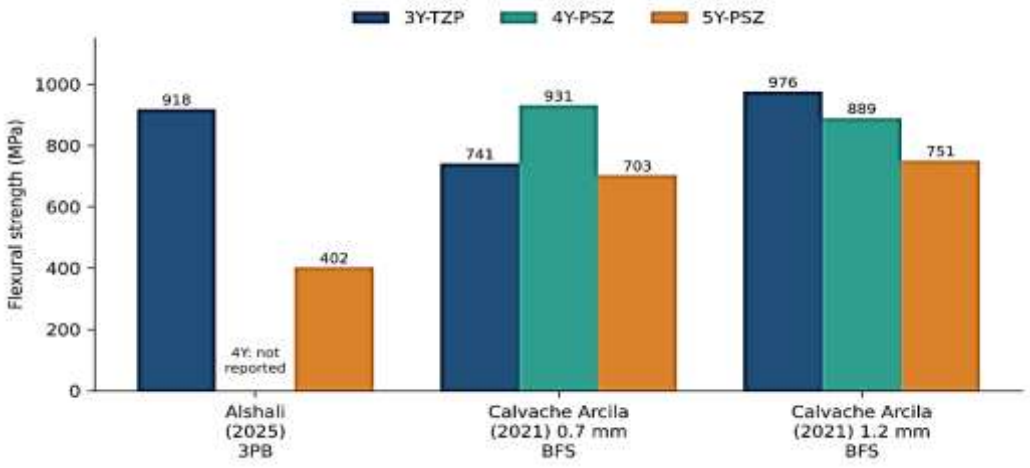

Figure 3. Flexural strength of 3Y-TZP, 4Y-PSZ and 5Y-PSZ in studies that reported group means for all or most grades (Alshali et al., 2025, three-point bending; Calvache Arcila et al., 2021, biaxial flexural strength at two thicknesses). Alshali et al. did not report a 4Y mean in the abstract.

Table 4 Quantitative mechanical outcomes reported in the primary and secondary evidence

Source	Material / condition	Value (mean ± SD or range)	Test / comment
Alshali et al. (2025)	3Y-TZP | 5Y-PSZ	918.46 | 401.58 MPa	Three-point bending, n = 120 specimens in total
Calvache Arcila et al. (2021)	3Y-TZP 0.7 / 1.2 mm	741.3 ± 78.2 / 975.7 ± 132.7 MPa	Quasi-static BFS; HV 1421.5 ± 109.7
	4Y-PSZ 0.7 / 1.2 mm	930.9 ± 326.0 / 889.1 ± 202.7 MPa	HV 1314.6 ± 80.1; IFR 4.44 ± 0.58
	5Y-PSZ 0.7 / 1.2 mm	702.6 ± 133.6 / 750.7 ± 127.2 MPa	HV 1529.8 ± 152.6; IFR 4.29 ± 0.38
	Fatigue BFS: 3Y | 4Y | 5Y at 0.7 mm	520.0 | 603.3 | 376.7 MPa	Step-stress; 1.2 mm: 516.7 | 546.6 | 440.0
Bruhnke et al. (2023)	Katana HTML	652.85–887.64 MPa	Three-point bending across layers/thicknesses
	Katana STML | UTML	280.17–435.95 | 258.25–331.26 MPa	FS and K*IC* lower than HTML ($P < .05$)
Bakitian (2024)	HTML layers: dentin | translucent | transition | multilayered	763 ± 56 | 791 ± 106 | 816 ± 85 | 793 ± 102 MPa	No layer differences ($P > .05$)
Bernauer et al. (2025)	4Y-PSZ | 5Y-PSZ (pooled)	803 ± 233 | 570 ± 116 MPa	78 laboratory studies; $P = .005$
Mayinger et al. (2024)	3/4Y | 3Y | 4Y three-unit FDPs	Fracture load: 3/4Y > 3Y > 4Y	Absolute values not reported in abstract

Note. HV = Vickers hardness; IFR = indentation fracture resistance (MPa·mm½); BFS = biaxial flexural strength. Values are quoted from the source articles and are not directly comparable across rows because specimen geometry and test method differ.

