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Systematic Review

Laboratory, Clinical-Related Processing and Time-Related Factors' Effect on Properties of High Translucent Zirconium Dioxide Ceramics Intended for Monolithic Restorations a Systematic Review

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Abstract: Because new zirconia materials are constantly being developed, the aim was to identify and qualitatively synthesize research on how processing and time-related factors affect the properties of high translucent (HT) zirconia intended for monolithic restorations. Cochrane Library, PubMed, Scopus, Web of Science, and reference lists were searched for in vitro and clinical studies. Eligibility and risk of bias were assessed. A synthesis of 142 publications was performed. HT 3Y-TZP was the most common, followed by 5YSZ, 4YSZ, and multilayer. In the laboratory, HT 3Y-TZP should be sintered according to the manufacturer's recommendation and polished before glazing to favour strength, roughness, and wear behaviour. In the clinic, polishing is necessary after grinding to favour roughness and aging resistance. Over time, when using hydrothermal aging, *t*–*m* phase transformation and reduced translucency are expected, without affecting the strength and roughness. The strength of 4YSZ and 5YSZ is unaffected. However, the time-related methods are of questionable clinical significance. The evidence of all other factors' effects on the properties of HT zirconia is lacking or limited; thus, these factors are of relevance for future research. There is a high heterogeneity of study designs and methods, and the results are brand-dependent.

Keywords: aging; crystalline phase; dental laboratory; glazing; flexural strength; manufacturing; material properties; polishing; sintering; YSZ

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1. Introduction

Zirconium dioxide, or zirconia, is a widely used material for fixed dental restorations due to its favourable mechanical properties, excellent biocompatibility, and comparatively good aesthetics [1,2]. Traditionally, yttrium oxide (yttria)-stabilized tetragonal zirconium dioxide polycrystal (Y-TZP) ceramics have been used as a core material veneered with porcelain to improve the aesthetic appearance. To overcome the commonly reported problem with veneering material fractures [3–6], full anatomical restorations made of monolithic zirconia have been introduced [7–9]. However, the optical properties and aesthetic appearance of the so-called first-generation zirconia were far from satisfactory. Therefore, more translucent materials have been developed, sometimes referred to as second- and third-generation zirconia, although they are not homogeneous groups [7,10,11]. Despite the somewhat limited data, these materials are used in patient treatments and are often handled in the same way during the production of a restoration; however, the material properties differ, affecting the success of the restoration and patient treatment.

Traditional zirconia has commonly been doped with 3 mol% yttria (3Y-TZP), corresponding to 5.15–5.35 wt%, to retain the tetragonal (*t*) crystalline phase at room temperature, enabling a stress-induced phase transformation to occur when the material is subjected to stresses [1,2,12–15]. Because the transformation of the *t* crystal grains into monoclinic (*m*) ones comprises a volume increase, generating compressive stresses, the crack propagation can be inhibited. This is the reason for the relatively high fracture toughness of traditional Y-TZP [1,12,13,15]. However, the metastable *t* phase also implies a susceptibility to low-temperature degradation (LTD), i.e., an undesirable *t*–*m* phase transformation causing microcracks and possibly grain pull-outs, consequently degrading the material [15–17].

In an effort to produce more translucent zirconia materials, modifications such as changes in the sintering temperature, dwell time, composition, microstructure, and crystalline phase have been made [7,10,18–20]. In the second-generation zirconia, introduced in 2011–2013 (defined as high translucent [HT] 3Y-TZP in this review), the amount of the sintering additive aluminium oxide (Al_2O_3, alumina) was reduced from approximately 0.25 wt% to 0.1–0.05 wt% [7,10,11]. In addition, a reduction in the grain size and reallocation of the alumina to the grain boundaries of the zirconia decreased the light scattering caused by the different refractive index, thereby improving the translucency to a certain extent [7,10,18]. Generating materials that consist of *t* as well as an increasing amount of cubic (*c*) crystalline phase, i.e., the third-generation zirconia, improves the translucency due to the isotropy and higher volume of the *c* crystalline phase compared to the birefringent *t* one, which results in a more even emission of light in all directions and less light scattering at the grain boundaries and porosities [10,18,19,21]. This is achieved by the endowment of yttria in concentrations of at least 4–5 mol% or 7.0–9.4 wt% (defined as 4- and 5YSZ, respectively, in this review) [7,10,18,22]. 5YSZ, containing approximately 50–70% *c* crystalline phase, was introduced in 2014–2015; further, 4YSZ, containing at least 25% *c* phase, was introduced in 2016 to find a middle ground between 3Y-TZP and 5YSZ [2,7,10,11,23–25]. However, the higher translucency is associated with a reduced flexural strength and fracture toughness, since the larger *c* grains are more brittle, implies fewer grain boundaries, and the unique *t*–*m* phase transformation ability is prevented [11,18,26–29]. In addition, multilayer materials have emerged consisting of either layers with different shades (shade-gradient) or layers with different material compositions regarding the crystalline phase and yttria content (composition-gradient) [20,30–34]. The composition-gradient materials combine high translucent incisal/occlusal layers with less-translucent but higher-strength cervical layers.

There is no consensus on how to name these materials; hence, different categorizations occur in the literature based on the stabilization type, such as yttria-stabilized zirconia (YSZ), partially stabilized zirconia (Y-PSZ), and fully stabilized zirconia (FSZ); the translucency degree, namely low, high, super, or ultra; or the yttria amount in mol%, such as 3Y-TZP and 4- and 5YSZ. Moreover, the amount of yttria can be expressed in either mol% or wt%, which are not mutually equivalent; thus, the unit has a significant impact. The large variety of available zirconia materials has caused a complex situation for the dental team as the material properties, and thus the indications and the handling, significantly differ between the materials.

In the dental laboratory, several processing steps—such as milling, sintering, individualization using immersion or staining techniques in the pre- or fully sintered stage, grinding, polishing, and glazing—are required to produce a restoration. In the clinic, adjustments of the approximal and occlusal contacts by grinding and polishing are needed to varying degrees. These processing factors might dramatically affect the material structure and properties and the final restoration's performance and longevity [35–37]. Furthermore, monolithic restorations are directly exposed to moisture, temperature changes, mechanical loading, and wear in the oral environment—time-related factors that are known to exacerbate the aging of zirconia [17,35,38,39].

Accordingly, it is essential to have knowledge about how the processing factors affect the materials' structure and properties in order to choose suitable laboratory and clinical procedures, ensure a proper handling of the materials, and thus provide predictable treatments. One processing factor might improve the flexural strength, but simultaneously reduce the translucency and increase the surface roughness, making it an inappropriate choice. The results from studies of traditional zirconia cannot be transferred to the later generations since the material compositions and behaviour might differ. A systematic approach is needed to summarize the available research on high translucent zirconia materials to clarify how processing factors affect the materials' properties. A comprehensive systematic review linking the processing factors during the manufacturing and time-related factors to the properties of specific zirconia types based on the quality assessment literature is important to the dental community.

This study aimed to identify and qualitatively synthesize research on how processing and time-related factors affect the properties of high translucent zirconium dioxide ceramics intended for monolithic restorations.

2. Materials and Methods

The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [40,41]. The protocol was registered on PROSPERO (232711) and can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021232711 (accessed on 12 March 2023) [42]. The following question was addressed:

How do laboratory and clinical-related processing factors and time-related factors affect the mechanical, physicochemical, surface, and optical material properties of high translucent zirconium dioxide ceramics intended for monolithic restorations?

The question was formulated according to Population, Intervention, Comparison, Outcomes and Study design (PICOS).

Population: High translucent zirconium dioxide ceramics for monolithic restorations.

Intervention: High translucent zirconium dioxide ceramics subjected to laboratory or clinical-related processing factors or time-related factors.

Comparison: A control group of zirconium dioxide as stated by the authors or as an untreated, standard treated, or treated according to the manufacturer's instructions group.

Outcome: Mechanical, physicochemical, surface, and optical material properties.

Study design: In vitro studies and clinical studies.

2.1. Definitions

High translucent zirconium dioxide ceramics were defined as oxide-stabilized zirconium dioxide ceramics intended for monolithic restorations and included materials with so-called high, super, and ultra translucency.

HT 3Y-TZP, 4YSZ, and 5YSZ zirconia types were defined as containing at least 3, 4, or 5 mol% yttria, respectively, and multilayer as composition-gradient.

Laboratory processing factors were defined as technical procedures conducted in or as if within a laboratory during the manufacturing process of a restoration and included CAM procedure, sintering, colouring, heat treatment, grinding, polishing, glazing, and airborne-particle abrasion.

Clinical-related processing factors were defined as technical procedures related to or conducted in or as if within a clinic during the manufacturing and finishing/adjustment process of a restoration and included chairside CAM procedure, sintering, grinding, and polishing.

Time-related factors were defined as aging and wear. Hydrothermal aging included autoclaving, thermocycling (TC), aging in a reactor or vessel, water and dry storage; mechanical aging included mechanical cyclic loading (ML) and thermocyclic-mechanical cyclic loading (TCML).

Mechanical properties were defined as any property describing how well the material withstands applied external forces, such as flexural strength, fracture toughness, load at fracture, and material loss.

Physicochemical properties were defined as any property that is inherent to the material, such as elastic modulus and hardness, including micro/atomic structures such as crystalline phase, elemental composition, and grain size, that affects the properties.

Surface properties were defined as any property closely related to the most superficial layer of the material, such as surface characterization and surface roughness.

Optical properties were defined as any property resulting from the interaction of the material with light at a wavelength of 400–700 nm, such as transmittance, translucency, contrast ratio (CR), colour, shade, colour difference (ΔE), and opalescence.

2.2. Inclusion and Exclusion Criteria

The inclusion criteria were original articles, in vitro studies, clinical studies, English language, abstract included, studies investigating properties of high translucent zirconium dioxide ceramics, and control group. The exclusion criteria were reviews and studies investigating bond strength, cementation surface or pre-treatment, fit, influence of restoration design, preparation design or finish line, use of subjective or experimental methods or materials, and patient-habit-related factors.

2.3. Search Strategy and Study Selection

An electronic search of the literature was conducted using the databases PubMed (the US National Library of Medicine), Cochrane Library (the Cochrane Collaboration), Scopus (Elsevier, Amsterdam, The Netherlands), and Web of Science (Clarivate, London, UK). In PubMed the following MeSH terms and free-text terms, in all fields, were used:

("Zirconium" [Mesh] OR zirconium OR zirconia OR zirconium dioxide OR Y-TZP) AND (translucent OR "monolithic" OR "full anatomical" OR "full contour" OR cubic OR multilayer OR FSZ OR 4Y-TZP OR 5Y-TZP) AND ("Heating" [Mesh] OR "Color" [Mesh] OR "computer aided manufacturing" OR milling OR "CAD CAM" OR sintering OR heat OR heating OR firing OR staining OR infiltrating OR color OR shade OR sandblasting OR airborne-particle abrasion OR glazing OR polishing OR grinding OR aging OR fatigue OR thermocycling OR thermal cycling OR LTD OR "low temperature degradation" OR wear OR abrasion).

The search strategies are presented in Supplemental Table S1. The searches were performed on 26 January 2021 and covered publications to that date. The publication year was set from 2010 to 2021 in Scopus and Web of Science. English was set as the language filter, except in Cochrane where it was unavailable. For additional eligible studies, the literature search was complemented with manual searches of the reference lists of identified reviews. Duplicates were removed in EndNote® X9 (Thomson Reuters, Philadelphia, PA, USA) referencing software according to the method of Bramer et al. [43].

Four reviewers (the authors CJ, EP, CL, and SFT) independently read the titles, and when at least one found a title relevant, the abstract was subsequently assessed for eligibility according to a protocol. The web application Rayyan (Qatar Computing Research Institute) was used for recording the decisions [44]. Potentially eligible publications were further analysed in full text and included when the eligibility criteria were met Figure 1. Any disagreements at the abstract and full text level were resolved by consensus. In the case of incomplete or unclear data, the corresponding author was contacted, and the study was re-evaluated and included only if adequate information was provided. One reminder was sent; hence, the total response period was at least four weeks. When study population overlaps were identified, the most recently published study was evaluated.

2.4. Data Extraction

Data from the publications were extracted and recorded in an Excel spreadsheet by one reviewer according to a pilot-tested protocol. For each reviewed study, the publication and affiliation, population, study characteristics, interventions, and outcomes were extracted.

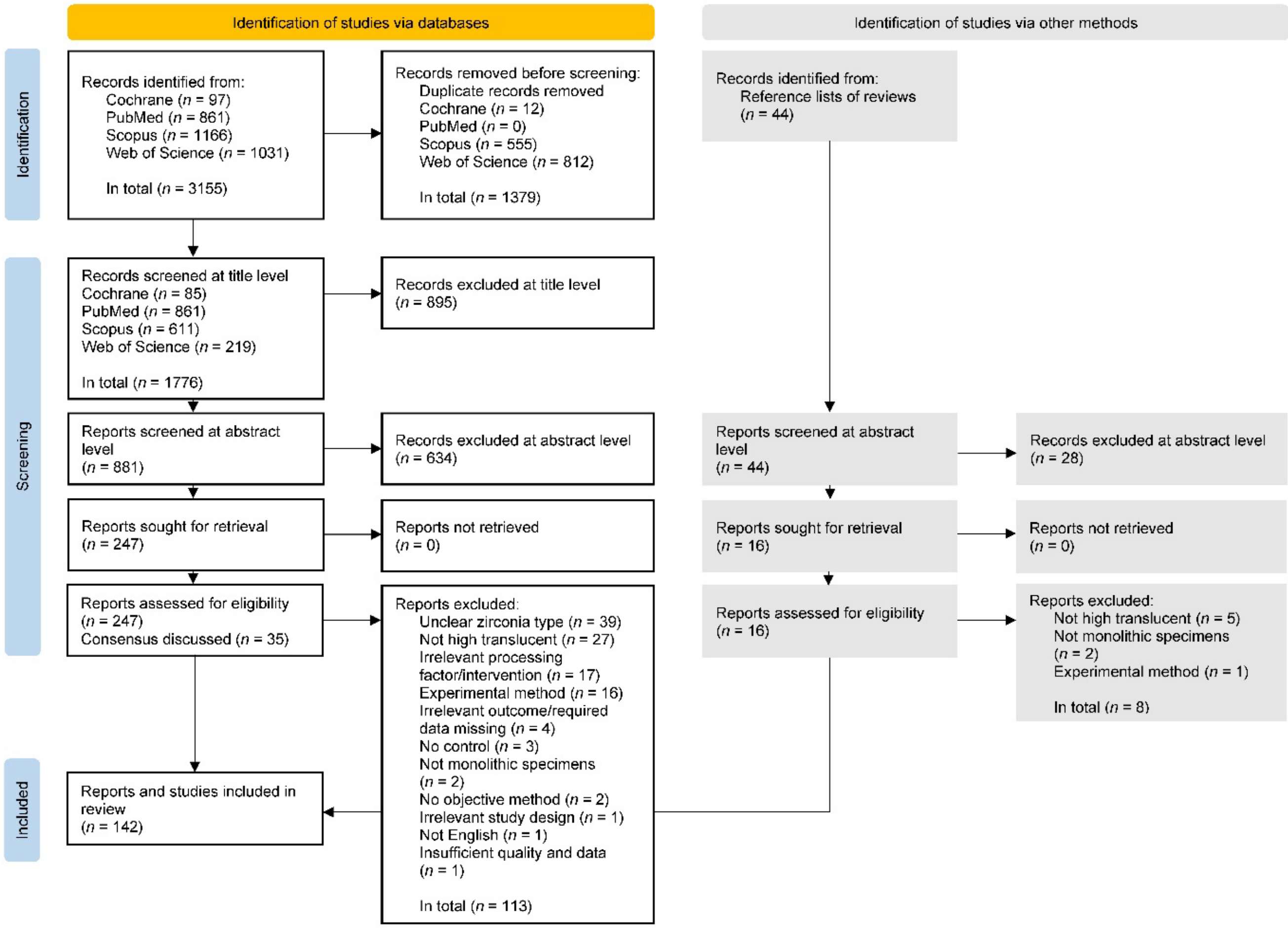

Figure 1. Flow diagram of the search strategy and results according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA): The PRISMA Statement.

2.5. Risk of Bias Assessment

The validation and relevance assessment were conducted at the study level (inclusion or not) and the quality assessment at the outcome level. The risk of bias (quality) of each study was independently assessed by two calibrated reviewers according to a pilot-tested protocol based on the tool from the Swedish Agency for Health Technology Assessment and Assessment of Social Services (SBU) for assessing RCTs and modified Consolidated Standards of Reporting Trials (CONSORT) for in vitro studies of dental materials [45–47]. The domain selection, performance, detection, attrition, report, and conflict of interest bias were assessed Supplemental Table S2. The quality of each domain and the overall risk of bias were assessed as low, moderate, or high. The overall risk of bias was determined as low if all domains were assessed as low; moderate if at least one domain was assessed as moderate; and high if at least one domain was assessed as high or at least four as moderate. Publications with a high risk of bias were only included in the descriptive study characteristics; thus, the results were not included in the qualitative synthesis.

2.6. Data Synthesis

A qualitative synthesis was performed due to the nature of the research question and heterogeneity within (multiple populations, interventions, outcomes) and between the included publications (different study designs, populations, controls, outcome measures). Meta-analyses regarding the effect of clinical grinding, polishing, and glazing on the surface roughness and on the flexural strength were performed and illustrated in forest plots. However, the high heterogeneity, assessed with the I^2 statistic and Cochran's Q test with a significance level of $\alpha = 0.05$, limited the data analysis. The characteristics of the publications were tabulated and summarized in descriptive text and figures, and the data were synthesized in text and visually presented in tables and figures. The materials were categorized into zirconia types, and the data were transformed into the same unit when possible. Zirconia types, processing factors, and properties were grouped in different ways to explore similarities, effects, and patterns.

3. Results

3.1. Search Strategy

The results of the search strategy are presented in Figure 1 and Supplemental Table S3. In total, 3155 publications were identified through the database searches and an additional 44 through manual searches of the reference lists of reviews. After de-duplication, screening on the title and abstract level, and assessment of eligibility at the full-text level, where 35 publications were discussed and resolved by consensus, 142 publications were included in the present review.

3.2. Study Characteristics

The publication period of the included publications ranged from 2012 to 2021, with the majority published in 2020 ($n = 44$) followed by 2019 ($n = 29$) and 2018 ($n = 26$) (Table 1). The publications originated from 27 countries, mainly from Brazil ($n = 27$) and Germany ($n = 24$). The assessment for risk of bias showed 35 publications as low-risk, 91 as moderate-risk, and 16 as high-risk [48–63], whereof two were clinical studies (Table 1). Insufficient presentation of results, limitations (report bias), materials and methods, or the performance thereof (performance/detection bias) were the main reasons for high risk of bias. The majority of the publications were in vitro studies, two were clinical studies and one study combined an in vitro and a clinical part [26–28,31–34,64–182] (Table 1).

Table 1. Study characteristics and risk of bias (low, moderate, high) of the included publications. Publication: author, year, country of origin; material: name, manufacturer, type of zirconia; factor: laboratory, clinical-, and time-related; and properties: mechanical, physicochemical, surface, and optical.