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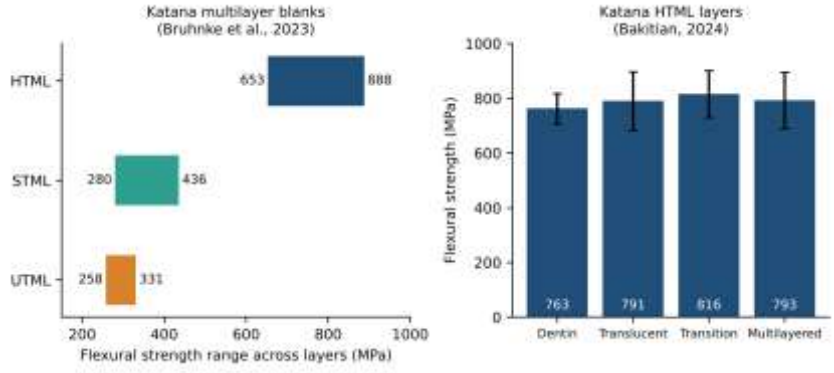

Figure 4. (A) Flexural strength ranges across layers and thicknesses of three Katana multilayer blanks (Bruhnke et al., 2023). (B) Flexural strength of the individual layers of Katana HTML, mean ± SD (Bakitian, 2024).

Fatigue, Hardness, and Toughness

In the case of step-stress fatigue, the data indicated that 5Y-PSZ at 0.7 mm thickness failed at the lowest stress (376.7 MPa) and the lowest number of cycles in comparison to 3Y-TZP and 4Y-PSZ, which showed statistically similar results (Calvache Arcila et al., 2021; Fig. 5B). 5Y-PSZ may therefore be thickness-dependent, although the trend is not present with quasi-static strength. Hardness and indentation fracture resistance did not show any clear trend with yttria content: 5Y-PSZ was the hardest (Vickers), 4Y-PSZ was the least, and 3Y-TZP was most resistant to indentation fracture. Jerman et al. (2021) also showed that material composition and ageing did not show any significant impact on the Martens hardness or indentation modulus.

3.4 Optical properties

Optical results were available for seven of the ten main articles (Table 5). Evidence points to increased translucency in relation to yttria concentration; Alshali et al. (2025) reported the lowest TP value for 3Y-TZP at 4.32, whereas Gupta et al. (2025) reported better translucency for 5Y-PSZ with similar roughness values. Regarding colored materials, Lümkemann and Stawarczyk (2021) ranked lithium di-silicate as superior, followed by 5Y-PSZ, 4Y-TZP, and 3Y-TZP; they also found that speed-sintered 4Y-TZP had the most opacity and matte surface. They concluded that "translucency in all white materials was lowest in the incisal layer and highest in the cervical layer of the multilayer blocks." In another study, Mayinger et al. (2024) found that 4Y-TZP had better optical characteristics than 3Y-TZP; they also reported a tendency for translucency to decrease from incisal to cervical layers in all multilayer blanks. Yousry et al. (2024) completed a systematic review on 53 studies, which confirmed these findings: it also found that the yttria level influences translucency and reported differences between products of a given generation.

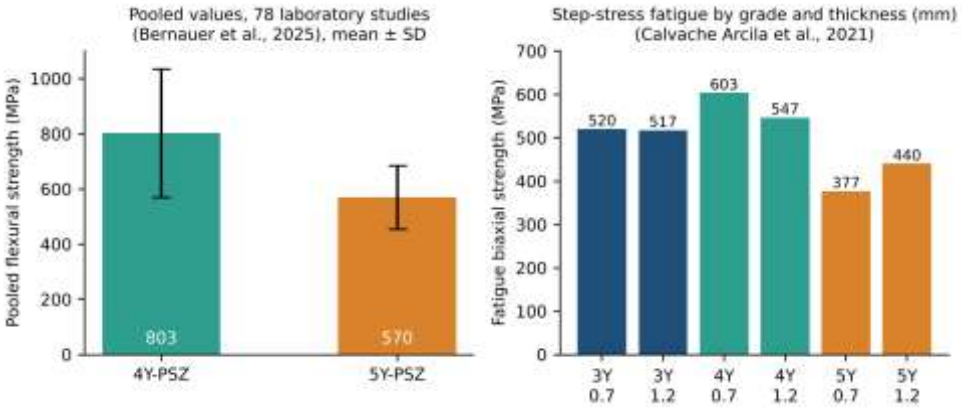

Figure 5. (A) Pooled flexural strength of 4Y-PSZ and 5Y-PSZ from a systematic review of 78 laboratory studies, mean ± SD (Bernauer et al., 2025). (B) Step-stress fatigue biaxial strength of 3Y-TZP, 4Y-PSZ and 5Y-PSZ at 0.7 and 1.2 mm (Calvache Arcila et al., 2021).

Table 5 Optical outcomes reported in the included studies

Study (year)	Optical measure	Principal result	Direction
Alshali et al. (2025)	TP, ΔE*ab after glazing/firing	3Y TP = 4.32 (lowest); 5Y translucency changed with firing (P = .003) and ΔE*ab 1.49–9.6	5Y unstable; 4Y most stable
Gupta et al. (2025)	TP, CR	5Y-PSZ higher translucency than 3Y-TZP	Higher yttria → more translucent
Lümkemann & Stawarczyk (2021)	Light transmittance after 0–160 h ageing	Lithium di-silicate > 5Y > 4Y > speed-sintered 4Y > 3Y variants	Higher yttria → more translucent
Jerman et al. (2021)	Translucency before/after thermomechanical ageing	Translucency of ET and HT increased after ageing	Ageing raises translucency
Kongkiatkamon & Peampring (2022)	TP, speed vs regular sintering, ± LTD	Significant TP differences between groups, except speed sintering vs speed sintering + LTD	Protocol-dependent
Elzoughary et al. (2024)	ΔE00, TP00, CR, ageing 1–5 h	Lithium disilicate highest TP00; UTML highest CR; translucency increased with ageing	Ageing raises translucency
Mayinger et al. (2024)	Translucency by blank layer	4Y higher than 3Y; translucency fell from layer 1 to layer 4	Layer- and sintering-dependent

TP = translucency parameter; CR = contrast ratio; ΔE = colour difference; LTD = low-temperature degradation.

3.5 Effect of processing, ageing and thickness

Glazing and Firing

Effects of heat treatment with repeated firing: Glazing along with repeated firing appeared to affect 5Y-PSZ to the largest extent; strength showed a significant decrease (P =.002) and translucency and color were changed beyond clinically acceptable levels. 4Y-PSZ showed the greatest stability in terms of strength, translucency and color (Alshali et al., 2025). 3Y-TZP had also shown a reduction in strength after heat treatment (P=.04).

Sintering

The most common use of speed and high-speed sintering was the satisfactory retention of mechanical behavior and a significant decrease in chairside treatment time; however, it seemingly did not have a predictable optical outcome. The results of a systematic review by Al-Haj Husain et al. (2022), involving 15 in vitro studies, showed that the mechanical and precision were comparable or even better with the use of speed or high-speed sintering of 3Y, 4Y and 5Y zirconia; however, translucency was negatively affected with the use of speed sintering on 3Y-TZP. Mayinger et al. (2024) suggested that sintering parameters had a direct impact on the grain size and translucency of 4Y-TZP but did not significantly alter its mechanical properties. In addition, Lümkemann and Stawarczyk (2021) found that high-speed sintering negatively affected the coloring process of manually colored 4Y-TZP.

Hydrothermal Ageing

Effects of ageing were grade-dependent. Strength increased following autoclave test in 3Y-TZP (P<.001), and was reduced in 5Y-TZP (P=.005) and speed-sintered, pre-coloured 4Y-TZP (P<.001) while no deterioration following ageing was observed

with conventionally sintered, manually coloured 4Y-TZP (Lümkemann & Stawarczyk, 2021). Fathy et al (2021), based on a review of 53 previously published studies, reported that ageing was not a concern for zirconia with high yttria level, and that surface polishing increased strength while coarse grinding and mechanical fatigue reduced it. Ageing also led to an increase in translucency of extra- and high-translucent materials (Jerman et al, 2021), gradient, and 5Y zirconia (Elzoughary et al, 2024).

Thickness

For the quasi-static biaxial strength, thickness did not have any effect because the ISO equation incorporated this parameter. However, the fatigue life was minimum at 0.7 mm of thickness of 5Y-PSZ (Calvache Arcila et al., 2021). Bruhnke et al. (2023) tested 0.4, 0.8, and 1.2 mm thickness, whereas Fathy et al. (2021) warned that thin sections of aesthetic zirconia need thorough evaluation in high stress region.