Author, Year	Country of Origin	Name of Material	Manufacturer	Type of Zirconia	Laboratory Processing Factors	Clinical-Related Processing Factors	Time-Related Factors	Mechanical Properties	Physicochemical Properties	Surface Properties	Optical Properties
Low Risk of Bias											
Al Hamad, 2019 [175]	Jordan	Zolid Fx	Amann Girrbach	5YSZ		Clinical grinding Clinical polishing				Characterization Roughness: Ra, Rz	
Alghazzawi, 2017 [181]	Saudi Arabia	Bruxzir DD-BioZX2 Katana HT NexxZr T Zenostar Zr translucent Zirlux FC2 DD-cubeX2	Glidewell Laboratories Dental Direkt GmbH Kuraray Noritake Dental Inc. Sagemax Bioceramics Inc. Ivoclar Vivadent Inc. Henry Schein Dental Direkt GmbH	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP 5YSZ			Hydrothermal aging: autoclave				Colour difference ΔE CR OP TP
Aliaga, 2020 [109]	Brazil	Prettau Zirkon	Zirkonzahn GmbH	HT 3Y-TZP		Clinical grinding		Flexural strength Weibull modulus	Crystalline phase	Characterization Roughness: Ra	
Auzani, 2020 [26]	Brazil	IPS e.max ZirCAD MT BL	Ivoclar Vivadent	4YSZ	Colouring: staining using brush, immersion technique			Flexural fatigue strength	Crystalline phase Grain size	Characterization Roughness: Ra Rz	Colour difference ΔE00 OP TP
Bömicke, 2016 [132]	Germany	Cercon ht	DeguDent GmbH	HT 3Y-TZP			Hydrothermal aging: thermocycling Mechanical aging: ML in water	Load at fracture			
Caglar, 2018 [159]	Turkey	Katana Zirconia HT	Kuraray-Noritake	HT 3Y-TZP		Clinical grinding Clinical polishing			Crystalline phase	Characterization Roughness: Ra	
Cardoso, 2020 [84]	Brazil	Prettau Anterior	Zirkonzahn	5YSZ	Sintering: final temperature			Flexural strength	Crystalline phase Grain size	Characterization	Absorption-scattering sum of light (S/A) Average reflectance Colour difference ΔE00 Opacity percentage TP
Choi, 2020 [123]	Republic of Korea	KATANA Zirconia HT KATANA Zirconia ML Lava Plus High Translucency Zirconia IPS e.max ZirCAD MT Lava Esthetic Fluorescent Full-Contour Zirconia IPS e.max ZirCAD MT Multi	Kuraray Noritake Dental Inc. Kuraray Noritake Dental Inc 3M ESPE Ivoclar Vivadent AG 3M ESPE Ivoclar Vivadent AG	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP multilayer shade 4YSZ 5YSZ multilayer shade Multilayer 4YSZ/5YSZ			Hydrothermal aging: autoclave	Characteristic strength Flexural strength Weibull modulus	Crystalline phase Elemental composition Hardness Young's modulus	Characterization Roughness: Ra	CR Transmittance
Chun, 2017 [96]	Brazil	Vita YZ HT	Vita Zahnfabrik	HT 3Y-TZP	Glazing	Clinical grinding Clinical polishing		Flexural fatigue strength	Crystalline phase	Roughness: Ra	
Dal Piva, 2020 [151]	The Netherlands	Vita YZ HT	Vita Zahnfabrik	HT 3Y-TZP	Colouring: external staining technique using brush Glazing		Wear: three-body wear, wear simulator	Material loss: vertical loss of extrinsic characterization		Characterization Roughness: Ra	
Dapieve, 2018 [110]	Brazil	Zirlux FC2 - Full-Contour zirconia	Ardent, INC, Ivoclar Vivadent	HT 3Y-TZP		Clinical grinding	Hydrothermal aging: autoclave, dry storage	Flexural fatigue strength	Crystalline phase	Characterization	
Ersoy, 2015 [80]	Turkey	InCoris TZI	SironaDental Systems GmbH	HT 3Y-TZP	Sintering: conventional, speed, super-speed			Flexural strength	Crystalline phase Grain size		
Fratucelli, 2021 [86]	Brazil	Prettau zirconia	Zirkonzahn	HT 3Y-TZP	Grinding Heat treatment: regenerative			Flexural strength Weibull modulus	Crystalline phase	Roughness: Ra, Rz	
Herpel, 2021 [177]	Germany	Cercon ht white	Dentsply Sirona	HT 3Y-TZP	Colouring: staining technique using brush	Clinical grinding					Colour difference ΔE00
Huh, 2018 [161]	Korea	Zenostar sun Zenostar sun chroma Zenostar T0	Ivoclar Vivadent Ivoclar Vivadent Ivoclar Vivadent	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP		Clincial grinding Clincial polishing			Elemental composition	Characterization Roughness: Ra	Lightness CIE L *
Jerman, 2021 [114]	Germany	Translucent T Extra Translucent ET High Translucent HT	Pritidenta GmbH Pritidenta GmbH Pritidenta GmbH	HT 3Y-TZP 4YSZ 5YSZ			Hydrothermal aging: autoclave Mechanical aging: TCML	Flexural strength Fracture toughness Weibull modulus	Grain size Hardness Indentation modulus		Transmittance
Juntavee, 2018 [76]	Thailand	VITA YZ HT colour	Vita Zahnfabrik	HT 3YTZP	Sintering: final temperature, short, regular, prolonged holding time			Flexural strength Weibull modulus Characteristic strength	Crystalline phase Grain size *		

Table 1. *Cont.*

Author, Year	Country of Origin	Name of Material	Manufacturer	Type of Zirconia	Laboratory Processing Factors	Clinical-Related Processing Factors	Time-Related Factors	Mechanical Properties	Physicochemical Properties	Surface Properties	Optical Properties
Low Risk of Bias											
Juntavee, 2018 [153]	Thailand	VITA YZ HT colour	Vita Zahnfabrik	HT 3Y-TZP	Sintering: final temperature, short, regular, prolonged holding time				Crystalline phase Grain size		Colour difference ΔE CR OP TP
Juntavee, 2020 [81]	Thailand	inCoris TZI	Sirona	HT 3Y-TZP	Sintering: slow, normal, fast cooling rate			Characteristic strength Flexural strength Weibull modulus	Crystalline phase Grain size		
Juntavee, 2019 [77]	Thailand	inCoris TZI	Sirona	HT 3Y-TZP	Sintering: slow, normal, fast cooling rate				Crystalline phase Grain size *		Colour difference ΔEw CR OP TP
Khayat, 2018 [94]	USA	Tizian Blank Translucent	Schütz	HT 3Y-TZP	Glazing	Clincial grinding Clinical polishing		Flexural strength		Characterization Roughness: Ra	
Kim, 2020 [88]	Korea	Luxen Zr Luxen Enamel Luxen Smile	Dentalmax Dentalmax Dentalmax	HT 3Y-TZP 4YSZ 5YSZ	Heat treatment: rapid cooling			Flexural strength Fracture toughness	Crystalline phase Grain size Hardness		Transmittance TP
Kou, 2019 [135]	Sweden	DD cubeX2 Prettau Anterior	DentalDirekt Zirkonzahn	5YSZ 5YSZ			Hydrothermal aging: autoclave	Flexural strength	Crystalline phase	Roughness: Ra	Transmittance
Nishioka, 2018 [139]	Brazil	Zirconia YZ HT	Vita Zahnfabrik	HT 3Y-TZP			Mechanical aging: ML	Flexural fatigue strength Flexural strength			
Oyar, 2020 [70]	Turkey	Upcera YZ HT Zircon X ST	Upcera DentalTechnology President Dental GmbH	HT 3Y-TZP HT 3Y-TZP	Sintering: heating rate, holding time		Hydrothermal aging: thermocycling	Flexural strength			
Pereira, 2016 [106]	Brazil	Zirlux FC	Ivoclar Vivadent, Amherst	HT 3Y-TZP		Clinical grinding	Hydrothermal aging: autoclave	Characteristic strength Weibull modulus	Crystalline phase Depth of transformed zone	Characterization Roughness: Ra, Rz	
Prado, 2020 [126]	Brazil	inCoris TZI Vita YZ HT	Dentsply Sirona Vita Zahnfabrik	HT 3Y-TZP HT 3Y-TZP			Hydrothermal aging: isothermal reactor	Characteristics strength Flexural strength Weibull modulus Residual stress	Crystalline phase Grain size Hardness		
Putra, 2017 [164]	USA	Lava Plus High Translucency Katana Zirconia Super Translucent BruxZir Anterior Solid Zirconia Katana Zirconia Ultra Translucent	3M Oral Care Glidewell Laboratories Kuraray Noritake Kuraray Noritake	HT 3Y-TZP 4YSZ 5YSZ 5YSZ			Hydrothermal aging: autoclave		Crystalline phase Elemental composition Grain size		Transmittance
Sen, 2018 [66]	Turkey	Prettau Zirkonzahn Vita YZ HT Colour A2 Vita YZ HT White Prettau Anterior	Zirkonzahn Vita Zahnfabrik Vita Zahnfabrik Zirkonzahn	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP 5YSZ	Colouring: immersion technique. Sintering: final temperature			Flexural strength			TP
Skjold, 2020 [121]	Norway	DD Bio ZX2 DD cube X2	Dental Direkt Dental Direkt	HT 3Y-TZP 5YSZ			Mechanical aging: ML in water Hydrothermal aging: autoclave	Load at fracture	Grain size Hardness		
Walczak, 2019 [180]	Germany	BruxZir Solid Zirconia Cercon ht white LavaPlus Zenostar T0	Prismatic Dentalcraft, Inc Glidewell Laboratories DeguDent GmbH 3M Deutschland GmbH Wieland Dental+Technik GmbH & Co.	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP			Hydrothermal aging: autoclave				CR TP
Wiedenmann, 2020 [83]	Germany	Ceramill Zolid HT+	Amann Girrbach AG	4YSZ	Sintering: control, high-speed		Mechanical aging: TCML Wear: two-body wear, TCML	Load at fracture Material loss: volume loss			
Zimmermann, 2020 [101]	Switzerland	InCoris TZI	Dentsply Sirona	HT 3Y-TZP		Chairside CAM procedure: milling, grinding. Sintering: conventional, speed-fire, super-speed		Load at fracture		Characterization	
Zucuni, 2019 [105]	Brazil	Zenostar T	Ivoclar Vivadent	HT 3Y-TZP		Clincial grinding Clincial polishing		Flexural fatigue strength	Crystalline phase	Characterization Roughness: Ra, Rz	

Table 1. *Cont.*

Author, Year	Country of Origin	Name of Material	Manufacturer	Type of Zirconia	Laboratory Processing Factors	Clinical-Related Processing Factors	Time-Related Factors	Mechanical Properties	Physicochemical Properties	Surface Properties	Optical Properties
Low Risk of Bias											
Zucuni, 2017 [87]	Brazil	Zenostar T	Ivoclar Vivadent	HT 3Y-TZP	Heat treatment: regenerative Glazing	Clinical grinding Clinical polishing		Flexural fatigue strength Flexural strength	Crystalline phase	Characterization Roughness: Ra, Rz	
Moderate risk of bias											
Abdelbary, 2016 [179]	Egypt	InCoris TZI	Sirona	HT 3Y-TZP			Hydrothermal aging: autoclave				TP
Abdulmajeed, 2020 [141]	Finland	Katana High Translucent Katana Super Translucent Multi Layered Katana Ultra Translucent Multi Layered	Kuraray Noritake Inc Kuraray Noritake Inc Kuraray Noritake Inc	HT 3Y-TZP 4YSZ 5YSZ			Mechanical aging: TCML	Load at fracture			
Abouelenien, 2020 [144]	Egypt	Prettau Zirconia	Zirkonzahn	HT 3Y-TZP	Polishing Glazing		Wear: two-body wear, ML	Material loss: weight loss		Characterization	
Agingu, 2018 [64]	China	Katana HT SuperfectZir HTS	Kuraray Aidite	HT 3Y-TZP HT 3Y-TZP	Colouring: immersion technique		Hydrothermal aging: autoclave	Flexural strength	Crystalline phase Depth of transformed zone		
Al-Haj Husain, 2016 [158]	Switzerland	Katana Zirconia HT	Kuraray-Noritake	HT 3Y-TZP		Clincial grinding Clinical polishing			Crystalline phase Elemental composition	Characterization Roughness: Ra	
Al-Haj Husain, 2018 [112]	Switzerland	Katana Zirconia HT	Kuraray-Noritake	HT 3Y-TZP		Clincial grinding Clinical polishing		Material loss: weight loss, volume loss, vertical loss after polishing		Characterization Roughness: Ra Wettability	
Aldegheishem, 2015 [147]	Germany	Zenostar Cercon HT	Wieland DeguDent	HT 3Y-TZP HT 3Y-TZP			Wear: two-body wear, TCML	Material loss: volumetric loss	Crystalline phase	Characterization	
Alghazzawi, 2015 [115]	Saudi Arabia	Argen HT BruxZir DD BioZX2 Lava Plus High Translucency ZenoStar Zirlux	Argen Corp. Glidewell Laboratories Dental Direkt 3M ESPE Wieland Dental Ardent	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP			Hydrothermal aging: autoclave	Crown strength Flexural strength	Grain size Elemental composition		
Aljanobi, 2020 [165]	Saudi Arabia	Prettau 2 Dispersive Prettau 4 Anterior Dispersive	Zirkonzahn GmbH Zirkonzahn GmbH	HT 3Y-TZP Multilayer shade 5YSZ multilayer shade			Hydrothermal aging: thermocycling		Grain size		Colour difference ΔE TP
Almansour, 2018 [130]	Saudi Arabia	Ceramill Zolid White HT Copran Zr-i Monolith HT Lava Plus HT	Amann Girrbach White Peaks 3M ESPE	HT 3Y-TZP HT 3Y-TZ HT 3Y-TZP			Hydrothermal aging: thermocycling Mechanical aging: ML in water	Flexural strength			
Alraheam, 2019 [182]	USA	BruxZir Shaded Zirconia BruxZir Anterior Solid Zirconia	Glidewell Laboratories Glidewell Laboratories	HT 3Y-TZP 5YSZ			Mechanical aging: TCML				CR Light blockage TP
Amaral, 2018 [103]	Brazil	Zirlux FC	Amherst	HT 3Y-TZP		Clincial grinding	Hydrothermal aging: autoclave	Flexural fatigue strength Slow crack growth susceptibility	Crystalline phase Depth of the transformed zone Hardness	Characterization Roughness: Ra, Rz	
Amarante, 2020 [128]	Brazil	VIPI Block Zirconn Translucent VIPI Block Zirconn High-translucent	VIPI VIPI	HT 3Y-TZP 5YSZ			Hydrothermal aging: reactor	Flexural strength Weibull modulus	Crystalline phase Grain size	Roughness: Ra, Rz	CR
Amer, 2015 [170]	USA	Crystal diamond, Crystal Zirconia	Dental Laboratory Milling Supplies	HT 3Y-TZP	Glazing	Clinical grinding Clinical polishing	Wear: three-body wear, wear simulator			Roughness: Ra	
Asli, 2019 [99]	Iran	Ceramill Zolid Fx multilayer	Amann Girrbach	5YSZ	Grinding Glazing	Clinical grinding Clinical polishing		Flexural strength			
Bergamo, 2016 [129]	Brazil	Ceramill Zolid	Amann Girrbach	HT 3Y-TZP			Hydrothermal aging: reactor, thermocycling Mechanical aging: ML in water	Characteristic load at fracture Load at fracture Weibull modulus	Crystalline phase	Characterization	
Borba, 2021 [138]	USA	Zpex Zpex Smile	Tosoh Corporation Tosoh Corporation	HT 3Y-TZP 5YSZ			Mechanical aging: ML in water	Flexural strength		Characterization	
Chavali, 2017 [171]	USA	Zenostar Zr Translucent	Wieland	HT 3Y-TZP	Glazing	Clinical polishing				Characterization Roughness: Ra	Gloss
Cokic, 2020 [73]	Belgium	CEREC Zirconia medi S inCoris TZI Katana STML Katana STML, 12Z	Dentsply Sirona Dentsply Sirona Kuraray Noritake Kuraray Noritake	HT 3Y-TZP HT 3Y-TZP 4YSZ 4YSZ	Sintering: conventional, speed		Hydrothermal aging: autoclave	Characteristic strength Flexural strength Fracture toughness Weibull modulus	Crystalline phase Density Elemental composition Grain size Hardness		CR TP

Table 1. *Cont.*

Low Risk of Bias											
Author, Year	**Country of Origin**	**Name of Material**	**Manufacturer**	**Type of Zirconia**	**Laboratory Processing Factors**	**Clinical-Related Processing Factors**	**Time-Related Factors**	**Mechanical Properties**	**Physicochemical Properties**	**Surface Properties**	**Optical Properties**
Coskun, 2019 [166]	Turkey	Katana ML	Noritake	HT 3Y-TZP multilayer shade	Sintering: speed, high-speed					Roughness: Ra	CR TP
D'Arcangelo, 2018 [145]	Italy	Katana Zirconia ML	Kuraray Noritake Dental Inc	HT 3Y-TZP Multilayer shade			Wear: two-body wear, ML	Material loss: vertical loss, volumetric loss		Characterization	
de Araújo-Júnior, 2020 [120]	Brazil	Zirconn translucent	VIPI	HT 3Y-TZP			Hydrothermal aging: autoclave, reactor	Residual stress: compressive stress Fracture toughness Characteristic strength Flexural strength Weibull modulus	Crystalline phase Grain size Hardness		CR TP
De Souza, 2020 [102]	Brazil	Vipi Block Zirconn Translucent	Vipi	HT 3Y-TZP		Clinical grinding Clinical polishing	Hydrothemral aging: autoclave, thermocycling	Flexural strength	Crystalline phase	Characterization Roughness: Ra	
Fathy, 2015 [162]	Egypt	Zirkonzahn Prettau	Zirkonzahn	HT 3YTZP			Hydrothermal aging: autoclave		Crystalline phase Grain size		TP
Flinn, 2017 [118]	USA	Prettau BruxZir Katana HT13 Katana ML	Zirkonzahn Glidewell Laboratories Kuraray Noritake Kuraray Noritake	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP multilayer shade			Hydrothermal aging: autoclave	Flexural strength	Crystalline phase Depth of transformed zone Elemental composition		
Gomes, 2018 [154]	Portugal	Prettau Zirkon	Zirkonzahn	HT 3Y-TZP	Colouring: immersion technique				Grain size		Transmittance
Goo, 2016 [174]	Malaysia	LAVA PLUS High Translucency	3M ESPE	HT 3Y-TZP		Clinical polishing				Characterization Roughness: Ra	
Güngör, 2019 [140]	Turkey	Incoris TZI	Sirona Dental Systems	HT 3YTZP			Mechanical aging: TCML	Load at fracture			
Harada, 2020 [119]	Japan	Lava Plus Zirconia Lava Esthetic Zirconia	3M ESPE 3M ESPE	HT 3Y-TZP 5YSZ multilayer shade			Hydrothermal aging: autoclave	Characteristic strength Weibull modulus	Crystalline phase Depth of transformed zone Hardness		
Hatanaka, 2020 [93]	Brazil	Prettau. Prettau Anterior	Zirkonzahn Zirkonzahn	HT 3Y-TZP 5YSZ	Glazing	Clinical grinding Clinical polishing	Hydrothermal aging: autoclave	Characteristic strength Flexural strength Weibull modulus	Depth of transformed zone	Roughness: Ra	
Holman, 2020 [28]	USA	Katana ML Lava Plus Katana STML Katana UTML Lava Esthetic	Kuraray Noritake Dental 3M ESPE Kuraray Noritake Dental Kuraray Noritake Dental 3M ESPE	HT 3Y-TZP HT 3Y-TZP multilayer shade 4YSZ multilayer shade 5YSZ multilayer shade 5YSZ multilayer shade			Mechanical aging: ML	Flexural fatigue strength Flexural strength			
Jerman, 2020 [74]	Germany	Ceramill Zolid Ceramill Zolid HT+	Amann Girrbach AG Amann Girrbach AG	HT 3Y-TZP 4YSZ	Sintering: conventional, high-speed		Hydrothermal aging: autoclave Mechanical aging: TCML	Flexural strength Weibull modulus			
Jum'ah, 2020 [168]	Jordan	DD Bio ZX DD cube ONE DD cubeX2	DentalDirekt GmbH	HT 3Y-TZP 4YSZ 5YSZ	Glazing	Clinical grinding Clinical polishing				Characterization Roughness: Ra	
Kashkari, 2019 [137]	USA	Prettau Zirconia	Zirkonzahn	HT 3Y-TZP			Mechanical aging: ML in water	Load at fracture			
Kengtanyakich, 2020 [134]	Thailand	Vita YZ ST Vita YZ XT Prettau Anterior	VITA Zahnfabrik VITA Zahnfabrik Zirkonzahn GmbH	4YSZ 5YSZ 5YSZ			Hydrothermal aging: autoclave	Flexural strength Fracture toughness	Crystalline phase Hardness		
Kim, 2019 [163]	Korea	Katana ML	Kuraray Noritake	HT 3Y-TZP Multilayer shade			Hydrothermal aging: autoclave		Crystalline phase	Characterization Roughness: Ra	Colour differences ΔE00 TP
Koenig, 2019 [152] (Clinical study)	Belgium	Lava Plus High Translucency Zirconia	3M ESPE	HT 3Y-TZP			Clinical wear	Clinical material loss: vertical loss			
Kolakarnprasert, 2019 [32]	USA	Katana ML Katana STML Katana UTML	Kuraray Noritake Kuraray Noritake Kuraray Noritake	HT 3Y-TZP multilayer shade 4YSZ multilayer shade 5YSZ multilayer shade			Hydrothermal aging: hydrothermal vessel		Crystalline phase		

Table 1. *Cont.*

Low Risk of Bias

Author, Year	Country of Origin	Name of Material	Manufacturer	Type of Zirconia	Laboratory Processing Factors	Clinical-Related Processing Factors	Time-Related Factors	Mechanical Properties	Physicochemical Properties	Surface Properties	Optical Properties
Kumchai, 2018 [90]	USA	InCoris TZI Prettau Zirconia Zirlux FC	Sirona Zirkonzahn Pentron Ceramics	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP	Heat-treatment: glaze firing cycle. Glazing			Flexural strength			
Kwon, 2018 [149]	USA	Katana HT Katana UTML	Kuraray Noritake Dental Kuraray Noritake Dental	HT 3Y-TZP 5YSZ multilayer shade			Wear: two-body wear, wear simulator	Material loss: volumetric material loss			
Lai, 2017 [91]	China	ST (super-translucent)	UPCERA	HT 3Y-TZP	Glazing	Clinical grinding	Hydrothermal aging: autoclave	Characteristic strength Flexural strength Weibull modulus	Crystalline phase Elastic modulus Hardness	Characterization	
Lawson, 2020 [82]	USA	Katana STML Prettau Anterior	Kuraray Noritake Zirkonzahn	4YSZ multilayer shade 5YSZ multilayer shade	Sintering: conventional, high-speed, custom high-speed			Flexural strength	Grain size		TP
Lee, 2019 [172]	Korea	Prettau	Zirkonzahn	HT 3Y-TZP		Clinical grinding Clincial polishing				Characterization Roughness: Ra	
Lopez-Suarez, 2019 [143]	Spain	Lava Plus	3M ESPE	HT 3Y-TZP			Mechanical aging: TCML	Characteristic load at fracture Load at fracture Weibull modulus			
Ludovichetti, 2018 [148]	Brazil	Lava Plus	3M ESPE	HT 3Y-TZP			Wear: two-body wear, wear simulator	Material loss: material loss			
Lümkemann, 2021 [69]	Germany	CeramillZolid. Ceramill Zolid fx. Ceramill Zolid ht+ Ceramill zolid ht+ Preshades	Amann Girrbach AG Amann Girrbach AG Amann Girrbach AG Amann Girrbach AG	HT 3Y-TZP 5YSZ 4YSZ 4YSZ	Colouring: immersion technique Sintering: conventional, high-speed (4YSZ)		Hydrothermal aging: autoclave	Flexural strength			Transmittance
Mai, 2019 [156]	Korea	Prettau	Zirkonzahn	HT 3Y-TZP		Clinical grinding Clinical polishing			Crystalline phase	Roughness: Ra	
Manziuc, 2019 [169]	Romania	IPS e. max ZirCAD MT Katana HT Vita YZ HT Cercon HT	Ivoclar Vivadent Kuraray Noritake Dental Inc. VITA Zahnfabrik Dentsply Sirona	4YSZ HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP	Glazing					Roughness: Ra	Colour difference ΔE00 TP
Michailova, 2020 [33]	Germany	Katana Zirconia STML Block Katana Zirconia STML Disc IPS e. max ZirCAD Prime	Kuraray Noritake Dental Kuraray Noritake Dental Ivoclar Vivadent	4YSZ multilayer shade 4YSZ multilayer shade Multilayer 3Y-TZP/5YSZ	CAM procedure Sintering: conventional	Chairside CAM procedure. Sintering: high-speed (4YSZ)	Mechanical aging: TCML Wear: two-body wear, TCML	Load at fracture Material loss: volumetric loss, vertical loss Weibull modulus			Transmittance
Moqbel, 2019 [111]	Germany	Katana HT10	Kuraray	HT 3Y-TZP		Clinical polishing	Hydrothermal aging: autoclave	Flexural strength	Crystalline phase Hardness	Roughness: Ra, Rz	
Muñoz, 2017 [27]	Brazil	Prettau Prettau Anterior	Zirkonzahn Zirkonzahn	HT 3Y-TZP 5YSZ			Hydrothermal aging: autoclave Mechanical aging: ML in water	Characteristic strength Flexural strength Weibull modulus	Crystalline phase Grain size	Characterization	
Nakamura, 2018 [127]	Japan	Lava Plus High Translucency Zirconia	3M ESPE	HT 3Y-TZP			Hydrothermal aging: water storage, thermocycling Mechanical aging: ML in water	Load at fracture Residual stress: von Mises stress			
Nakamura, 2015 [124]	Japan	Lava Plus High Translucency Zirconia	3M ESPE	HT 3Y-TZP			Hydrothermal aging: autoclave Mechanical aging: ML in water	Load at fracture	Crystalline phase Depth of transformed zone		
Nakamura, 2020 [78]	Japan	inCoris TZI	Dentsply Sirona	HT 3Y-TZP	Sintering: conventional, high-speed		Hydrothermal aging: decomposition vessel	Load at fracture	Crystalline phase		
Nam, 2018 [89]	Korea	Lava plus	3M ESPE	HT 3Y-TZP	Glazing		Hydrothermal aging: autoclave	Flexural strength	Crystalline phase Grain size	Characterization	
Nossair, 2019 [65]	Egypt	Bruxzir shaded A2 Bruxzir unshaded Katana HT shade A2 Katana HT white Prettau unshaded Katana ST shade A2 Katana ST white Bruxzir anterior white Bruxzir anterior shade A2 Prettau anterior white	Glidewell Glidewell Kuraray Kuraray Zirkonzahn Kuraray Kuraray Glidewell Glidewell Zirkonzahn	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP 4YSZ 4YSZ 5YSZ 5YSZ 5YSZ	Colouring: immersion technique			Flexural strength			

Table 1. *Cont.*

Low Risk of Bias											
Author, Year	**Country of Origin**	**Name of Material**	**Manufacturer**	**Type of Zirconia**	**Laboratory Processing Factors**	**Clinical-Related Processing Factors**	**Time-Related Factors**	**Mechanical Properties**	**Physicochemical Properties**	**Surface Properties**	**Optical Properties**
Oblak, 2017 [136]	Slovenia	inCoris TZI	Sirona	HT 3Y-TZP			Mechanical aging: ML in water	Characteristic load at fracture Load at fracture Weibull modulus			
Ozer, 2018 [108]	Turkey	Prettau	Zirkonzahn	HT 3Y-TZP		Clinical polishing		Flexural strength Weibull modulus	Crystalline phase	Characterization	
Pereira, 2018 [122]	Brazil	Katana ML/HT Katana STML Katana UTML	Kuraray Noritake Dental Inc Kuraray Noritake Dental Inc Kuraray Noritake Dental Inc	HT 3Y-TZP multilayer shade 4YSZ multilayer shade 5YSZ multilayer shade			Hydrothermal aging: autoclave	Characteristic strength Flexural fatigue strength Weibull modulus	Crystalline phase	Characterization	
Pereira, 2016 [104]	Brazil	Zirlux FC	Ivoclar Vivadent	HT 3Y-TZP		Clinical grinding	Hydrothermal aging: autoclave	Flexural fatigue strength Flexural strength	Crystalline phase	Characterization Roughness: Ra, Rz	
Pfefferle, 2020 [97]	Germany	Ceramill Zolid HT+	Amann Girrbach	4YSZ	Polishing: pre-sintered, fully sintered stage			Flexural strength		Free energy SFE Roughness: Ra	Transmittance
Poole, 2019 [125]	Brazil	ZirkOM SI	Qinhuangdao Aidite High-Technical Ceramics Co. Ltd	HT 3Y-TZP			Hydrothermal aging: autoclave	Flexural strength Fracture toughness	Crystalline phase Hardness	Roughness: Ra	
Prado, 2017 [107]	Brazil	Zirlux FC	Ardent Dental Inc	HT 3Y-TZP		Clincial grinding	Hydrothermal aging: autoclave	Characteristics strength Weibull modulus	Crystalline phase Depth of transformed zone	Characterization Roughness: Ra, Rz	
Preis, 2015 [157]	Germany	Cercon HT	DeguDent	HT 3Y-TZP		Clincial grinding Clincial polishing	Wear: two-body wear, wear simulator		Crystalline phase Elemental composition	Characterization Roughness: Ra	
Rafael, 2018 [176]	Brazil	Prettau	Zirkonzahn	HT 3Y-TZP	Colouring: immersion technique		Hydrothermal aging: autoclave				Colour difference $\Delta E00$ Fluorescence Lightness, chroma, hue
Rosentritt, 2020 [142]	Germany	DD Bio ZX2 DD cube ONE DD cube ONE Multilayer ML DD cubeX2	Dental Direkt Dental Direkt Dental Direkt Dental Direkt	HT 3Y-TZP 4YSZ 4YSZ multilayer shade 5YSZ			Mechanical aging: TCML Wear: two body wear, pin-on-block in water	Load at fracture Material loss: wear depth		Roughness: Ra, Rz	
Rosentritt, 2020 [85]	Germany	IPS e.max ZirCAD Prime	Ivoclar Vivadent	Multilayer 3Y-TZP/5YSZ	Sintering: fast, normal, long			Load at fracture	Grain size		
Sabet, 2018 [155]	Egypt	inCoris TZI	Dentsply Sirona **	HT 3Y-TZP	Colouring: immersion technique. Sintering: final temperature				Grain size		TP
Sanal, 2020 [178]	Turkey	Katana 12Z/STML A2 zirconia block Katana 12Z/STML A3 zirconia block	Kuraray Noritake Kuraray Noritake	4YSZ multilayer shade 4YSZ multilayer shade	Sintering: final temperature				Grain size		TP
Sarıkaya, 2018 [131]	Turkey	Incoris TZI	Sirona Dental Systems	HT 3Y-TZP			Hydrothermal aging: thermocycling Wear: two-body wear, ML in water	Load at fracture Material loss: volumetric loss		Characterization	
Schatz, 2016 [95]	Germany	Ceramill Zolid. DD Bio zx2 Zenostar Zr Translucent.	AmannGirrbach Wieland+Dental Dental Direkt	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP	Polishing: pre-sintered manually dry, fully sintered stage machine wet			Characteristic strength Flexural strength Weibull modulus	Crystalline phase	Characterization Roughness: Ra	
Schlenz, 2021 [150]	Germany	Lava Plus Priti multidisc ZrO_2 extra translucent Prettau anterior	3M ESPE Pritidenta Zirkonzahn	HT 3Y-TZP 4YSZ 5YSZ			Wear: two-body wear, ML in water	Material loss: vertical, horizontal damage			
Shen, 2019 [116]	China	Ceramill Zolid White Lava Plus Katana UTML	AmannGirrbach 3M ESPE Kuraray Noritake	HT 3Y-TZP HT 3Y-TZP 5YSZ			Hydrothermal aging: autoclave	Flexural strength	Crystalline phase Grain size Hardness		TP
Spies, 2020 [133]	Germany/ Belgium	Priti multidisc ZrO_2 translucent Priti multidisc ZrO_2 extra translucent Priti multidisc ZrO_2 high translucent	Pritidenta Pritidenta Pritidenta	HT 3Y-TZP 4YSZ 5YSZ			Hydrothermal aging: water storage Mechanical aging: TCML Wear: two-body wear, TCML	Load at fracture Material loss: intrusion depth, surface area, worn volume	Crystalline phase		

Table 1. *Cont.*

Author, Year	Country of Origin	Name of Material	Manufacturer	Type of Zirconia	Laboratory Processing Factors	Clinical-Related Processing Factors	Time-Related Factors	Mechanical Properties	Physicochemical Properties	Surface Properties	Optical Properties
Low Risk of Bias											
Stawarczyk, 2016 [117]	Germany	Ceramill Zolid DD Bio ZX2 InCoris TZI Zenostar	Amann Girrbach Dental Direkt Sirona Wieland+Dental	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP			Hydrothermal aging: autoclave Mechanical aging: TCML Wear: two-body wear, TCML	Flexural strength Material loss: volume loss Weibull modulus			
Stawarczyk, 2013 [146]	Switzerland	ZENOTEC Zr Bridge transluzent	Wieland Dental + Technik	HT 3Y-TZP	Polishing: manually, mechanically Glazing		Wear: two-body wear, TCML	Material loss: vertical loss		Characterization	
Sulaiman, 2015 [67]	Finland	Prettau Zirconia Prettau Anterior	Zirkonzahn Zirkonzahn	HT 3Y-TZP 5YSZ	Colouring: staining technique using brush. Sintering: non-vacuum, vacuum			Flexural strength		Characterization	CR Gloss TP
Sulaiman, 2017 [68]	USA	Prettau zirconia Prettau anterior	Zirkonzahn Zirkonzahn	HT 3Y-TZP 5YSZ	Colouring: staining technique using brush, immersion technique. Sintering: regular, vacuum		Hydrothermal aging: autoclave	Flexural strength	Grain size		
Tachibana, 2021 [167]	Japan	inCoris TZI	Sirona	HT 3Y-TZP	Polishing Grinding		Wear: two-body wear, ML in water			Roughness: Ra	
Vardhaman, 2020 [34]	USA	IPS e.max ZirCAD LT IPS e.max ZirCAD Multi	Ivoclar Vivadent Ivoclar Vivadent	HT 3Y-TZP Multilayer 4YSZ/5YSZ			Wear: two-body wear, wear simulator	Material loss: volume loss, wear depth		Characterization	
Vila-Nova, 2020 [98]	Brazil	Prettau Anterior	Zirkonzahn	5YSZ	Glazing	Clinical grinding Clinical polishing	Hydrothermal aging: autoclave	Characteristic strength Flexural strength Weibull modulus	Crystalline phase Elemental composition	Characterization Roughness: Ra	
Wille, 2018 [113]	Germany	IPS e.max ZirCAD Katana Zirconia ML Lava Plus	Ivoclar Vivadent Kuraray 3M ESPE	HT 3Y-TZP HT 3Y-TZP multilayer shade HT 3Y-TZP			Hydrothermal aging: autoclave	Flexural strength	Crystalline phase		
Yang, 2020 [75]	Taiwan	Copran Zr-i Ultra-T A2 Copran Zr-i Ultra-T white Cercon HT Cercon XT	Whitepeaks dental Whitepeaks dental Dentsply Sirona Dentsply Sirona	HT 3Y-TZP HT 3Y-TZP HT 3Y-TZP 5YSZ	Sintering: conventional, rapid			Characteristic strength Flexural strength Weibull modulus	Crystalline phase Grain size Hardness	Characterization	Colour difference ΔE TP
Yu, 2019 [31]	Korea	3M Lava Esthetic	3M	5YSZ	Colouring: immersion technique, acid-based, aqueous colouring liquids			Flexural strength		Characterization	
Zucuni, 2019 [92]	Brazil	Vita YZ-HT	Vita Zahnfabrik	HT3-YTZP	Glazing: powder/liquid by brush, spray	Clinical grinding		Flexural strenght Flexural fatigue strenght	Crystalline phase	Characterization Roughness: Ra, Rz	
Zucuni, 2020 [100]	Brazil	ZirCAD MT Multi	Ivoclar Vivadent	Multilayer 4YSZ 5YSZ	Glazing	Clinical grinding Clinical polishing		Flexural fatigue strength Weibull modulus	Crystalline phase	Characterization Roughness: Ra, Rz	
Öztürk, 2019 [71]	Turkey	Incoris TZI C Upcera ***	Sirona Dental Systems GmbH Shenzhen Upcera Co. Ltd.	HT 3Y-TZP	Sintering: final temperature, holding time			Flexural strength	Crystalline phase	Roughness: Ra	
Öztürk, 2019 [72]	Turkey	Upcera ST-Colour	Shenzhen Upcera Dental Technology Co., Ltd	HT 3Y-TZP	Sintering: heating rate			Characteristics strength Flexural strength Weibull modulus	Crystalline phase Grain size		
High risk of bias ****											
Ahmed, 2020 [48]	Egypt	DD cube X2	Dental Direkt **	5YSZ			Hydrothermal aging: autoclave	Flexural strength			Colour difference ΔE CR TP
Alraheam, 2020 [49]	USA	BruxZir Shaded Zirconia BruxZir Anterior Solid Zirconia	Glidewell Laboratories Glidewell Laboratories	HT 3Y-TZP 5YSZ			Mechanical aging: TCML	Load at fracture			
Ban, 2013 [50]	Japan	Zenostar pure Zirkonzahn Prettau	Wieland Zirkonzahn	HT 3Y-TZP HT 3Y-TZP	Colouring: immersion technique			Flexural strength			Colour difference ΔE
Camposilvan, 2018 [51]	France	Aadva EI Aadva NT Katana UTML	Aadva, GC Tech Aadva, GC Tech Kuraray Noritake Dental Inc.	HT 3Y-TZP 5YSZ 5YSZ multilayer shade	Polishing Glazing		Hydrothermal aging: autoclave	Flexural strength Fracture toughness	Crystalline phase Grain size Hardness		CR Transmittance

Table 1. *Cont.*

Low Risk of Bias											
Author, Year	**Country of Origin**	**Name of Material**	**Manufacturer**	**Type of Zirconia**	**Laboratory Processing Factors**	**Clinical-Related Processing Factors**	**Time-Related Factors**	**Mechanical Properties**	**Physicochemical Properties**	**Surface Properties**	**Optical Properties**
Cattani-Lorente, 2016 [52]	Switzerland	Lava Plus	3M ESPE	HT 3Y-TZP		Clincial grinding	Hydrothermal aging: autoclave, water storage		Crystalline phase Depth of transformed zone Elastic modulus Hardness	Characterization Roughness: Ra	
Elsayed, 2019 [53]	Germany	DD Bio ZX2 DD cubeX2 HS DD cubeX2	Dental Direkt Dental Direkt Dental Direkt	HT 3Y-TZP 4YSZ 5YSZ			Mechanical aging: TCML	Load at fracture			
Fontolliet, 2020 [54]	Switzerland	Zenostar Zr Translucent	Wieland Dental	HT 3Y-TZP	Glazing	Clinical polishing	Wear: two-body wear, ML	Material loss: weight loss, volume loss, vertical loss		Roughness: ΔRz, ΔRa	
Gaonkar, 2020 [55]	India	Ceramill Zolid HT	Amann Girrbach	HT 3Y-TZP	Glazing	Clinical polishing				Characterization Roughness: Ra	
Habib, 2019 [56]	Saudi Arabia	Zolid fx preshade	Amann Girrbach	5YSZ			Wear: two-body wear, TCML	Material loss: vertical loss, weight loss		Characterization Roughness *****	
Kaizer, 2017 [57]	USA	inCoris TZI	Sirona	HT 3Y-TZP	Sintering: long-term, speed, super-speed		Wear: two-body wear, TCML	Material loss: wear depth, volume loss	Crystalline phase Grain size Hardness		TP
Kumar, 2020 [58]	India	Ceramill Zolid	Amann Girrbach	HT 3Y-TZP			Wear: three-body wear, pin-on-disc	Material loss: weight loss		Roughness: Ra	
Park, 2014 [59]	Korea	Prettau ZirBlank *** Zeno Zr ***	Zirkonzahn GmbH Acucera Inc. Wieland Dental	HT 3Y-TZP	Colouring: external staining technique using brush. Polishing Glazing		Wear: two-body wear, ML in water			Characterization Roughness *****	
Preis, 2012 [60]	Germany	Cercon HT	DeguDent	HT 3Y-TZP	Glazing	Clincial grinding Clincial polishing	Mechanical aging: TCML	Load at fracture		Roughness: Ra	
Stober, 2016 [61] (Clinical study)	Germany	Zenostar Zr Translucent	Wieland Dental	HT 3Y-TZP			Clincial wear	Clinical material loss: vertical loss			
Wiedenmann, 2020 [62]	Germany	Zenostar ZR Translucent	Wieland Dental	HT 3Y-TZP	Glazing	Clincial grinding Clincial polishing	Mechanical aging: TCML Wear: two-body wear, TCML	Load at fracture Material loss: volume loss		Characterization	
Yang, 2019 [63] (Clinical part)	Korea	Katana ML Block Rainbow Shade Block	Genoss Kuraray Noritake	HT 3Y-TZP HT 3Y-TZP			Clincial wear Wear: two-body wear, TCML.	Clinical material loss: vertical loss Material loss: vertical wear	Crystalline phase (clinical) Crystalline phase	Roughness: Ra	

CR: contrast ratio; ML: mechanical cyclic loading; OP: opalescence parameter; TCML: thermocyclic-mechanical cyclic loading; TP: translucency parameter. * Study population overlap, not included. ** Not presented, the author's note. *** Unclear zirconia type, not included. **** Publications are only included in study characteristics. The results are not included in the synthesis. ***** Unclear roughness parameter.