Synthesis of the Strength-Translucency Trade-off

Figure 6 – Harvest plot of directionality across the ten studies. Seven out of the eight studies that compared higher vs lower grades or designs in each study found lower strength for the higher-yttria grade; Jerman et al. (2021) was the only study to find the highest flexural strength with an extra-translucent grade. Seven studies measured optical differences and found a difference between groups, while processing or ageing altered at least one outcome in seven studies. Such unanimity is essential for interpretation: although the magnitude of strength values differs with different testing regimes, the direction of the strength-translucency trade-off does not.

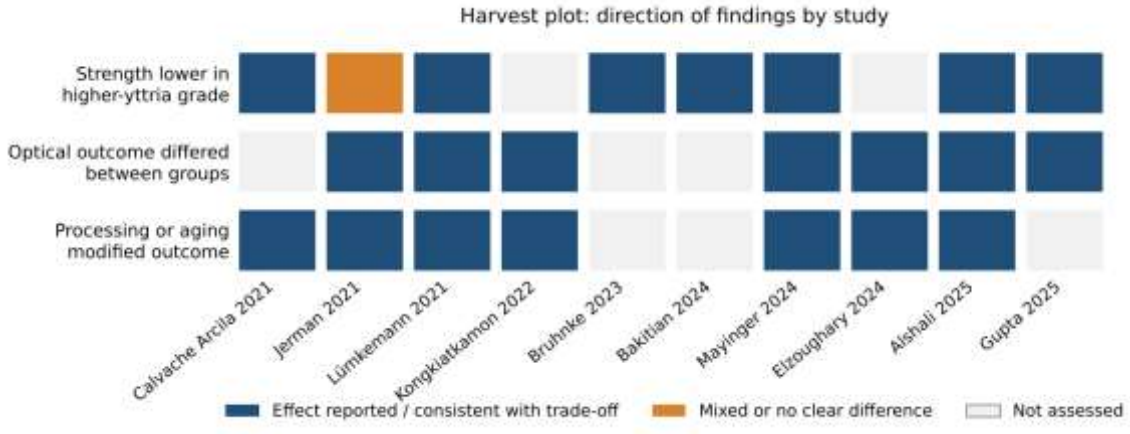

Figure 6. Harvest plot of the direction of findings in the ten included studies. Dark cells indicate that the effect was reported or consistent with the strength–translucency trade-off; the orange cell marks a study with a mixed or contrary result; grey cells indicate that the domain was not assessed.

3.7 Secondary evidence

Table 6 summarizes the clinical syntheses and systematic reviews that were selected for cross-validation of the main results. The laboratory reviews show a considerable agreement on the question of the nature of the compromise and the relevance of the testing procedures. The two syntheses from the clinical field imply a good performance of monolithic zirconia, when veneer chipping is avoided.

Table 6 Systematic reviews and clinical syntheses used as secondary evidence

Review (year)	Scope	Evidence base	Main conclusion
Fathy et al. (2021)	Strength and translucency of monolithic zirconia	53 in vitro studies (Oct 2009–Oct 2019)	Composition, microstructure and surface treatment affect both; higher-yttria grades lost some strength; ageing not a concern for high-yttria grades; care with thin sections.

Review (year)	Scope	Evidence base	Main conclusion
Al-Haj Husain et al. (2022)	Conventional, speed and high-speed sintering	15 in vitro studies	Mechanical and precision outcomes similar or better with faster protocols; 3Y translucency usually reduced by speed sintering; zirconia stronger than lithium disilicate, glass-ceramic more translucent.
Yousry et al. (2024)	Translucency of recent zirconia (PROSPERO CRD42023474482)	53 in vitro studies (2010–2023)	Yttria content, thickness, phase distribution, additives and sintering conditions control translucency; durability data needed.
Bernauer et al. (2025)	Flexural strength of translucent zirconia	78 laboratory studies	4Y 803 ± 233 MPa vs 5Y 570 ± 116 MPa; findings support 4Y for three-unit FDPs and 5Y for anterior three-unit FDPs per ISO 6872.
Shihabi & Chrcanovic (2023)	Tooth-supported monolithic vs porcelain-veneered zirconia FDPs	Clinical studies, meta-analysis	Veneered zirconia showed higher failure and complication rates, strikingly so for chipping.
Kim et al. (2022)	Implant-supported monolithic zirconia crowns/FDPs	644 restorations, up to 5 years	One failure; cumulative survival 99.84%; medium-term evidence lacking.