3.3. Zirconia Types, Processing Factors, Properties, and Methods

Several publications included more than one type and brand of zirconia. High translucent 3Y-TZP was the most frequently used zirconia type (67%), followed by 5YSZ (19%), 4YSZ (12%), and composition-gradient multilayer (2%). Few publications reported the content and type of zirconia material. The laboratory and clinical-related processing factors and time-related factors evaluated in the publications, and their frequencies, are presented in Figures 2 and 3.

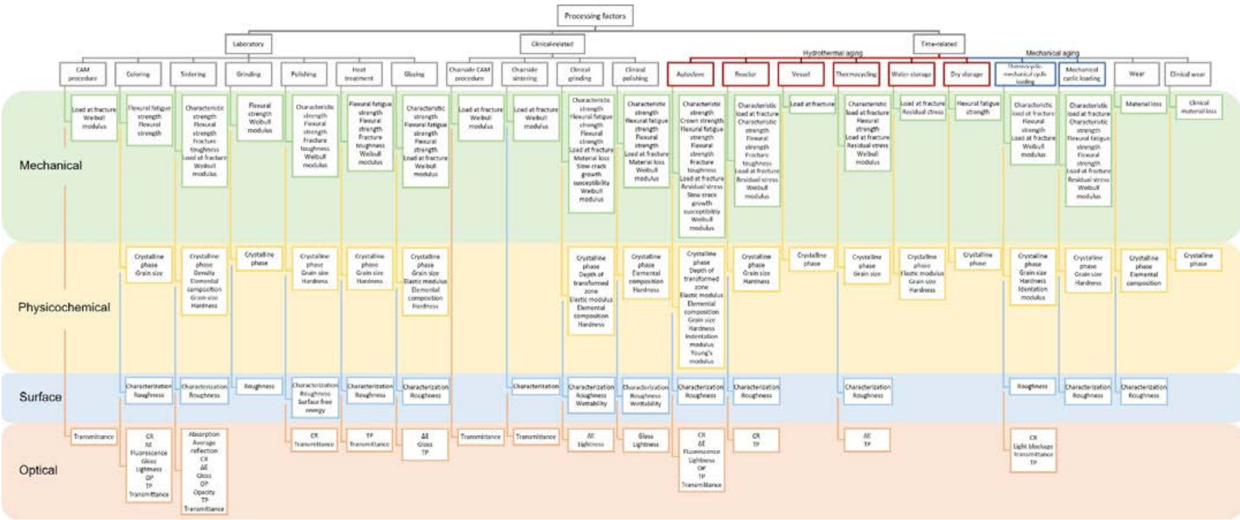

Figure 2. Overview of the relationship between the laboratory and clinical-related processing factors and time-related factors and the mechanical, physicochemical, surface, and optical properties included in the review. ΔE: colour difference; CR: contrast ratio; OP: opalescence parameter; TP: translucency parameter.

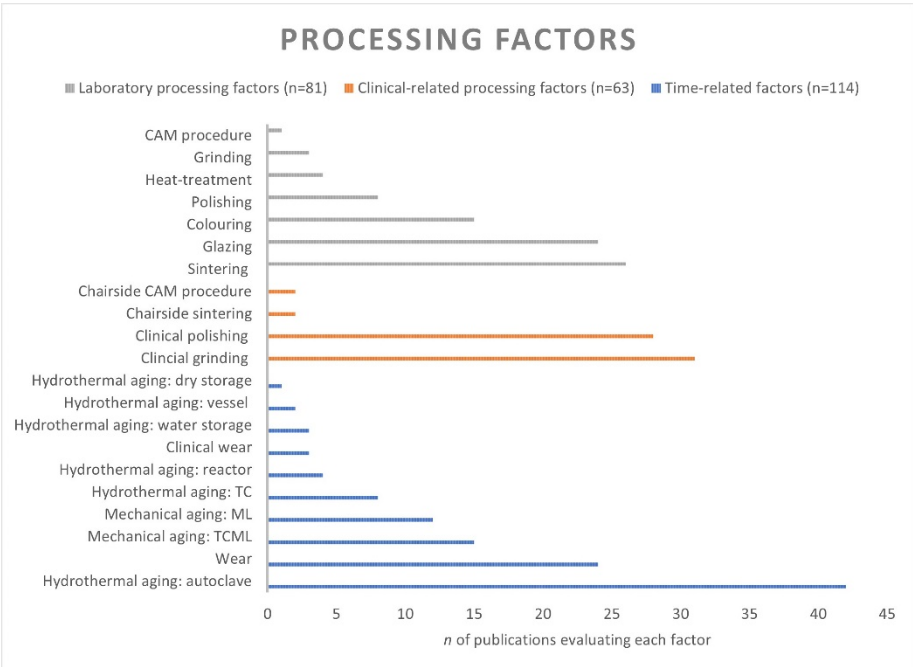

Figure 3. Overview of the laboratory and clinical-related processing factors and time-related factors evaluated in the publications (at the top: *n* of times laboratory, clinical-, and time-related factors were evaluated; at the bottom: *n* of publications evaluating each factor).

The majority of the publications evaluated mechanical properties (n of studies = 106), followed by physicochemical (n = 75), surface (n = 71), and optical properties (n = 41). A number of processing or time-related factors and several properties were included in most of the publications (Figures 2 and 3). The parameters of the processing and time-related factors are presented in Tables 2–15.

Table 2. Parameters of the laboratory processing factor CAM procedure used in the publications.

CAM Procedure	
Type of milling unit	Milling/grinding: tools
Ceramill Motion [33]	Milling: NA [33]

NA: not available.

Table 3. Parameters of the laboratory processing factor colouring used in the publications.

Colouring				
Technique	**Colouring Liquid**	**Shade**	**Time (s/min)/ Strokes (No)**	**Drying Condition (min, Temperature °C)**
External staining using brush	Vita Akzent® Plus Effect Stains [151]	ES14 [151]	NA [151]	NA [151]
Immersion (pre-sintered)	TZI Sirona coloring liquid [155], Zirconia coloring liquid (Aidite) [64], IPS e.max ZirCAD MT Colouring Liquid (Ivoclar Vivadent) [26], Aquarell (Zirkonzahn)/SF1/SF4 (3M ESPE) [154], Ceramill Liquid (Amann Girrbach) [69], Zirkonzahn coloring liquid (Zirkonzahn) [65], Vita YZ HT shade liquid/Prettau Aquarell coloring liquid (Zirkonzahn) [66], Ko's Liquid (Kuwotech)/Colour Liquid for Prettau Aquarell (Zirkonzahn) [31], Color Liquid Prettau/Liquid Fluoreszenz/Liquid Fluoreszenz, Color Liquid Prettau (Zirkonzahn) [176]	A1/A4/A1/A4 [154], A2 [26,64–66], A2/NA/NA, A2 [176], A3 [31,155], A4 [69]	15/1 [66], 5 s × 2 [31], 10 [154] 30 [65] s 2 [64], 2/4 [26] 3/5/7 [69,155], 10/5/5, 10 [176] min	Bench dry 1440 min [155], 120 min, 37° [64] Drying lamp 3 min [65] Infrared drying lamp 1 min [176], NA/20 min [66], 45 min/Drying NA [154] Furnace 15 min, 70° [26], 60 min, 80° [69], 15 min, 150° [31]
Staining using brush (pre-sintered)	IPS e.max ZirCAD MT Colouring Liquid (Ivoclar Vivadent) [26] Color Liquid Prettau Watercolor (Zirkonzahn) [177], Color Liquid Prettau Anterior Aquarell (Zirkonzahn) [67,68]	A2 [26,67], A2/A3.5/A4 [177], A3.5 [68]	1/3 [26], 2 [67,68], 4 × 6 applications [177]	Infrared drying lamp 20 min [67,68] Furnace 15 min, 70° [26], 20 min, 150° [177]

NA: not available.

Table 4. Parameters of the laboratory processing factor sintering used in the publications.

Sintering							
Sintering Variable *	**Starting Temperature (°C)**	**Heating Rate (°C/min) to Temperature (°C)**	**Heating Rate (°C/min) to Final Temperature**	**Final Sintering Temperature, FT (°C)**	**Holding Time, HT (min)**	**Cooling Rate (°C/min) to Temperature (°C)**	**Total Time (min)**
Conventional [33], **Conventional/ High-speed** [69,74,78], **Control/High-speed** [83], **Speed/ High-speed** [166], **Conventional/ Speed/ Super-speed** [80], **Control/High-speed/ High-speed** [79], **Conventional/ High-speed/ Custom high-speed** [82], **Conventional/ Conventional / Speed/ Speed** [73], **Conventional/ Conventional/ Rapid/ Rapid** [75], **Fast/ Normal/ Long** [85]	20 [83], RT/Placed in final temp [166], NA/NA/ Placed in FT [80], NA [33,69,73–75,78,79,82,85]	NA/NA/350 to 1300, 150 to 1500/330 to 1050 [73], 10 to 950/22 to 880/50 to 1100/NA [75], NA [33,69,74,78–80,82,83,85,166]	8/NA [69], 8/300 [83], NA/NA/10/150 [73], 6/11/20/69 [75], NA [33,74,78–80,82,85,166]	1450/1580 [69,74], 1450/1570/1590 [79,83], 1500 [85], 1500/1550 [33], 1500/1520/1500/1540 [75], 1510/1580 [78,166], 1510/1540/1580 [80], 1550/NA/NA [82], 1550/1510/1560/ 1580 [73]	30/10 [166], 120/10 [74,83], 120/NA [69], 120/10/10 [79], 120/25/10 [80], 120/120/16/3 [73], 120/NA/NA [82], 90/130/30/35 [75], NA [33,78,85]	15 to 25/NA [69], 80 min to 20/10 min to 950 [83], Cooled to 600/Removed from FT [166], NA/NA/Removed from FT [80], NA/170 to 1200°, 480 to RT/175 to 1200°, 400 to RT [73], 30 to 750/30 to 750, 31 to 300/30 to 750/70 to 750 [75], NA [33,74,78,79,82,85]	NA/10 [166], 220/15 [78], 480/120/10 [80], 420/30/18 [82], 408/240/28/NA [73], 146/265/590 [85], NA [33,69,74,75,79,83,85]
FT [66,84,155,178], **FT/Short/Regular/ Prolonged HT **** [76,153], **FT/HT **** [71]	RT [84], NA [66,71,76,153,155,178]	8 [84], 25 to 800 [155], NA [66,71,76,153,178]	10 [66,71,178], 15 [155], 17 [76,153], NA [84]	1350/1450/1550 ** [76,153], 1350/1450/1600 [66,178], 1400/1500/1600 [155], 1450/1600 [84], NA/1400/1450/1500/1600 ** [71]	NA/30/60/120/240 ** [71], 60/120/180 ** [76,153], 120 [66,84,155,178]	8 [84], 10 to RT [178], 10 [66,71], 17 [76,153], 30 to 200° [155]	NA [66,71,76,84,153,155,178]
Heating rate [72] **Heating rate/HT ***** [70], **Slow/Normal/ Fast cooling rate** [77,81], **Non-vacuum/ Vacuum** [67] **Regular/ Vacuum** [68]	NA [67,68,72,77,81], *** [70]	25 to 800 [66,71,77,81], NA [67,68,70,72]	5/6 **** [67,68], 10/15/20/40 [72], 15 [77,81], *** [70]	1450/1600 **** [67,68], 1500 [70,72], 1510 [77,81]	30/60/90/60/90/120 [70], 90 [72], 120 [67,68], NA [77,81]	5/6 **** [67,68], 5/25/50 [77,81], Natural cooling [72], *** [70]	90/120/150/155/185/ 215 [70], 235/186/163/126 [72], NA [67,68,77,81]

FT: final temperature; HT: holding temperature; NA: not available; RT: room temperature. * According to the authors' definitions. ** The different final temperatures and holding times were combined. *** Unclear starting temperature, heating, and cooling rate. **** Same sintering parameters for vacuum and non-vacuum but different for zirconia type.

Table 5. Parameters of the laboratory processing factors grinding and polishing used in the publications.

Grinding					
Type of Grinding Tool	**Grit Size ***	**Hand Piece/Machine**	**Time (s)**	**Speed (rpm)**	**Water-Cooling**
Diamond bur [167], **Diamond stone** [86,99]	Medium grit [86], NA [99,167]	Low-speed hand piece [86], Hand piece [99], NA [167]	20 [99], N [86,167]	20,000 [86], According to manufacturer [168], NA [99]	Y [167], NA [86,99]
Polishing					
Polishing system *					
Cerashain 112C (GC) [167], **Silicon polishers** [144], **Manually goat hair brush (DT & Shop), diamond paste Dia-Glace (Yeti Dental)/Mechanically diamond suspensions (Struers)** [146],	NA/diamond suspensions 3 µm [146], Medium and fine [167], NA [144]	Hand piece [144], NA/Polishing machine [146], NA [167]	60/NA [146], 120 [167], NA [144]	According to manufacturer [144,167], NA [146]	Y [167], NA [144,146]
Pre-sintered: Felt wheel/Felt wheel polishing paste/Goat hair brush/Goat hair brush polishing paste (Komet, YETI dental)/Green-state finishing kit/Universal polisher (Amann Girrbach)/SiC polishing paper Buehler/Fully sintered: Polishing lab kit Post Wheel fine/Post Wheel medium, fine (Amann Girrbach) [97], **Pre-sintered: manually dry SiC discs (Struers)/Fully sintered: machine wet diamond pads Code Granu, polishing plates MD-Largo, MD-Chem, diamond suspensions Dia Pro Allegro/Largo, Largo, colloidal silica suspension OP-S (Struers)** [95]	SiC paper: #2000, #4000 granularity/Polishing lab kit: fine, medium [97], P400, P500, P1000/Coarse 40, 20 µm, fine polishing plate, diamond suspensions 9, 3 µm, high polishing plate, colloidal silica suspension [95]	Hand piece [97], Manually/Polishing machine [95]	Pre-sintered: 180/Fully sintered: 240/Polishing lab kit: 900 [97], 5/disc/360 360, 30 [95]	Pre-sintered: 5000/Fully sintered: 10,000 min−1 [97] NA/150, NA, 150 [95]	N/Y [95], NA [97]

N: no; NA: not available; Y: yes. * According to the authors' definitions.

Table 6. Parameters of the laboratory processing factor heat treatment used in the publications.

Heat Treatment							
Type of Treatment	**Start Temperature**	**Drying Time (s)**	**Heating Rate (°C/min)**	**Final Temperature (°C)**	**Holding Time (min)**	**Cooling Rate (°C/min)**	**Environment**
Rapid cooling [88], **Regenerative** [86,87], **Simulated glaze firing** [90]	350/350/- [90], NA [86–88]	5/5/360 [90], 18 [87], NA [86,88]	65 [87], Placed in preheated furnace [86], 55 [91], NA [88]	820/820/1000 [90], 900/1000 [86], 1050 [87], 1550 [88]	2/2/0 [90], 15 [87], 60/30 [86], 60 [88]	25 [87], Air-cooled within 1–2 min [88], −/−/Tray open at 480° [90], NA [86]	Air [88], Vacuum [90], NA [86,87]

NA: not available.

Table 7. Parameters of the laboratory processing factor glazing used in the publications.

Glazing					
Glaze System	**Predrying Standby Temp. (°C)**	**Time (min)**	**Heating Rate (°C/min)**	**Firing Temperature (°C)**	**Holding Time (min)**
Glaze spray Zenostar Magic Glaze (Ivoclar Vivadent) [94], **Glaze Zirox, Stain Liquid/Glaze spray ZenoStar Magic (Wieland Dental + Technik) *** [146] **Vita LT Glaze** [171], **Vita Akzent Glaze** [151], **Vita Akzent Plus Glaze powder** [169], **Vita Akzent powder/Vita Akzent Plus Spray** [92], **Glaze spray Vita Akzent Plus** [100], **Plus Glaze Body Spray** [96] **(Vita Zahnfabrik) Glaze Plus** [93,144], **Zirkonzahn glaze paste (Zirkonzahn)/Zirlux FC glaze paste (Pentron Ceramics)** [90] **Ivocolor fluor** [98], **IPS Ivocolor Glaze Paste** [87], **Glaze paste IPS e.max** [91] **(Ivoclar Vivadent) Cercon ceram kiss glasur *** [89], **Cercon glaze Glasur (DeguDent)** [170], **Ceramill Glaze (Amann Girrbach)** [168], **NA** [99]	350/NA [90], 403 [87], 500 [92,100,171], 575 [146], NA [89,91,93,94,96,98,99,144,151,168–170]	2 [171], 4 [92,100], 5/2 [146], 5/6 [90], 6 [87], NA [89,91,93,94,96,98,99,144,151,168–170]	45 [87,146], 50 [171], 55/55 [90], 80 [92,100], NA [89,91,93,94,96,98,99,144,151,168–170]	500, 830 [91], 710 [87], 780–800 [144], 800 [169], 820/1000 [90], 880 [94,146], 900 [168,170], 900/950 [92], 950 [100], 960 [171], NA [89,93,96,98,99,151]	1 [87,92,100,144,146,169], 2/0 [90], 3, 2 [91], NA [89,93,94,96,98,99,151,168,170,171]

NA: not available. * Fired twice.

Table 8. Parameters of the clinical-related processing factors chairside CAM procedure and sintering used in the publications.

Chairside CAM Procedure			
Type of Milling Unit	**Milling/Grinding: Tools**		
3 + 1 axis, CEREC MCXL [33,101]	Milling: NA [33], Milling: carbide burs Shaper 25/RZ, Finisher 10. Grinding: diamond-coated burs, Step bur 20, Cylinder pointed bur 20) [101]		
Chairside sintering			
Sintering parameter *	Final sintering temperature (°C)	Holding time (min)	Total time (min)
Conventional/Speed-fire/ Super-speed [101], **High-speed** [33]	1510/1580/1580 [101], 1560 [33]	120/2/10 [101], 19 ** [33]	480/13.34/10 [101], 19 ** [33]

NA: not available. * According to the authors' definitions. ** Unclear if holding or total time.

Table 9. Parameters of the clinical-related processing factor clinical grinding used in the publications.

Clinical Grinding					
Type of Grinding Tool	**Grit Size**	**Hand Piece/Machine**	**Time (s)**	**Speed (rpm)**	**Water-Cooling**
Diamond bur [87,92,93,98–100,102–108,110,112,157–159,161,168,172]	25/181 [106], 27–76 [157], 30 [107], 46/30/181 [105], 90–120 [93,98], 96 [108], 181 [87,92,100,103,104,110], 220 µm [112,158], Medium grit [102,161], Coarse grit [159,172], NA [100,168]	High-speed hand piece [93,99,108,112,158,159,161,172], Low-speed hand piece [92,102,168], Contra-angle hand piece [87,92,100,103–107,110], High-speed [98], NA [157]	10 [112,157,158,172], 10 × 2 [159], 20 [98,99], 30 [168], NA [87,92,93,100,102–108,110,161]	8000–10,000 [102], 20,000 [93,108], 159,000 [112,157,158], 169,000 [87,92,100,103–106,110], 200,000 [172], 300,000 [168], 80% of max rpm recommended by manufacturer [159], NA [98,99,107,161]	Y [87,92,93,98–100,103–108,110,112,157–159,168,172], NA [102,161]
Diamond stone [109,156,172], **Diamond tool of silicon carbide** [156]	Medium grit [109], NA [156,172]	Low-speed hand piece [109,156,172]	20 [156,172], NA [109]	12,500 [172], 10,000–20,000 [156], 20,000 [109]	Y [172], Y/N [109], NA [156]
Abrasive papers [91], **Diamond-impregnated lapidary wheel** [170], **Resin-bonded diamond disk** [96], **NA** [94,177]	120 grit [96], 320/2000 grit [91], 100 µm [170], NA [94,177]	Grinding/polishing machine [91,96,170,177], Hand piece [94]	20 [96], 30 [94], 60 [170], 60 × 4 [91], NA [177]	200 [91], 500 [96], NA [94,170,177]	Y [91,170], NA [94,96,177]

N: no; NA: not available; Y: yes.

Table 10. Parameters of the clinical-related processing factor clinical polishing used in the publications.

Clinical Polishing						
Polishing System *	**No. of Steps**	**Grit Size ***	**Hand Piece/Machine**	**Time (s)**	**Speed (rpm)**	**Water-Cooling**
Luster for zirconia intra-oral adjustment kit [159], **Luster for zirconia adjusting and polishing kit** [156,160,161], **Luster intraoral twist kit** [173] **(Hager & Meisinger)**	3 [159–161], NA [156,173]	Pregrinding, smoothing prepolishing, high gloss polishing [156,159–161], NA [173]	Low-speed hand piece [156,159], High-speed hand piece [161], NA [160,173]	20/step [156], 20 × 2 [161], 30 × 2/step [159], 30 [173], 60/120 [160,161]	Step 1: 8000–12,000, 2–3: 7000–12,000 [159,160], 8500–20,000 [156], 10,000 [173], NA [161]	Y [159], NA [156,160,161,173]
Eve Diacera [100,105,159,160], **Diacera Twist** [168], **Eve Diapol** [159], **Eve kit** [112,158,168] **(Eve Ernst Vetter)**	2 [100,105,160,168], 3 [112,158,159]	Fine, extra-fine [100], Medium, fine grit [105], Smoothing prepolishing, high gloss polishing [160,168], Pregrinding, smoothing prepolishing, high gloss polishing [159], NA [112,158]	Low-speed hand piece [112,158–160,168], Contra-angle hand piece [100,105]	10/step [112,158], 25 [100,105], 30 × 2/step [159], 60/120 [160], 90 [168]	7000 [168], 7000–12,000 [100,159,160], 17,000 [105], step 1: 7000, 2–3: 10,000 [112,158]	Y [100,105,112,158,159,168], NA [160]
CeraGloss [112,158], **Cerapro CeraGloss/Cerapro StarGloss** [160] **Edenta Magic KIT Zir** [156,172] **(Edenta AG)**	3 [112,156,158,172], 4 [160]	Polisher standard, coarse, medium-coarse, super-fine grit/ Polisher standard, coarse, medium, super-fine [160], Diamond stone, silicone, fine silicone polishing bur [172], Coarse finishing, medium, fine polishing [156], NA [112,158]	Low-speed hand piece [112,156,158,160,172]	10/step [112,158], 20/step [156,172], 60/120 [160]	Step 0,3: 10,000, 1–2: 20,000/Step 0: 10,000, 1–2: 15,000, 3: 7000 [160], Step 1: 10,000–20,000, 2: 8500–20,000 [156], 10,000 [112,158], Step 1: 12,500, 2: 20,000, 3: 10,000 [172]	Y [112,158,172], NA [156,160]
Dialite ZR polishing wheels [94,171], **Komet ZR flash polisher** [94], **Komet ZR zirconia polishers** [174], **Keramikpolitur kit** [173], **(Gebr. Brasseler, Komet)**	2 [94,171,174], NA [173]	Medium, fine grit [171], Blue, light-grey polisher [174], NA [94,173]	Low-speed hand piece [171], Hand piece [94], NA [173,174]	30/step [94,171,173], 90/step [173,174]	5000/15,000/40,000 [171], 6000 [173], 8000 [174], According to manufacturers [94]	Wet slurry [174], N [171], NA [94,173]
Optrafine system (Ivoclar Vivadent) [87,105,173]	3 [87,105,173]	46, 30 µm, diamond paste 2–4 µm [87], Light-, dark-blue tips, nylon brush, diamond paste 2–4 µm [105], NA [173]	Contra-angle hand piece [87,105], NA [173]	25/step [87,105], 30, diamond paste 60 [173]	10,000 [173], 169,000 [87,105]	Y [87,105], NA [173]
CeraMaster [93,108,171], **Brownie, Greenie, SuperGreenie** [112,158], **Ceramisté porcelain polishers** [175], **Shofu zirconia polishing kit/Ceramaster porcelain polishers/Dura White stone, Shofu zirconia polishing kit/Ceramisté porcelain polishers** [174] **(Shofu)**	2 [93,171], 3 [112,158], 2/2/3/3 [174], 4 [175], NA [108]	CeraMaster Coarse, CeraMaster [93,171], NA [108,112,158], Prepolisher, polisher/Coarse polisher, polisher/Stone, prepolisher, polisher/Prepolisher, yellow band polisher, white band polisher [174], Prepolishing regular, fine, ultra-fine grit, super polishing diamond paste [175]	Low-speed hand piece [112,158,171], High-speed hand piece [93,108], Hand piece [175], NA [174]	10/step [112,158], 30/step [171], 60/step [175], 90/step/90/step/ 60/step/60/step [174], NA [93,108]	5000 [112,158], 5000/15,000/40,000 [171], 10,000/10,000/Step 1: 200,000, 2–3: 10,000/ 10,000 [174], 20,000 [93,108], 80% of maximum rpm recommended by manufacturer [175]	Y [93,108,112,158,175], Stone: Y/Polishers: wet slurry [174], N [171]

Table 10. *Cont.*

Clinical Polishing						
Polishing System *	**No. of Steps**	**Grit Size ***	**Hand Piece/Machine**	**Time (s)**	**Speed (rpm)**	**Water-Cooling**
Suprinity polishing set (Vita Zahnfabrik) [96], **Zr polishing rubbers (Frank Dental)** [102], **D&Z Zirconia polishing set (D&Z)/DFS Diamond Zirconia Tools (DFS-Diamond)** [160], **Jota kit (Jota)** [156], **CeraGlaze (NTI)** [157], **Kg Viking (Kg Sorensen)** [105], **Identoflex (Kerr)/DiaShine dentist zirconia adjusting and polishing kit (VH Technologies)** [168], **3 step zirconia RA (Prima Dental)** [99], **Premium Compact (Dhpro)** [98]	1/4 [168], 2 [96,105], 3 [98,99,102,156,157,160]	Prepolishing, high brightness [96], Fine, extra-fine grit [105], Coarse, intermediate finish, final finish [102], Grinding, polishing, glazing wheel [160], Coarse finishing, medium, fine polishing [156], NA/Diamond stone, medium prepolisher, fine polisher, horse hair brush diamond paste [168], Wear, prepolishing, high gloss [98], NA [99,105,157]	Low-speed hand piece [99,102,156,160,168], Contra-angle hand piece [105], Hand piece [96], High-speed [98], NA [157]	15/step [96], 20/step [98,156], 25/step [105], 30 [157], 30 × 2 [99], 60/120 [160], NA [102], 180/Step 1–3: 60, 4: 30 [168]	Step 1: 7000–12,000, 2: 4000–8000 [96], Step 1: 15,000, 2: 10,000, 3: 5000 [157], 6000/Step 1: 1000, 2–3: 8000, 4: 9000 [168], 8000–10,000 [102], 8000–12,000/Step 1: 8000, 2–3: 10,000 [160], Step 1: 10,000–20,000, 2–3: 8500–20,000 [156], 12,000 [98], 170,000 [105], NA [99]	Y [99,105,157,168], NA [96,98,102,156,160]
Diamond bur (Intensiv)/Soflex Finishing and Polishing System Kit (3M ESPE) [112,158], **Diamond grinding disc (Apex CGD), silicon carbide papers (CarbiMet), diamond suspensions MetaDi (Buehler)** [111], **Abrasive paper (NA), Axis High Shine (Axis Dental)** [170]	1/4 [112,158], NA [111,170]	8 µm/NA [112,158], NA, 1200/2500 grit, 3/1 µm [111], 180, 600 grit, NA [170]	Low-speed hand piece [112,158], Polishing machine [111], Grinding/polishing machine, NA [170]	10/step [112,158], 600, 8400–9000, 300 [111], NA [170]	75,000/10,000 [112,158], NA [111,170]	Y [111,112,158], NA [170]

N: no; NA: not available; Y: yes. * According to the authors' definitions.

Table 11. Parameters of the time-related factors hydrothermal aging: autoclave, reactor, vessel, thermocycling, and water/dry storage used in the publications.

Hydrothermal Aging: Autoclave		
Temperature (°C)	**Pressure (Bars)**	**Duration (h)**
122 [134], **125** [68], **127** [98]	1.7 [98], 2 [68,134]	8 [68,134], 24 [98]
134	2	1–3 [48], 5 [89,91,102,114,125,179,180], 8 [27] 1–10 [163], 5–10 [123,135], 10 [74] 15 [162], 5–20 [64,113], 20 [94,103,104,106,107,110,111,116,122] 50 [115,119], 2–54 [51], 60 [73] 5–100 [164], 10–100 [124] 2–160 [69], 5–200 [118]
134	2.1 [181], 2.2 [120], 2.3 [117], 3 [176], 3.2 [121]	1 [121], 1–5 [176], 5 [12], 20 [120], 20–100 [181]
Hydrothermal aging: hydrothermal reactor		
Temperature (°C)	Pressure (bars)	Duration (h)
122	2	1 [129]
134	2 [126,128] *, 2.2 [120]	5 [128], 20 [120], 6–140 [126]
Hydrothermal aging: vessel in oven		
Temperature (°C)	Pressure (bars)	Duration (h)
120 [32] **, **134** [78] ***	2.0265 [78], NA [32]	10 [78], 12 [32]
Hydrothermal aging: thermocycling		
Temperature (°C)	Dwell time (s)	*N* of cycles
5, 55	10 [127], 15 [102], 20 [130], 30 [70,129,165], 60 [131]	3500 [130], 10,000 [70,129,131], 10,000/30,000/50,000 [165], 100,000 [127] 200,000 [102]
6.5, 60	45 [132]	10,000 [132]
Hydrothermal aging: water/dry storage		
Temperature (°C)	Storage environment	Duration (days)
27	Dry	730 [110]
37	Pure water	80 [127]
80	Water	90 [133]

NA: not available. * Isothermal reactor. ** Distilled water in hydrothermal vessel. *** Distilled water in decomposition vessel.

Table 12. Parameters of the time-related factor mechanical aging: mechanical cyclic loading used in the publications.

Mechanical Aging: Mechanical Cyclic Loading (ML)					
Specimen Design	**Load (N)**	**Frequency (Hz)**	***N* of Cycles**	**Environment, Temperature (°C)**	**Antagonist Material**
Bars	Staircase method: initial 50% of maximum FS, step size 20%	2	10,000	Dry	NA [28]
Discs	50/200 [138], 200 [130], 250/350 [27], Staircase method: initial 60% of mean FS, step size 5% [139]	1.6 [130], 2 [138], 4 [27] 10 [139]	250,000 [130], 100,000 [139], 2–1,000,000 [138], 1,000,000 [27]	Distilled water [138], Distilled water, 37 [27,130], Water [139]	3Y-TZP [138], Stainless steel [27], NA [130,139]
Crowns	70 [129], 60–200 [121], 250 [137], 50–300 [124,127]	1 [121], 1.4 [129], 2 [137], 10 [124], 14.5 [127]	30,000 [121], 10,000/50,000 [137], 1,000,000 [129], 2,400,000 [124,127]	Water [124], 37 [121], Pure water 37 [127], Distilled water, 37 [129,137]	Stainless steel [121,129], Steel [127,137], NA [124]
FDPs	0–300 [136], 588–5104 [132]	15 [136], NA [132]	1,000,000 [136], 1,200,000 [132]	Deionized water [132], 37 [136]	Steel [132], Stainless steel [136]

FS: flexural strength; ML: mechanical cyclic loading; NA: not available.

Table 13. Parameters of the time-related factor mechanical aging: thermocyclic-mechanical cyclic loading used in the publications.

Mechanical Aging: Thermocyclic-Mechanical Cyclic Loading (TCML, Chewing Simulator)							
Specimen Design	**TC Temperature (°C)**	**Dwell Time (s)**	***N* of Cycles**	**ML Load (N)**	**Frequency (Hz)**	***N* Of Cycles**	**Antagonist Material**
Bars	5, 55	120 [117], NA [74]	6000 [74], NA [117]	10 [74], 100 [117]	1.64 [117], NA [74]	1,200,000 [74,117]	Steel [74], NA [117]
Discs	5, 55	30 [141,182], NA [114]	6000/12,000 [114], NA [141,182]	10 [114], 110 [141,182]	1.4 [141,182], NA [114]	1,200,000 [141,182], 1,200,000/ 2,400,000 [114]	Steatite [141,182], Steel [114]
Crowns	5, 55	NA [33,83,142]	6000 [33,83,142]	50 [33,83,142]	0.7 [33], 1.1 [83], NA [142]	1,200,000 [33,83,142]	Enamel [33,83], Steatite [142]
FDPs	5, 55	30 [133,143], NA [140]	1032 [143], 2000 [140], 36,000 [133]	50 [143], 98 [133], 200 [140]	2 [133,140], NA [143]	120,000 [143], 500,000 [140], 2,500,000 [133]	Steel [133,140], NA [143]

ML: mechanical cyclic loading; NA: not available; TC: thermocycling.

Table 14. Parameters of the time-related factor wear used in the publications.

Wear								
Two-Body Specimen Design	**TC Temperature (°C)**	**Dwell Time (s)**	***N* of Cycles**	**ML Load (N)**	**Frequency (Hz)**	***N* of Cycles**	**Environment, Temperature (°C)**	**Antagonist Material**
Discs	5, 50 [146]	120 [146]	NA [146]	49 [146]	1.67 [146]	120,000–1,200,000 [146]	Water [146]	Molar [146]
	-	-	-	25 [157], 49 [144,145], 50 [142]	1.2 [142], 1.6 [145], 1.7 [144], 8 [157]	120,000 [142,145,157], 2,400,000 [144]	Distilled water [142] 37 [144], Water [157], NA [145]	Incisors [144], HT 3Y-TZP [145], Steatite [142,157]
Rectangular	5, 55 [117,147]	NA [117,147]	NA [117,147]	50 [117], 97 [147]	1.6 [147], NA [117]	120,000–1,200,000 [117], 1,200,000 [147]	Distilled water [117], NA [147]	Enamel [117], Enamel, lithium disilicate, feldspathic porcelain [147],
	-	-	-	15 [148], 20 [149], 30 [34]	0.4 [149], 1 [148], 1.5 [34]	200,000 [148], 300,000 [149], 500,000 [34]	Distilled water [34] room temperature [148], 33% glycerin lubricant [149]	Enamel [149], Composites, lithium disilicate, zirconia reinforced lithium silicate, HT 3Y-TZP, bovine enamel [148], Zirconia [34]
Crowns	5, 55 [33,83]	30 [83], NA [33]	6000 [33,83]	50 [33,83]	1.1 [83], NA [33]	1,200,000 [33,83]	Distilled water [83], Water [33]	Enamel [33,83]
	-	-	-	49 [167], 50–500 [150]	2 [150,167]	300,000–900,000 [167], 1,000,000 [150]	Distilled water [167] 37 [150]	Enamel [167], Stainless steel [150]
FDPs	5, 55 [133]	30 [133]	36,000 [133]	98 [133]	2 [133]	2,500,000 million [133]	Water [133]	Enamel [133]
	-	-	-	49 [131]	NA [131]	1,200,000 [131]	NA [131]	Steatite [131]
Three-body								
Rectangular				15 [151], 20–70 [170]	1 [170], NA [151]	50,000 [170], 1,000,000 [151]	Food-like slurry [170], Rice grains, millet seed shells, bacteriostatic preservative, buffer solution [151]	Enamel [170], NA [151]

ML: mechanical cyclic loading; NA: not available; TC: thermocycling.

Table 15. Parameters of the time-related factor clinical wear used in the publications.

Clinical Wear							
***N* of Patients (*N* at Follow up)**	**Patient Gender m/f (%), Mean Age (Years)**	**Follow up Time (Months)**	**Restoration Type**	**Position**	***N* of Restorations**	**Surface Treatment**	**Antagonist**
47 (45) [152]	29.8/70.2, 54 [152]	24 [152]	Tooth-, implant-supported crowns, implant-supported FDPs [152]	Premolars or molars [152]	75 [152]	Glazed or unglazed [152]	Teeth or implants [152]

3.4. Mechanical Properties

Mechanical properties were evaluated in 93 publications (the high-risk-of-bias publications excluded), and flexural strength was the most frequent property (Tables 2–15 and Figure 4). HT 3Y-TZP was evaluated much more often (n = 81) than 5YSZ (n = 30) and 4YSZ (n = 18). The methods used in the publications are presented in Figure 5.

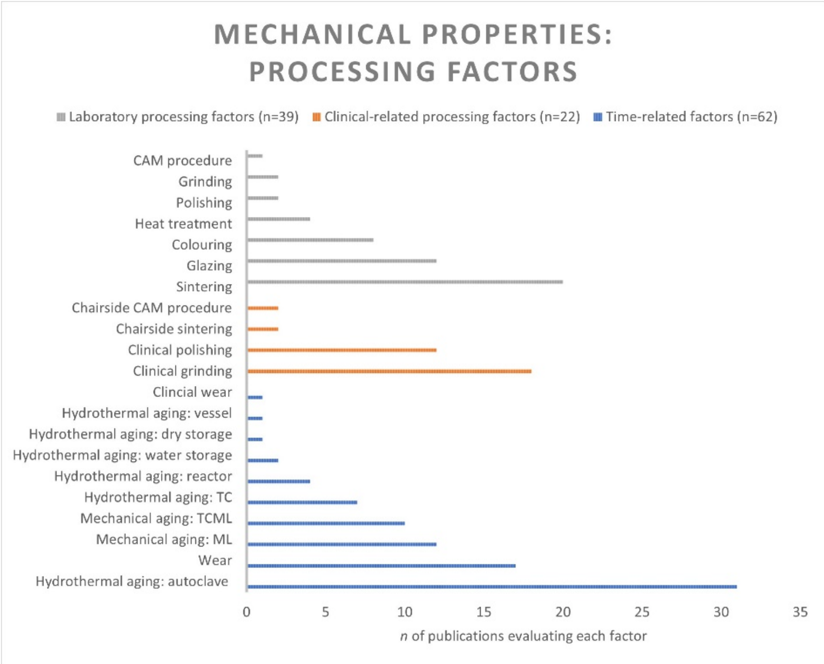

Figure 4. Laboratory and clinical-related processing factors and time-related factors evaluated for the mechanical properties (at the top: n of publications evaluating laboratory, clinical-, and time-related factors, respectively; at the bottom: n of publications evaluating each factor; several factors can be included in one publication).

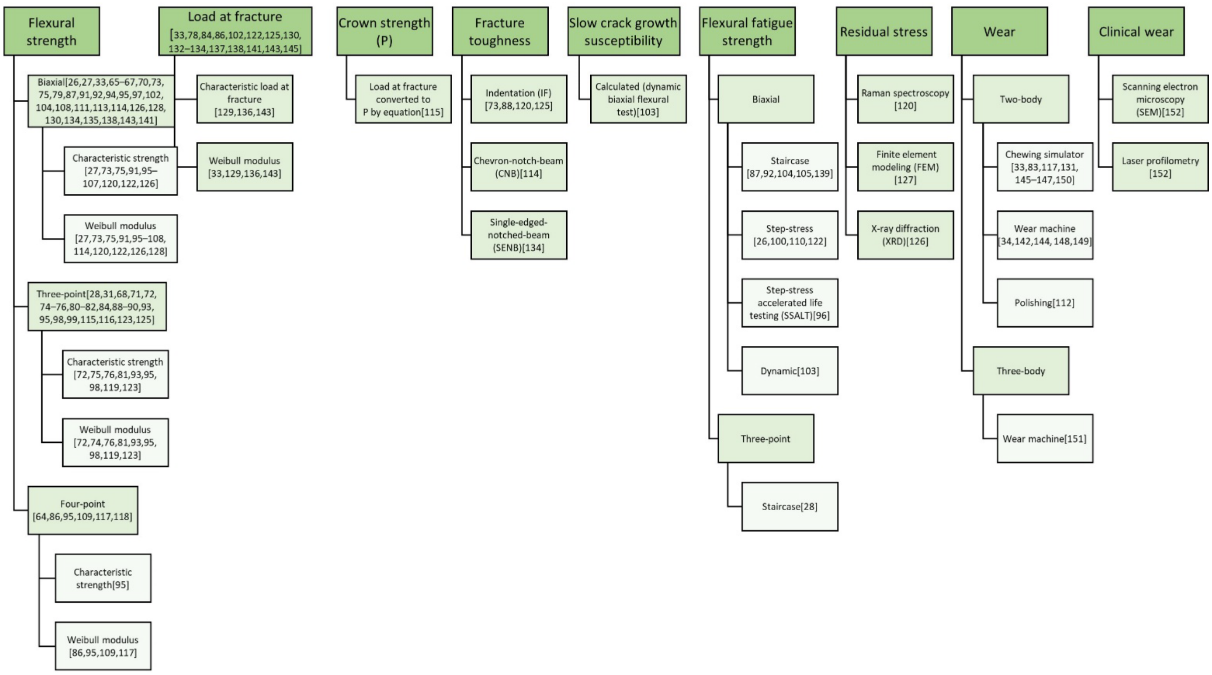

Figure 5. Methods/equipment used in publications for the evaluation of the mechanical properties.