FDP = fixed dental prosthesis. Summaries reflect the authors' reported findings.

4. DISCUSSION

4.1 Principal findings

This review highlights an unrelenting and clinically relevant trade off: translucency is achieved at the expense of strength through enhancing yttria content and cubic phase. The degree of strength decrement is rather drastic for 5Y-PSZ and variable for 4Y-PSZ with values being dependent on aspect ratio/thickness, device configuration and processing variables. This explains why 4Y and 3Y zirconia have ranked inconsistently among different labs (Bernauer et al., 2025; Calvache Arcila et al., 2021). The proposed microstructural rationale is well supported: increased yttria content yields an increased volume of nontransferable cubic grains leading to reduced toughness and strength (Bernauer et al., 2025; Gupta et al., 2025; Calvache Arcila et al., 2021).

There is no clear link between the yttria content of the material and its properties. Calvache Arcila et al. (2021) cited biaxial strength data in which 4Y-PSZ outperformed 3Y-TZP at 0.7mm thickness, and that an extra-translucent grade had the highest flexural strength (Jerman et al. 2021), which is likely to reflect variations in processing, grain size and other factors rather than yttria content. An article in press for Mayinger et al. (2024) found the low strength of homogeneous 4Y-TZP material to be overcome by a gradient design, which also highlights the importance of considering the product and its processing in the selection of material.

4.2 Gradients and multilayers

The strength-gradient blanks intend to place a strong-to-strong zone in the incisal or occlusal regions with a stronger 3Y zone in the cervical and connector regions. The evidence is promising for fixed prostheses. The strongest dose response for the three-unit FDPs was for the 3/4Y gradient material. Mayinger et al. (2024) explicitly concluded that the new design allows high optical properties in the incisal area, and mechanical properties are preserved in the tensile- and flexural-stressed area. However,

Bakitian (2024) and Bruhnke et al. (2023) advise that multilayer products are not simply interchangeable. Differences in the strength of the same manufacturer's HTML, STML, and UTML blanks varied by a factor of two to three, and layers with differing yttria contents may have compromised the blank. Clinicians should consult for product-specific data instead of making assumptions based solely on a multilayer blank designation.

4.3 Processing, Glazing, and Ageing

The effects of glaze and multiple firing are not neutral in effect, glaze firing and multiple firing have shown to reduce the strength and colour of 5Y-PSZ, while 4Y-PSZ was more stable in both cases (Alshali et al., 2025). It is therefore preferable to glaze once and polish carefully where possible, although chairside sintering allows fast speed sintering protocols. The results are dependent upon the grade of zirconia: strength is probably preserved, but translucency may be reduced for 3Y-TZP (Al-Haj Husain et al., 2022) and the coloured 4Y-TZP may not be able to develop colour in a speed-sintering cycle (Lümkemann & Stawarczyk, 2021). There is currently ongoing work into surface treatment and accelerated ageing of zirconia (Pantea et al., 2025). Ageing effects should not be assumed to be negative for all grades; one study demonstrated an increase in strength for 3Y-TZP after autoclave ageing but a decrease for 5Y-TZP (Lümkemann & Stawarczyk, 2021). As autoclaving is an accelerated model with an uncertain in vivo link, the results for ageing can be taken as stress tests.

4.4 Clinical Implications

The above collective and clinical data justify a proposed selection rationale according to indications. For single crowns and limited anterior-span restorations with sufficient minimal wall thickness, 4Y-PSZ and 5Y-PSZ provide some aesthetic benefit. Bernauer et al. (2025) recommend 4Y-PSZ for three-unit FDPs and 5Y-PSZ for three-unit anterior FDPs in accordance with the strength levels given by ISO 6872, while for posterior multi-unit FDPs, thin preparations and high loading situations, the more justifiable alternative seems to be 3Y-TZP or a strength-gradient blank with a strongly reinforced cervical zone (according to fracture-load data for 3/4Y design of Mayinger et al., 2024). A handy summary is provided in Table 7; note that it reflects the consensus interpretation of the data by the reviewers rather than an "official" guideline.