3.4.1. Laboratory Processing Factors

Factor: CAM Procedure. Properties: Load at Fracture and Weibull Modulus

4YSZ and Multilayer 3Y-TZP/5YSZ

Milling using a laboratory procedure combined with conventional sintering or chair-side milling with high-speed sintering of 4YSZ and multilayer 3Y-TZP/5YSZ affected neither the load at fracture nor the Weibull modulus [33] (Table 2).

Factor: Colouring. Properties: Flexural Strength and Flexural Fatigue Strength

HT 3Y-TZP

Colouring with an immersion or staining technique (with a brush) at the pre-sintered stage resulted in similar biaxial and four-point flexural strength as non-coloured and pre-coloured HT 3Y-TZP [64–68] (Table 3).

4YSZ

The biaxial flexural strength was not influenced by the colouring procedure, whether colouring with an immersion technique or pre-coloured material [69]. However, the biaxial flexural fatigue strength was lower for coloured 4YSZ, using either an immersion or a staining technique, than for non-coloured 4YSZ [26]. Immersion and staining, using different immersion times and numbers of applications, showed similar flexural fatigue strength [26].

5YSZ

Colouring with an immersion or staining technique and using acid- or aqueous-based colouring liquids at the pre-sintered stage led to similar biaxial and three-point flexural strength to that of non-coloured and pre-coloured 5YSZ [31,66,68]. However, the staining technique using a brush increased the biaxial flexural strength by approximately 20%, unlike the behaviour of HT 3Y-TZP [67].

Factor: Sintering. Properties: Flexural Strength, Weibull Modulus, Characteristic Strength, Load at Fracture, and Fracture Toughness

HT 3Y-TZP

Many publications reported that the flexural strength was unaffected by modifying the sintering parameters such as the heating rate, final sintering temperature, holding time, total time, and environment (i.e., vacuum or non-vacuum) [66–68,70–75] (Table 4). A few publications reported that an increased final sintering temperature, prolonged holding or sintering time, or slow cooling rate increased the three-point flexural strength [76,77] and the load at fracture [78]. In some publications, single brands showed a higher flexural strength after increasing the final sintering temperature [66], sintering time [70], or the final temperature in combination with high-speed sintering [79]. Ersoy et al. [80] reported a higher three-point flexural strength after high-speed sintering in comparison to speed sintering (approximately 120 min total time) and conventional sintering.

The Weibull modulus was similar [74] or higher after conventional sintering compared to speed or high-speed sintering, except for a single brand [73,75]. Increasing the final sintering temperature and holding time also increased the Weibull modulus, whereas the characteristic strength was highest for an increased sintering temperature but regular holding time [76]. The characteristic strength was lower for conventionally sintered HT 3Y-TZP than for the speed-sintered material [73]. A heating rate of 20 °C/min led to a higher Weibull modulus, as well as characteristic strength, in comparison to 10 °C, 15 °C, and 40 °C/min [72]. Although slow cooling increased both the flexural and characteristic strength, the Weibull modulus was reduced compared to normal and fast cooling [81]. The fracture toughness was not influenced by the sintering protocol, whether speed or conventional sintering [73].

4YSZ

The flexural strength [73,74,79,82] and load at fracture [33,83] were either unaffected [33,73,79] or increased [74,82,83] after high-speed sintering in comparison to conventional sintering (Table 4). However, one publication [69] reported a lower biaxial flexural strength after high-speed sintering than after conventional sintering. Both conventionally and high-speed-sintered 4YSZ had a lower flexural strength than conventionally sintered HT 3Y-TZP but higher than 5YSZ [69]. The Weibull modulus was either not affected [74], higher [33], or lower [73] after high-speed sintering. The only publication evaluating the characteristic strength and fracture toughness reported a lower strength and higher toughness after speed sintering in comparison to conventional sintering [73].

5YSZ, Multilayer 3Y-TZP/5YSZ, and 4YSZ/5YSZ

The biaxial and three-point flexural strength were mainly not affected by the sintering program: vacuum or non-vacuum, sintering temperature, and speed sintering or conventional sintering [66–68,75,84] (Table 4). However, one publication [82] reported a lower three-point flexural strength after high-speed sintering than after conventional sintering. Conventionally sintered 5YSZ had a lower biaxial flexural strength than conventionally or high-speed-sintered 4YSZ [69]. The characteristic strength for speed-sintered 5YSZ was 590 MPa, and the Weibull modulus was lower than for the conventionally sintered 5YSZ [75]. Conventionally sintered multilayer 3Y-TZP/5YSZ had a similar load at fracture to conventional or high-speed-sintered 4YSZ [33], and the load at fracture of multilayer 3Y-TZP/5YSZ was not influenced by the sintering time [85]. The Weibull modulus was numerically lower than for chairside-milled and high-speed-sintered 4YSZ.

Factors: Grinding, Polishing, Heat Treatment, and Glazing. Properties: Flexural Strength, Weibull Modulus, Characteristic Strength, Flexural Fatigue Strength, and Fracture Toughness

HT 3Y-TZP

Grinding increased the four-point flexural strength of HT 3Y-TZP compared to as-sintered material [86] (Table 5). Heat treatment to decrease the residual stresses resulted in lower biaxial flexural fatigue and biaxial and four-point flexural strength compared to ground HT 3Y-TZP [86,87] (Table 6). However, in comparison to as-sintered materials, the flexural strength was not affected by heat treatment, nor was the Weibull modulus [86]. Rapid cooling to create *t*′ phase for improved translucency and sustained strength decreased the three-point flexural strength, but it increased the fracture toughness [88].

Glazing reduced the three-point and biaxial flexural strength in comparison to as-sintered [89], polished [90], or ground materials [91–93] (Tables 5 and 7). Using heat treatment to simulate glaze firing led to higher three-point flexural strength than using the same firing with glaze paste applied [90]. Glazing ground surfaces resulted in similar three-point flexural and characteristic strength as glazing non-ground surfaces [93]. However, glazing after grinding led to a lower biaxial flexural and flexural fatigue strength compared to as-sintered, ground, or polished HT 3Y-TZP [87]. Adding polishing after grinding and before glazing increased the three-point, biaxial flexural, and flexural fatigue strength in comparison to glazing alone or grinding and glazing combined [87,93]. In contrast, glazing increased the Weibull modulus compared to grinding [91,93]. Khayat et al. [94] found no differences in the biaxial flexural strength among ground, glazed, or clinically polished HT 3Y-TZP.

Comparing the brush- and spray-glazing techniques, glazing previously ground materials with a brush resulted in a higher biaxial flexural strength [92]. In contrast, the flexural fatigue strength of spray-glazed materials was similar irrespective of grinding, and it was higher than non-ground material glazed with a brush. However, when glazing after grinding, the flexural fatigue strength was not influenced by the glazing technique [92].

Overall, machine wet polishing in the fully sintered stage resulted in a higher characteristic strength and biaxial, three-, and four-point flexural strength, in descending order, compared to manual dry polishing in the pre-sintered stage [95]. The Weibull modulus was only higher for one single material and test method after wet polishing in the fully sintered stage [95].

Ground and glazed HT 3Y-TZP had a higher probability of survival after ML than as-sintered material [96].

4YSZ

After polishing in the pre-sintered stage, two-step polishing (fine and rough laboratory diamond wheel polisher) in the fully sintered stage generally resulted in a higher biaxial flexural strength than one-step polishing [97]. Rapid-cooling heat treatment decreased the three-point flexural strength but increased the fracture toughness [88] (Table 6).

5YSZ and Multilayer 4YSZ/5YSZ

5YSZ had a lower three-point flexural strength than HT 3Y-TZP, regardless of the surface finishing [98]. In contrast to the results of HT 3Y-TZP, grinding [99] or grinding combined with glazing [98,99] of 5YSZ led to a lower three-point flexural strength than for as-sintered [99] and clinically polished materials [98]. However, glazing without prior grinding showed a similar three-point flexural and characteristic strength as grinding or grinding and clinical polishing combined, and a higher strength than grinding and glazing or grinding, polishing, and glazing [93]. Conversely, the Weibull modulus was higher after grinding and glazing [93,98]. After rapid-cooling heat treatment the three-point flexural strength decreased, but the fracture toughness increased [88]. For multilayer 4YSZ/5YSZ, neither the flexural fatigue strength nor the probability of survival nor the Weibull modulus was influenced by the finishing procedure (grinding, glazing, or polishing) after ML [100].

3.4.2. Clinical-Related Processing Factors

Factors: Chairside CAM Procedure and Sintering. Properties: Load at Fracture and Weibull Modulus

HT 3Y-TZP

Chairside milling using carbide burs or grinding using diamond-coated burs, combined with super-speed, speed, or conventional sintering, did not affect the load at fracture for lower thicknesses (0.5–1.0 mm) [101] (Table 8). For a thickness of 1.5 mm, grinding in combination with speed sintering led to a higher load at fracture than milled speed-sintered and milled or ground super-speed-sintered HT 3Y-TZP [101].

Factors: Clinical Grinding and Polishing. Properties: Flexural Strength, Weibull Modulus, Characteristic Strength, Flexural Fatigue Strength, Slow Crack Growth Susceptibility, and Material Loss

HT 3Y-TZP

Clinical grinding increased the biaxial [87,91,92,102], three-point flexural [93], and flexural fatigue strength [87,103–105] as well as the characteristic strength [91,93,106,107] compared to as-sintered [87,91,92,102–107] (Tables 9 and 10). On the other hand, the biaxial [94,108], four-point [109] flexural, and flexural fatigue strength [110] for ground HT 3Y-TZP were also reported as similar to those for as-sintered [94,108–110] or ground and polished material [94]. Grinding with coarse or extra-fine diamond burs led to a similar biaxial flexural strength [106], but simulating clinical grinding using fine silicon carbide abrasive papers led to a higher biaxial flexural strength than ultra-fine grinding [91]. Aliaga et al. [109] found no differences between wet and dry grinding. The Weibull modulus of clinically ground HT 3Y-TZP was either similar to [87,106,107,109] or lower than [91,93] as-sintered [87,91,106,107,109] or glazed material [87,91,93]. The slow crack growth susceptibility was higher for ground than for as-sintered HT 3Y-TZP [103].

Clinical polishing, alone [111] or after grinding [87,102,105], increased the biaxial flexural [87,102,111] and flexural fatigue strength [87,105] compared to as-sintered HT 3Y-TZP. On the other hand, grinding followed by polishing was also reported to have similar biaxial flexural strength [94,108] to as-sintered [108] or ground HT 3-YTZP [94]. The Weibull modulus was not affected by the surface finishing, whether as-sintered, polished [87,108], ground, or glazed [87]. Grinding and polishing had a higher biaxial flexural strength than only glazing or grinding and glazing in combination [93]. The sequence glazing, grinding, and polishing had a higher probability of survival after ML than as-sintered HT 3Y-TZP [96]. Adding a finishing step using fine or extra-fine diamond bur before polishing did not increase the flexural fatigue strength [105].

One publication [112] reported similar weight, volume, and vertical height loss after polishing with silicon carbide or diamond-impregnated polishers, urethane-coated papers, or diamond burs, whereas a synthetically bonded grinder interspersed with diamond showed higher material loss.

5YSZ and Multilayer 4YSZ/5YSZ

Grinding decreased the three-point flexural strength compared to as-sintered 5YSZ [98,109]. Polishing with diamond rubber polishers showed either similar three-point flexural and characteristic strength as glazing [93], or higher than as-sintered, ground, or glazed material [98]. However, the Weibull modulus was lower for polished than for glazed 5YSZ [93,98]. Adding polishing as the last step after grinding, glazing, and regrinding to simulate the laboratory and clinical procedures increased the flexural strength [99].

3.4.3. Time-Related Factors

Factors: Hydrothermal Aging. Properties: Flexural Strength, Weibull Modulus, Characteristic Strength, Load at Fracture, Characteristic Load at Fracture, Crown Strength, Flexural Fatigue Strength, Fracture Toughness, Slow Crack Growth Susceptibility, and Residual Stress

HT 3Y-TZP

Most publications found no difference in biaxial [27,113,114], three-point [68,74,93,115,116], or four-point [64,117,118] flexural strength; flexural fatigue [110]; characteristic [27,89,119,120] or crown strength [115]; or load at fracture [121] after hydrothermal aging in an autoclave (Table 11). Several publications reported a higher biaxial flexural [69,91,104,111], characteristic [91,107,122], or flexural fatigue strength [103,104,122] after autoclave aging for 5–160 h. In contrast, the biaxial [102] or three-point [123] flexural strength or load at fracture [124] were shown to decrease after autoclave aging for 5, 10, or 100 h, respectively.

However, the behaviour was partly dependent on the surface finishing and brand. Glazed HT 3Y-TZP showed a lower biaxial [91], three-point, or characteristic flexural strength [89,91] after 5 h of autoclave aging, whereas ground [93,106,110] or ground and polished [93] showed either similar biaxial [104] or characteristic strength [91,106] or higher three-point [93] or flexural fatigue strength [110] after 20 h of aging. In some publications, the three-point [115] and four-point [118] flexural strength after autoclave aging was brand-dependent—half of the evaluated materials showing no difference, half either a higher strength after 50 h [115] or a lower after 200 h [118]. Four HT 3Y-TZP brands had lower four-point flexural strength [117] and one had higher three-point flexural strength [125] than a traditional 3Y-TZP after aging in an autoclave. Yet another brand had a higher biaxial flexural strength than traditional 3Y-TZP, 4YSZ, and 5YSZ, in descending order, after autoclave aging [114]. The probability of survival in a fatigue test after aging was higher for HT 3Y-TZP in comparison to 4YSZ and 5YSZ [122].

Aging in an autoclave generally did not influence the Weibull modulus [74,106,107,114,117,119,120,122]. However, aging in a reactor increased it [120]. The surface finish had a certain influence on the Weibull modulus as well, where as-sintered, ground, ground and glazed, or ground and polished HT 3Y-TZP had a higher Weibull modulus after autoclave aging for 5–20 h [91,93]. As-sintered or glazed HT 3Y-TZP also showed lower Weibull modulus after autoclave aging for 5–8 h [27,91].

The fracture toughness of HT 3Y-TZP was affected neither by autoclave nor by reactor aging [120] and was similar to that of traditional 3Y-TZP after aging in an autoclave [125] The slow crack growth susceptibility (SCG) decreased for as-sintered HT 3Y-TZP after aging in an autoclave but was unaffected for ground HT 3Y-TZP [103]. The level of residual stresses after aging in an autoclave or reactor was either non-existent [120] or lower in comparison to traditional 3Y-TZP [126]. TC generated the highest stresses in the cervical area of the crowns [127].

Hydrothermal aging in a decomposition vessel decreased the load at fracture for conventionally and speed-sintered HT 3Y-TZP compared to non-aged conventionally sintered HT 3Y-TZP [78]. Aging in a hydrothermal [128,129] or isothermal [126] reactor did not influence the biaxial flexural strength [126,128] or load at fracture [129]. Aging in a hydrothermal reactor led to a lower characteristic strength in comparison to as-sintered and autoclaved HT 3Y-TZP [120]. The Weibull modulus was either lower after 1 h [129], unaffected after 5–140 h [126,128], or higher after 20 h of aging in a reactor [120].

TC decreased the biaxial flexural strength [70,102,130] and load at fracture [127], but was partly dependent on the brand [70,131], sintering time [70], or die material [127]. The load at fracture, characteristic load at fracture, and Weibull modulus were also reported as unaffected by TC [129,132], as was the biaxial flexural strength for one of two HT 3Y-TZP brands [70]. Water storage at 80 °C for 90 days did not influence the load at fracture [133]. Water storage at 37 °C for 80 days did, however, result in higher load at fracture compared to TC or ML [127]. Likewise, dry storage at room temperature for two years, as well as autoclave aging followed by water storage, increased the flexural fatigue strength for ground HT 3Y-TZP [110]. Meanwhile, as-sintered HT 3Y-TZP was not affected by either dry storage or autoclave aging [110].

4YSZ

Generally, hydrothermal aging in an autoclave did not affect the biaxial [69,114], three-point [123], characteristic [122,123], or flexural fatigue strength [122]. Jerman et al. [74] reported an increased three-point flexural strength for conventionally sintered 4YSZ, whereas the strength of high-speed-sintered 4YSZ decreased after aging in an autoclave. Further, Kengtanyakich et al. [134] reported a lower biaxial flexural strength after aging in an autoclave. The biaxial flexural [69,134] and flexural fatigue strength [122] of 4YSZ were reported as lower compared to HT 3Y-TZP but higher compared to 5YSZ after autoclave aging.

The Weibull modulus varied between being unaffected [122], reduced [74], or increased [114] by autoclave aging. The Weibull modulus of 4YSZ was lower than that of both HT 3Y-TZP and 5YSZ after aging in an autoclave [123]. The fracture toughness was reduced after autoclave aging but was higher than that of 5YSZ materials [134]. Water storage at 80 °C for 90 days increased the load at fracture, contrary to HT 3Y-TZP, which was unaffected [133].

5YSZ

The biaxial [27,114,134,135], three-point [68,93,116,123], and characteristic flexural strength [27,93,119,122,123] and flexural fatigue strength [122] were not influenced by hydrothermal aging in an autoclave for 3–50 h. Neither was the load at fracture [121]. However, autoclave aging for 160 h decreased the biaxial flexural strength [69], and 50 h of aging decreased the characteristic strength of the incisal and transition layers of a shaded multilayer 5YSZ [119]. The three-point flexural and characteristic strength of multilayer 4YSZ/5YSZ were not affected by hydrothermal aging in an autoclave [123].

The surface finish affected the flexural strength to a certain extent [93,98]. Ground and glazed 5YSZ showed a lower three-point flexural strength after aging in an autoclave, while as-sintered, ground, ground and polished, and ground, polished, and glazed 5YSZ were unaffected [93]. On the other hand, as-sintered or ground and polished 5YSZ had a higher three-point flexural strength, whereas ground, polished, or ground and glazed showed no difference after autoclave aging [98]. Further, in comparison to HT 3Y-TZP, 5YSZ had a lower biaxial [27] and three-point [68,116,123] flexural strength and load at fracture [121] after autoclave aging, as well as after TCML [133].

Generally, the Weibull modulus was not affected by autoclave aging [93,98,114,119,122]. Nonetheless, one publication reported a lower Weibull modulus [27], and another a higher for ground, polished, and glazed 5YSZ [93]. Aged 5YSZ had a lower Weibull modulus than aged HT 3Y-TZP and 4YSZ [114]. The fracture toughness was unaffected by autoclave aging [134].

Moreover, aging in a hydrothermal reactor did not influence the biaxial flexural strength but increased the Weibull modulus [128]. Water storage did not influence the load at fracture [133].

Factors: Mechanical Aging. Properties: Flexural Strength, Weibull Modulus, Characteristic Strength, Load at Fracture, Characteristic Load at Fracture, Flexural Fatigue Strength, and Residual Stress

HT 3Y-TZP

Several publications reported that ML did not affect the biaxial flexural [27] or characteristic strength [27], nor the load at fracture [121,124,127,129,132,136,137] or characteristic load at fracture [129,136] (Table 12). On the other hand, TC followed by ML [130] or ML alone [138,139] were reported to decrease the biaxial flexural [130,138] and flexural fatigue strength [139]. Holman et al. [28] reported some brand-dependent results, with one HT 3Y-TZP showing higher flexural fatigue strength than another after ML.

The Weibull modulus results varied: it was unaffected by ML alone [129] or in combination with TC [129], increased [27], or decreased by 60% after loading [136]. The highest stress concentrations were located in the cervical area of crowns subjected to ML [127].

TCML did not influence the load at fracture [133,140], the biaxial [114,141] or four-point flexural strength [117], or the Weibull modulus [74,114,117], with a few exceptions (Table 13). Two publications reported a higher three-point flexural strength [74] or load at fracture [142], and one publication a lower load at fracture, characteristic load at fracture, and Weibull modulus [143] after TCML.

The load at fracture [121,129,133] and the biaxial [114] or four-point [117] flexural strength did not differ between the aging methods autoclaving and ML [121], autoclaving and TCML [114,117], or water storage and the combination of water storage and TCML [133], nor did the load at fracture differ between aging in a reactor, TC, ML, or the combination ML and TC [129]. However, the three-point flexural strength [74] or load at fracture [124] were also reported as lower after autoclave aging than after TCML [74] or ML [124]. In contrast, Muñoz et al. [27] reported higher biaxial flexural strength after autoclave aging than after ML. HT 3Y-TZP showed a higher load at fracture [121] and higher biaxial flexural [27], three-point flexural [28], or flexural fatigue strength than 4YSZ and 5YSZ [27,28,121] after ML.

4YSZ

TCML either had no effect [33,141,142] or reduced [33,83] the load at fracture [33,83,142] or biaxial flexural strength [141]. However, TCML for 1.2×10^6 cycles increased the biaxial [114] or three-point [74] flexural strength, but doubling the number of cycles had no effect [114]. Water storage followed by TCML did not influence the load at fracture [133]. The Weibull modulus was either similar [33,114], lower [33], or higher [74] after TCML.

In comparison to aging in an autoclave, TCML led to a higher biaxial [114] or three-point flexural strength [74]. Water storage resulted in a higher load at fracture compared to the combination of water storage and TCML [133]. TCML of 4YSZ led to a lower three-point flexural strength than correspondingly aged HT 3Y-TZP [74]. After aging with ML, 4YSZ had a similar flexural fatigue strength as 5YSZ [28].

5YSZ, Multilayer 3Y-TZP/5YSZ, and 4YSZ/5YSZ

ML for 30,000 cycles [121] had no effect on the load at fracture, but 10^6 cycles decreased the characteristic [27] and biaxial flexural strength [27,138]. The Weibull modulus was not affected by ML [27]. For multilayer 3Y-TZP/5YSZ, TCML had no effect on the load at fracture or the Weibull modulus [33].

The load at fracture of 5YSZ decreased after TCML, compared to 4YSZ, which showed similar results, and HT 3Y-TZP, which showed an increased load at fracture after the same TCML procedure [142]. On the other hand, TCML did not affect the biaxial flexural strength, in accordance with the behaviour of HT 3Y-TZP and 4YSZ [114,141]. TCML of previously water-stored 5YSZ did not influence the load at fracture either [133]. The biaxial flexural strength [114,141] and load at fracture [133] were lower for 5YSZ than for HT 3Y-TZP and 4YSZ after aging with TCML. The Weibull modulus increased after TCML for 1.2×10^6 cycles and was higher compared to TCML with double the number of cycles or aging in an autoclave [114].

Comparing aging methods, autoclaving for 1 h and ML for 30,000 cycles showed similar loads at fracture [121], whereas autoclaving for 8 h led to a higher biaxial flexural strength than ML for 10^6 cycles [27]. Jerman et al. [114] reported a lower biaxial flexural strength after autoclaving compared to after TCML. Further, the load at fracture was similar after water storage to that after water storage and TCML [133].

Compared to HT 3Y-TZP, 5YSZ materials showed similar or higher and faster degradation after ML [28,138]. Holman et al. [28] reported similar flexural fatigue strength for one 4YSZ and two 5YSZ brands after ML, but the strength of 5YSZ was brand-dependent. A multilayer 3Y-TZP/5YSZ material showed a higher load at fracture compared to 4YSZ after TCML [33].

Factors: Two-Body, Three-Body, and Clinical Wear. Properties: Material Loss and Clinical Material Loss

HT 3Y-TZP

Two-body wear evaluated with ML [34,131,144,145] or TCML [117,146,147] led to vertical [34,145,146], volume [34,117,131,145,147], and weight [144] loss (Tables 14 and 15). Simulating wear using a pin-on-block test [142] or a wear machine with rotating wheels [148] resulted in vertical loss. Three publications reported that vertical or volume loss were not measurable [133,149] or that vertical or horizontal fatigue damage were absent [150] after ML or TCML. A higher surface roughness resulted in a higher volume loss [147], and glazed surfaces showed a higher vertical and volume loss than polished after wear simulation [117,146]. Three-body wear using an abrasive medium led to a gradually increasing vertical loss of the applied external stains [151].

Tooth- or implant-supported crowns or fixed dental prostheses (FDPs) with both glazed and non-glazed occlusal surfaces showed a vertical loss lower than 15 µm after 24 months [152]. Wear of the glaze was, however, detected on all occlusal surfaces after 12 months [152].

4YSZ

Three of five publications reported neither differences in vertical [33,133] or volume loss [33,133] nor any vertical or horizontal fatigue damage [150] after two-body wear simulation with ML or TCML. In the other two publications, volume [83] or vertical loss [142] were reported after TCML [83] or a pin-on-block wear test [142].

5YSZ

Two-body wear, evaluated with ML or TCML, did not result in measurable vertical [33,133] or volumetric loss [33,133,149] of 5YSZ [133,149] or multilayer 3Y-TZP/5YSZ [33]. Rosentritt et al. [142] reported a vertical loss after a pin-on-block wear test, but they found no differences in material loss between HT 3Y-TZP, 4YSZ, and 5YSZ. On the other hand, vertical and horizontal fatigue damage were reported for 5YSZ after wear simulation with ML, whereas HT 3Y-TZP and 4YSZ showed no signs of damage [150]. A multilayer 4YSZ/5YSZ material showed a higher volume loss and wear depth than a HT 3Y-TZP material after wear simulation [34].

3.5. Physicochemical Properties and Structures

Seventy-one publications (the high-risk-of-bias publications excluded) evaluated physicochemical properties and structures, of which the crystalline phase was the most common (Tables 2–15 and Figure 6). HT 3Y-TZP was the predominant zirconia type (n = 63), and 5YSZ (n = 21) was more common than 4YSZ (n = 10). The methods used in the publications are presented in Figure 7. A study population overlap for the physicochemical properties was identified in two publications [76,153] and [77,81]; thus, only the most recent publications were included [81,153].

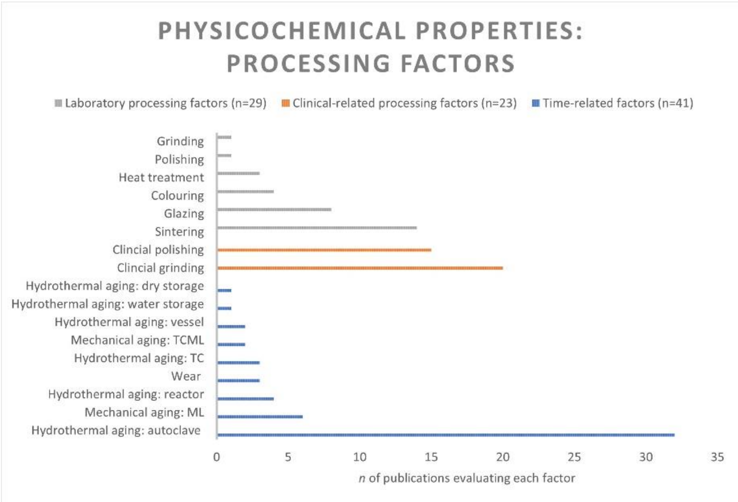

Figure 6. Laboratory and clinical-related processing factors and time-related factors evaluated for the physicochemical properties (at the top: n of publications evaluating laboratory, clinical-, and time-related factors, respectively; at the bottom: n of publications evaluating each factor; several factors can be included in one publication).

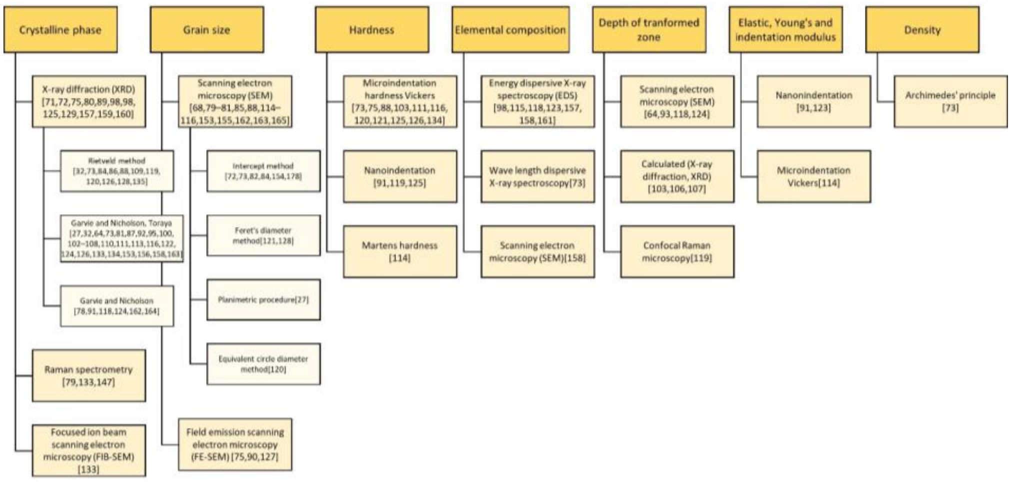

Figure 7. Methods/equipment used in publications for the evaluation of the physicochemical properties and structures.

3.5.1. Laboratory Processing Factors

Factor: Colouring. Properties: Grain Size and Crystalline Phase

HT 3Y-TZP

The mean grain size increased with increasing A shade value and compared to non-coloured HT 3Y-TZP after being coloured with an immersion technique in the -sintered stage [154] (Table 3). After hydrothermal aging, pre-coloured HT 3Y-TZP displayed a higher amount of m phase compared to immersion-coloured [64].

4YSZ

The mean grain size of 4YSZ increased after an increased number of colouring liquid applications using a staining technique with a brush and after an increased immersion time in the colouring liquid in the pre-sintered stage [26]. The grains were, however, mainly tetragonal, regardless of the colouring technique [26].

5YSZ and Multilayer 3Y-TZP/5YSZ

5YSZ coloured with a staining technique with a brush in the pre-sintered stage had a larger grain size than HT 3Y-TZP coloured with the same technique [68].

Factor: Sintering. Properties: Grain Size, Crystalline Phase, Hardness, Elemental Composition, and Density

HT 3Y-TZP

Increasing the final sintering temperature increased the grain size [153,155] (Table 4). Conventional sintering tended to increase the grain size compared to a shorter sintering protocol [75]. On the other hand, the grain size was also reported as similar after conventional and speed sintering [73,80]. High-speed sintering with a final temperature of 1590 °C and holding time of 10 min resulted in larger grain sizes than sintering at 1450 °C for 120 min [79]. Furthermore, changing the heating rate did not influence the grain size [72], whereas a fast cooling rate resulted in a larger grain size than a slow cooling rate [81]. In general, the sintering protocol did not affect the crystalline phase, which was predominately tetragonal, and no *t*–*m* phase transformation occurred [71–73,75,78–80]. Exceptions to the pattern were that a higher sintering temperature, longer holding time, and faster cooling rate increased the amount of *m* phase [81,153]. Cokic et al. [73] reported that a speed-sintered HT 3Y-TZP material had a lower tetragonality ($c/a\sqrt{2}$) in the *t* phase, i.e., closer to *c* phase, than another HT 3Y-TZP material conventionally sintered. Additionally, they found that speed sintering resulted in a higher hardness than conventional sintering [73], whereas Yang et al. [75] found no difference between sintering protocols. The density was not influenced by the sintering time [73]. The effect of sintering on the elemental composition of HT 3Y-TZP and 4YSZ is presented in Figure 8. Hafnium oxide (hafnia, HfO_2) was reported as an impurity in both zirconia types and erbium oxide (erbia, Er_2O_3) as a colouring agent in HT 3Y-TZP [73].

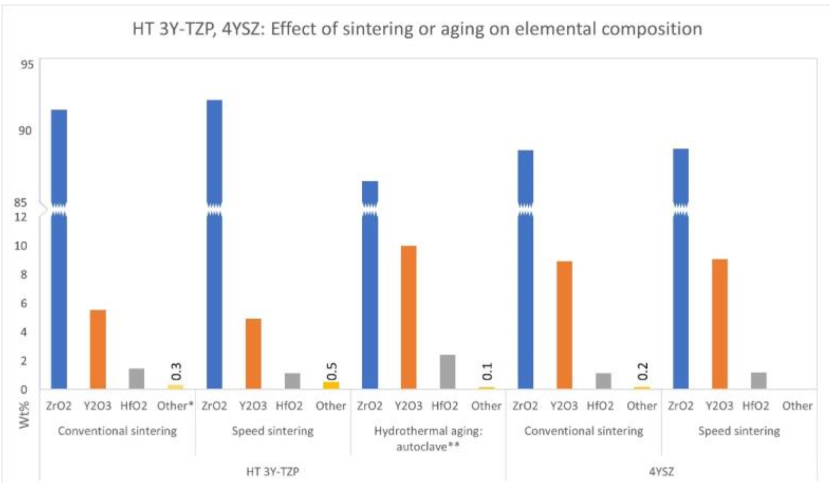

Figure 8. The effect of sintering [73] or aging [118] on the elemental composition of HT 3Y-TZP and 4YSZ. No publications on 5YSZ were identified. * Other: MgO, Er2O3, Fe2O3, Al2O3. ** Unclear if aged and *n* of h, mean of four HT 3Y-TZP brands [118].

4YSZ

Speed or high-speed sintering led to a larger grain size than conventional sintering [73,79]. On the contrary, a similar grain size was reported after conventional and high-speed sintering [82]. The amount of *c* phase (53 wt%) was higher in 4YSZ than in HT 3Y-TZP (8–20 wt%), but it was not dependent on the sintering protocol, nor was the density [73].

The *t* phase had, however, a lower tetragonality after speed sintering than after conventional sintering, and the hardness was lower after speed sintering, contrary to the behaviour of HT 3Y-TZP [73]. No *m* phase was detected [73,79].

5YSZ and Multilayer 3Y-TZP/5YSZ

An increased final sintering temperature resulted in a larger grain size and more defined grain boundaries of 5YSZ than a lower temperature [84]. Unlike conventional sintering, high-speed and rapid sintering increased the grain size [75,82]. Moreover, 5YSZ displayed large grains combined with few small grains, whereas HT 3Y-TZP showed smaller grains and a more even grain size distribution [75]. A slightly higher amount of *c* phase (47%) together with the *t* phase (53%) was identified after sintering at a higher final sintering temperature than at a lower temperature (46% *c*, 54% *t* phase) [84]. No *t*–*m* phase transformation or *m* phase was found [75,84]. The sintering time of FDPs positioned in different locations in a multilayer 3Y-TZP/5YSZ blank varied from shorter in the upper position, containing mainly 5YSZ, to longer in the bottom position, containing mainly 3Y-TZP [85]. Larger grain sizes (>1 µm) were found in the upper position than in the central and bottom position (0.5 µm) [85]. 5YSZ had a lower hardness than one of three HT 3Y-TZP materials, and the hardness was unaffected by the sintering protocol [75].

Factors: Grinding, Polishing, Heat Treatment, and Glazing. Properties: Grain Size, Crystalline Phase, Hardness, Elemental Composition, and Elastic Modulus

HT 3Y-TZP

Grinding generated *m* phase but reduced the amount of *m* phase compared to that of as-sintered HT 3Y-TZP [86]. Polishing and glazing led to a crystalline structure mainly consisting of *t* phase and no [89,91,96] or a limited amount of *m* phase (2% after dry polishing in the pre-sintered stage or wet polishing in the fully sintered stage) [95] (Tables 5 and 7). Glazing of the ground surfaces had a reversing effect of the *m* phase previously induced by grinding; thus, *m*–*t* phase transformation occurred [87,92]. Glazed HT 3Y-TZP had a larger grain size than as-sintered HT 3Y-TZP [89]. Further, glazing led to lower hardness and elastic modulus than for as-sintered [91]. However, after grinding with an ultra-fine diamond bur followed by glazing, the hardness and elastic modulus were higher than for as-sintered material [91].

Regenerative heat treatment completely reversed the *m* phase found in as-sintered, ground, or polished HT 3Y-TZP [86,87]. Rapid cooling of HT 3Y-TZP decreased the low-yttria *t* phase and increased the high-yttria *t*′ phase [88]. Furthermore, it tended to increase the grain size and decrease the hardness.

4YSZ

Rapid cooling of 4YSZ led to a decrease in the *t* phase and an increase in the *t*′ phase, and there was a tendency towards a larger grain size, corresponding to the behaviour of HT 3Y-TZP [88]. The hardness was relatively unaffected, with a small decrease after rapid cooling [88].

5YSZ and Multilayer 4YSZ/5YSZ

The influence of the surface finish on the elemental composition of 5YSZ is presented in Figure 9 [98]. The carbon (C) detected was hypothesized as a remnant from the grinding, polishing, and glazing procedures [98]. Furthermore, *t* and *c* phases were found in multilayer 4YSZ/5YSZ subjected to glazing; thus, glazing did not induce a *t*–*m* phase transformation [100].

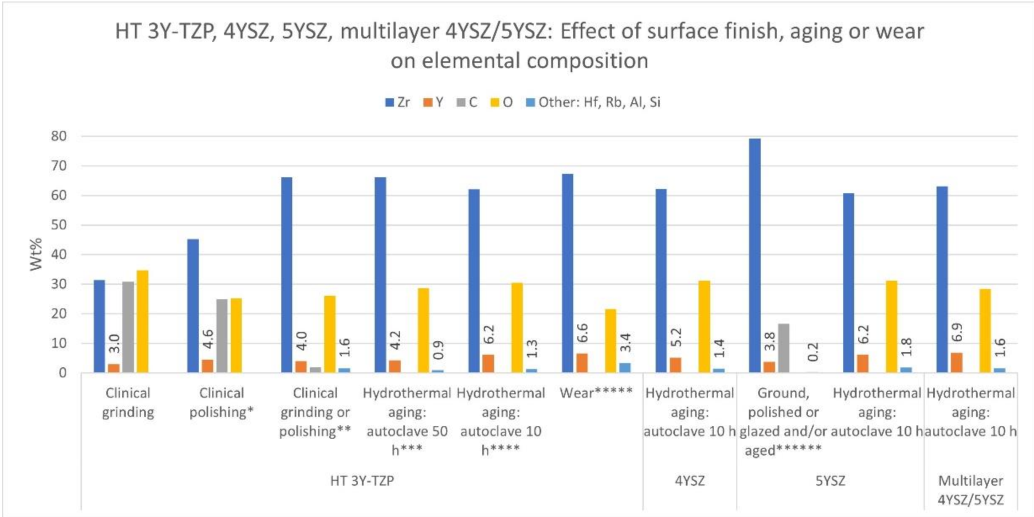

Figure 9. The effect of surface finish [98,158,161], aging [98,115,123], or wear [157] on the elemental composition (wt%) of HT 3Y-TZP, 4YSZ, 5YSZ, and multilayer 4YSZ/5YSZ based on the mean from each study. * Mean of five polishing systems [158]. ** Unclear if ground or polished, mean of one non-, two pre-coloured [161]. *** Mean of six HT 3Y-TZP brands [115]. **** Mean of three HT 3Y-TZP brands [123]. ***** Mean of lowest and highest values in range [157]. ****** Unclear if ground, polished, or glazed and/or aged; one 5YSZ brand [98].

Rapid cooling of 5YSZ also decreased the amount of *t* phase and increased the *t*′ phase, and the higher the amount of yttria, the higher the proportion of t′ phase (64.4 wt% compared to 26.1 wt% for HT 3Y-TZP) [88]. The grain size of 5YSZ was larger than that of HT 3Y-TZP and 4YSZ, and it tended to increase with rapid cooling; accordingly, rapidly cooled 5YSZ had the largest grain size [88]. The hardness was slightly reduced after rapid cooling [88].

3.5.2. Clinical-Related Processing Factors

Factors: Clinical Grinding and Polishing. Properties: Crystalline Phase, Depth of Transformed Zone (TZD), Elemental Composition, Hardness, and Elastic Modulus

HT 3Y-TZP

Most of the publications reported the presence of *m* phase after clinical grinding and polishing, although *t* phase was the predominant one [87,92,102–111,156,157] (Tables 9 and 10). The depth of the transformed zone (TZD) was 0.5–0.7 µm [103,106,107]. In some cases, polishing subsequent to grinding triggered a reverse *m*–*t* phase transformation, reducing the amount of *m* phase [87,105,157]. Nonetheless, grinding and polishing were also reported not to alter the crystalline phase [91,96,158–160]. The effect of grinding and polishing on the elemental composition of HT 3Y-TZP and 5YSZ is presented in Figure 9 [158,161]. For HT 3Y-TZP, polishing increased the amount of Y for all except one polishing system (silicone carbide polishers) [158].