Table 7 Suggested material selection by clinical scenario (interpretation of the synthesized evidence)

Clinical scenario	Preferred grade/design	Evidence-based rationale
Posterior multi-unit FDP, bruxism, thin preparation	3Y-TZP; 3Y/4Y gradient	Highest strength and fracture load; strength-gradient design retained fracture load in three-unit FDPs (Mayinger et al., 2024).
Posterior single crown, normal load	4Y-PSZ or gradient	Intermediate strength with improved translucency; 4Y most stable after glazing and firing (Alshali et al., 2025).
Anterior single crown, adequate thickness	4Y-PSZ or 5Y-PSZ	Highest translucency; 5Y reduced strength and fatigue life at 0.7 mm (Calvache Arcila et al., 2021).
Anterior three-unit FDP	4Y-PSZ; 5Y-PSZ only with adequate connector size	Bernauer et al. (2025) support 5Y for three-unit anterior FDPs under ISO 6872.
Chairside speed sintering	Grade-specific protocol	3Y translucency may fall; 4Y mechanics largely unaffected (Al-Haj Husain et al., 2022; Mayinger et al., 2024).

The scenarios are generalizations; individual product data and occlusal analysis should guide the final choice.

4.5.Clinical Syntheses / Laboratory Evidence

Contemporary clinical synthesises show that those laboratory disparities are less visible in survival data thus far. Tooth-supported monolithic zirconia demonstrated fewer complications relative to porcelain-veneered zirconia, chipping being the chief disadvantage (Shihabi & Chrcanovic, 2023). Implant-supported monolithic zirconia had a survival of 99.84% (644

restorations for up to five years), although the medium term data was deficient (Kim et al., 2022). These issues arguably facilitate the discontinuation of veneering porcelain, but do not sufficiently separate out the particular characteristics of the recent 4Y and 5Y zirconia grades.

4.6.Strengths and Limitations

The strengths of this review are the focus on data from 2020-25, the combination of mechanical and optical outcomes, and the triangulation of results with contemporary systematic reviews. The limitations are: 1) in all cases primary evidence was laboratory based and therefore the translation into clinical survival is indirect, 2) the samples examined had a wide variation in geometry, thickness, testing standards, sintering protocols and aging protocols therefore pool estimates were inappropriate. The pooled values from Bernauer et al. (2025) are therefore used as tables to describe the heterogeneity present, 3) some values are only available in the abstract form and absolute values in several studies such as the Mayinger et al. (2024) fracture loads data were not extracted, 4) the search was limited to the English language and 4 sources which may have led to bias in omission; the manufacturer represented a source of heterogeneity which could not be separated from the impact of yttria content, and 5) publication bias favoring large significant differences cannot be excluded.

4.7.Suggestions for future research

Future studies should report on specimen thickness, surface finish, sintering profile, testing protocol, and aging protocol as much as possible to allow for pooling of studies. Inclusion of a lithium di-silicate and 3Y-TZP control would be desirable. 3D printed and milled specimens and real restorations with load to fracture should be conducted, which are not as relevant as the anatomically shaped crowns and multi-unit FDPs with fatigue loading that would be more relevant clinically than flat discs. Optical testing should be limited to thickness specific translucency and color stability after glazing and aging, while clinical studies of 4Y, 5Y and gradient crowns for at least 5 years are recommended with at least one fracture, chipping, antagonist wear and color change reporting.

5.CONCLUSIONS

Though limited to the laboratory evidence, published studies from 2020 to 2025 suggest that translucency in modern dental zirconia comes at the expense of strength with biggest compromises with 5Y-PSZ, medium and variable levels of compromises with 4Y-PSZ and minimal compromises with 3Y-TZP and strength-gradients blanks. Clinical glazings, multiple firings, sintering protocols, aging and thickness affect both properties grade-dependently. 3Y-TZP and gradient materials are preferred for load bearing and multi-unit restorations, 4Y-PSZ is a reasonable compromise for single crowns and short spans, and 5Y-PSZ should be limited to anterior single-unit or limited-span restorations with high enough thickness. The new grades require standardized reporting and long-term clinical trials before they can be recommended for wider use.

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