Grinding resulted in a similar hardness to as-sintered material [103]. However, ultra-fine grinding increased both the hardness and elastic modulus in comparison to as-sintered and finely ground HT 3Y-TZP [91]. Polishing led to a lower hardness than as-sintered material [111].

5YSZ and Multilayer 4YSZ/5YSZ

Grinding of multilayer 4YSZ/5YSZ did not trigger a *t*–*m* phase transformation, and only *t* and *c* phases were identified [100].

3.5.3. Time-Related Factors

Factors: Hydrothermal Aging and Mechanical Aging. Properties: Crystalline Phase, TZD, Elemental Composition, Hardness, Elastic Modulus, Grain Size, Young's Modulus, and Indentation Modulus

HT 3Y-TZP

The most common aging method was hydrothermal aging in an autoclave [125], which induced a *t*–*m* phase transformation [27,64,73,89,91,102–104,106,107,110,111,113,116,118–120,122–124,162–164] (Tables 11–13 and Figure 10). The amount of *m* phase increased with increasing aging time (5–100 h) [64,73,118,123,124,163,164]. Figure 11 shows the influence of other aging methods on the *m* phase [32,78,110,120,126,128,129,133].

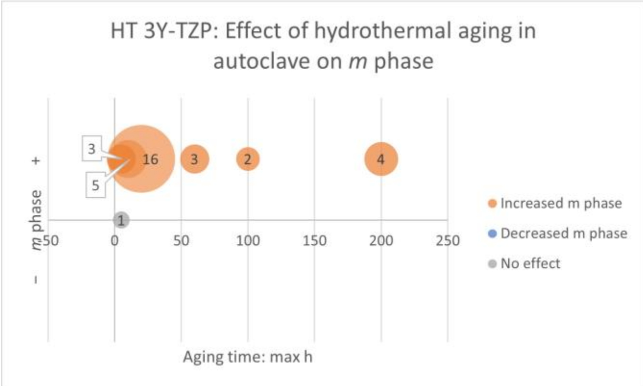

Figure 10. The effect of hydrothermal aging in an autoclave on the *m* phase for HT 3Y-TZP: decreasing/increasing [27,64,73,89,91,102–104,106,107,110,111,113,116,118–120,122–124,162–164]/no effect [126] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles.

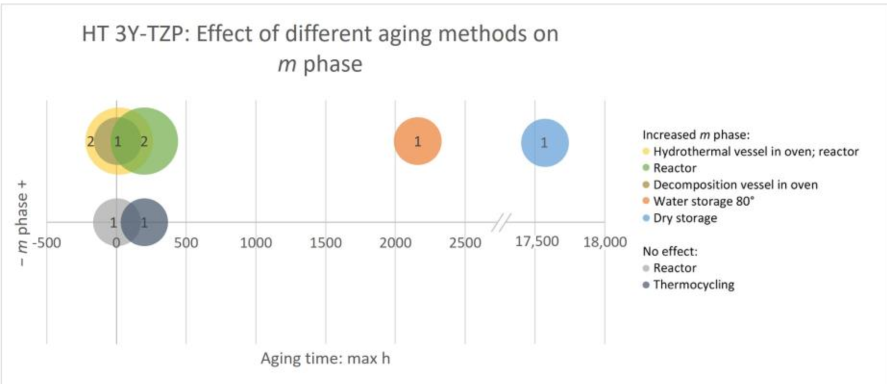

Figure 11. The effect of different aging methods on the *m* phase for HT 3Y-TZP: increasing [32,78,110,120,126,133]/no effect [128,129] (not exact values). The number of materials evaluated is presented in the bubbles and by the size of the bubbles.

When comparing aging methods, the publications reported that aging in a hydrothermal reactor led to higher amounts of *m* phase compared to autoclaving [120]. ML alone did not trigger a *t*–*m* phase transformation, but aging in an autoclave or in combination with ML did [27,127]. Accordingly, dry storage promoted less *m* phase than autoclaving [110], and ML subsequent to water storage did not exacerbate it [133]. Bergamo et al. [129] reported an increase in *m* phase after TC combined with ML or after ML alone, whereas TC alone did not affect the *m* phase amount.

Ground materials showed lower amounts of *m* phase in comparison to as-sintered materials after 5–20 h of aging in an autoclave [91,103,104,106,107,110], except in one publication, showing higher amounts after 5 h [102]. TC, similarly, increased the *m* phase of as-sintered materials, but it did not affect ground and polished materials [102]. Moreover, the TZD was lower for ground than for as-sintered materials [103,106,107]. Glazed materials showed no [91] or an indication of *t*–*m* phase transformation [89] after aging for 2–54 h. After aging in an autoclave, the TZD was 0–8.4 µm after 20–50 h [64,93,103,106,107,119] and 5–60 µm after 100–200 h [118,124]. Flinn et al. [118] reported a TZD difference of 55 µm between different HT 3Y-TZP brands after 100 h of aging.

The grain size was less than 1 µm [27,89,115,120,121,162,164] and either increased [89,120,126], decreased [162], or was unaffected [128] after aging in an autoclave or reactor. The increase in grain size was more pronounced after aging in a hydrothermal reactor than in an autoclave [120].

The effect of autoclave aging on the hardness varied from no effect [91,103,111,114,120] to a decreasing effect [119,123,134] or, for as-sintered and ultrafine ground materials, an increasing effect [91]. The hardness was lower for HT 3Y-TZP than for traditional 3Y-TZP [125]. Aging in a reactor decreased the hardness [120,126], but a combination of TC and ML (TCML) for up to 2.4 × 10^6 cycles had no effect [114]. For as-sintered [91,114] and ultrafine ground materials [91], the elastic modulus and indentation modulus [114] followed the same pattern, varying from no effect [114] to an increasing effect [91].

The influence of autoclave aging on the elemental composition of HT 3Y-TZP, 4YSZ, 5YSZ, and multilayer 4YSZ/5YSZ is presented in Figure 8 [118] and Figure 9 [98,115,123]. One publication [115] found no difference in each specific element for HT 3Y-TZP before and after aging for 50 h, whereas another [123] found lower amounts of Zr and Y but higher amounts of oxygen (O) after aging in an autoclave for 10 h for all zirconia types.

4YSZ

Either no [73,122] or minor amounts [123,134,164] of *m* phase, 5–12 vol%, were detected after hydrothermal aging in autoclave or water storage at 80 °C for 90 days [133] (Figure 12). The *t*–*m* phase transformation was, however, less extensive compared to HT 3Y-TZP [123,133,134,164]. In comparison to 5YSZ, the amount of *m* phase was either higher [133,134,164] or lower [123]. TC in combination with ML (TCML) for up to 2.4 × 10^6 cycles or aging in a hydrothermal vessel in an oven at 120 °C for 12 h did not trigger any *t*–*m* phase transformation of 4YSZ, unlike the HT 3Y-TZP material [32]. The crystalline phase of 4YSZ was mainly *t* phase with more *c* phase than in HT 3Y-TZP [122].

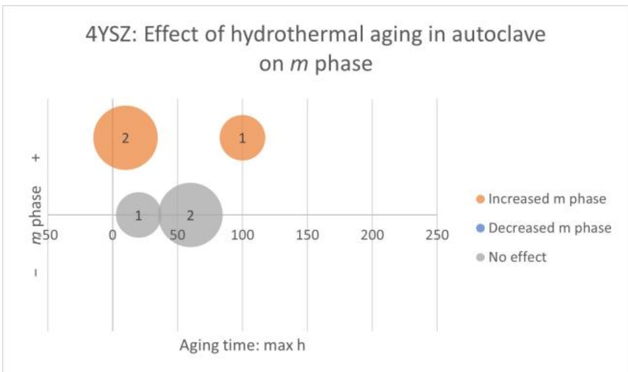

Figure 12. The effect of hydrothermal aging in an autoclave on the *m* phase for 4YSZ: decreasing/increasing [123,134,164]/no effect [73,122] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles.

The grain size was bigger for 4YSZ than for HT 3Y-TZP [164]. Autoclave aging did not influence the indentation modulus [114] and the hardness [114,123,134], which was similar to that of 5YSZ and multilayer 4YSZ/5YSZ but higher than that of HT 3Y-TZP [123,134].

5YSZ and Multilayer 4YSZ/5YSZ

The influence of hydrothermal aging in autoclave on *m* phase is presented in Figure 13 [27,98,116,119,122,123,134,135,164]. In the cases of detected *m* phase, the amount was minor (<1–6 vol% or ≤8 wt%) [119,123,135,164]. Aging in a hydrothermal vessel in an oven [32], ML for 10^6 cycles [27], or TCML for up to 2.4×10^6 cycles [114] did not result in any phase transformation. Water storage at 80 °C for 90 days resulted in some *m* phase, but it was about half the amount of that for 4YSZ, and it was not increased by the following ML [133]. The TZD was either non-existent, due to the absence of phase transformation [93], or approximately 6.3 µm after 50 h of aging [119]. *T* and *c* phases were the main phases identified in 5YSZ [27,116,122,135].

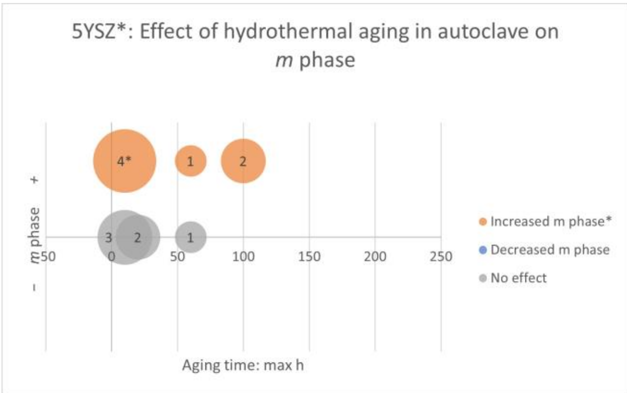

Figure 13. The effect of hydrothermal aging in an autoclave on the *m* phase for 5YSZ and multilayer 4YSZ/5YSZ: decreasing/increasing [119,123,135,164]/no effect [27,98,116,122,134] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles. * Including one multilayer 4YSZ/5YSZ, 10 h aging time [123].

The grains of 5YSZ were less homogenous than those of HT 3Y-TZP [27,68,116,121,164] and bigger (0.8–4.9 µm) than those of HT 3Y-TZP [121,164,165] and 4YSZ [114] after aging. The grain size was not affected by aging in a reactor [128].

The hardness was mostly not affected by autoclave aging [114,119,134], although Choi et al. [123] reported a decrease in hardness with increasing aging time for up to 10 h. 5YSZ was reported to have a higher hardness than HT 3Y-TZP after autoclave aging [121,123,134], but similar to 4YSZ and multilayer 4YSZ/5YSZ [123,134]. Multilayer 4YSZ/5YSZ had a similar hardness after aging for 10 h [123]. The indentation modulus was not influenced by aging [114].

Factors: Two-Body and Clinical Wear. Properties: Crystalline Phase and Elemental Composition

HT 3Y-TZP

Two-body wear evaluated by ML (25 N and 120,000 cycles) in water did not affect the amount of *m* phase [157] (Table 14). However, a protocol of 98 N for 1.2×10^6 cycles with simultaneous TC led to *t*–*m* phase transformation [147]. Wear with TCML of previously water-stored HT 3Y-TZP did not exacerbate the *t*–*m* phase transformation [133]. Preis et al. [157] reported a decrease in Zr, O, Y, silicon (Si), and Hf, but not in Al, after wear simulation (Figure 9). In addition, small amounts of magnesium (Mg) were found after wear testing, potentially as remnants from the steatite antagonist.

4YSZ

The limited amount of *m* phase caused by water storage was not increased after wear with TCML at 98 N for 2.5×10^6 cycles [133].

5YSZ

Wear evaluated with TCML of previously water-stored 5YSZ did not increase the amount of *m* phase [133].

3.6. Surface Properties

Surface properties were evaluated in 62 publications (the high-risk-of-bias publications excluded), and the surface roughness and characterization were the most common properties (Tables 2–15 and Figure 14). HT 3Y-TZP constituted a clear majority (*n* = 54) and 5YSZ (*n* = 15) was represented more often than 4YSZ (*n* = 7). The methods used in the publications are presented in Figure 15.

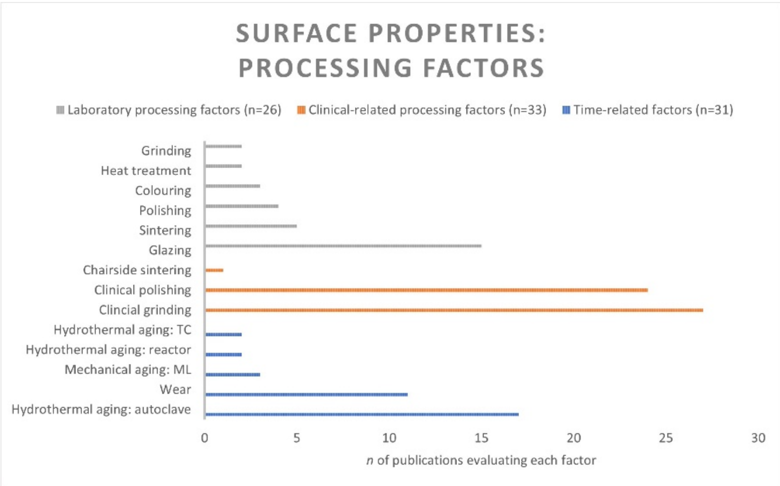

Figure 14. Laboratory and clinical-related processing factors and time-related factors evaluated for the surface properties (at the top: *n* of publications evaluating laboratory, clinical-, and time-related factors respectively; and at the bottom: *n* of publications evaluating each factor; several factors can be included in one publication).

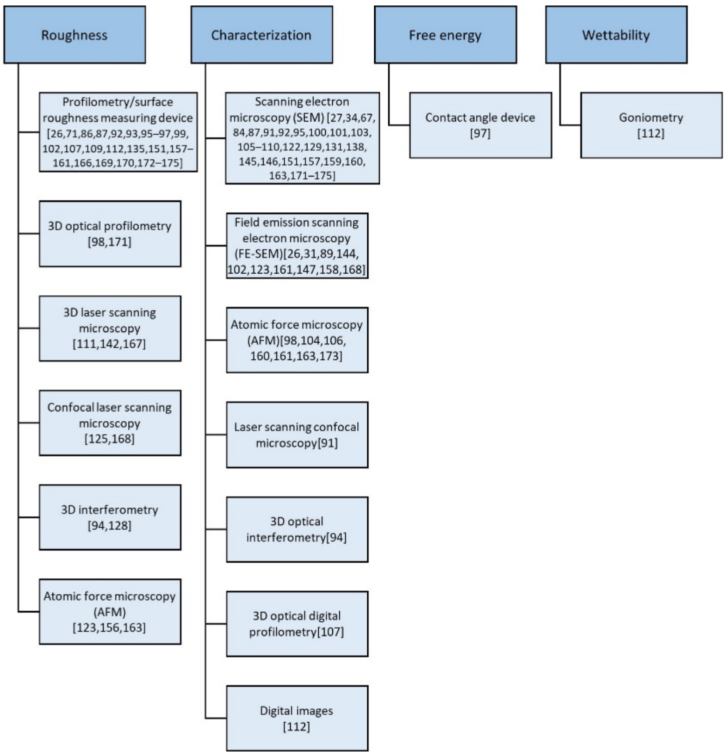

Figure 15. Methods/equipment used in publications for the evaluation of the surface properties.

3.6.1. Laboratory Processing Factors

Factor: Colouring. Properties: Surface Roughness and Surface Characterization

HT 3Y-TZP

External staining and glazing resulted in a surface roughness of 0.2 µm (Ra parameter), and the morphology was not altered by the staining [151] (Table 3).

4YSZ

When 4YSZ was coloured in the pre-sintered stage, neither the surface roughness (Ra and Rz parameters) nor the topography was affected by the type of colouring technique, i.e., immersion or staining, or the number of applications and immersion time [26].

5YSZ

The type of colouring liquid, i.e., acid-based or aqueous, used in the immersion technique in the pre-sintered stage resulted in different surface characterizations [31]. The acid-based liquid partially remained on the surface, whereas the aqueous liquid was absorbed [31].

Factor: Sintering. Properties: Surface Roughness and Surface Characterization

HT 3Y-TZP

The choice of sintering protocol, i.e., high-speed or speed and different combinations of sintering temperatures and holding times, had no effect on the surface roughness (Ra) [71,166] (Table 4). Vacuum sintering presented a surface with fewer cracks compared to regular sintering [67]. Both conventional and rapid sintering led to dense surfaces without pores or microcracks [75].

5YSZ

The surface characterization was mainly qualitatively presented [67,75,84]. As with HT 3Y-TZP, both conventional and rapid sintering of 5YSZ resulted in dense surfaces [75].

Factors: Grinding, Polishing, Heat Treatment, and Glazing. Properties: Surface Roughness, Surface Characterization, and Surface Free Energy

HT 3Y-TZP

Grinding with diamond stones or points increased the surface roughness compared to as-sintered surfaces (Ra and Rz) [86] and polished surfaces (Ra) [167] (Tables 5 and 16). Laboratory polishing followed by glazing resulted in a surface roughness (Ra) comparable to a clinical four-step polishing protocol [168] (Tables 5 and 7). In comparison to manual dry polishing at the pre-sintered stage, machine wet polishing at the fully sintered stage resulted in a lower surface roughness (Ra), which was confirmed with SEM images [95]. Further, heat treatment (performed in order to remove residual stresses induced during the processing) did not influence the roughness (Ra, Rz) [86,87] (Table 6).

The surface roughness was reduced after glazing [169], and using the brush technique presented a lower surface roughness (Ra, Rz) than using spray glaze [92]. A ground and spray-glazed surface showed similar roughness (Ra, Rz) to a ground surface [92]. Overall, glazing and clinical polishing resulted in equivalent surface roughness (Ra) [96,170,171]. Hatanaka et al. [93] reported that the combination of grinding, polishing, and glazing led to the lowest surface roughness (Ra), followed by the combination of grinding and glazing and grinding and polishing. Zucuni et al. [87] confirmed that grinding, polishing, and glazing led to a lower surface roughness (Ra, Rz) than grinding and polishing, but they found no difference compared to grinding and glazing. According to Khayat et al. [94], the roughness (Ra) of a glazed surface was lower compared to that of the same surface after grinding, and lower or similar to that after polishing with clinical polishing systems. Dal Piva et al. [151] reported a surface roughness of 0.2 µm after external staining and glazing.

Table 16. The effect of clinical and laboratory grinding, polishing, and glazing on the surface roughness parameters Ra and Rz for HT 3Y-TZP.

Author, Year	Name of Material (Manufacturer)	Clinical Grinding Ra/Rz (µm) Mean (±SD)	Clinical Polishing Ra/Rz (µm) Mean (±SD)	Laboratory Grinding Ra/Rz (µm) Mean (±SD)	Laboratory Polishing Ra (µm) Mean (±SD)	Glazing Ra/Rz (µm) Mean (±SD)
Al-Haj Husain, 2016 [158]	Katana Zirconia HT (Kuraray Noritake)	0.3	Shofu 0.3 Ceragloss 0.4 Eve 1.1 Soflex 0.3 Diamond bur 0.1			
Al-Haj Husain, 2018 [112]	Katana Zirconia HT (Kuraray Noritake)	0.27	Shofu 0.27 Ceragloss 0.40 Eve 1.11 Soflex 0.29 Diamond bur 0.13			
Aliaga, 2020 [109]	Prettau Zirkon (Zirkonzahn)	Dry ground 1.53 (0.36) Wet ground 3.26 (0.43)				
Amer, 2015 [17]	Crystal diamond, Crystal Zirconia (Dental Laboratory Milling Supplies)	0.45 *	0.1 *			0.25 *
Caglar, 2018 [159]	Katana Zirconia HT (Kuraray Noritake)	1.77 (0.26)	Luster 0.28 (0.11) Eve Diacera 0.28 (0.07) Eve Diapol 0.78 (0.14)			
Chavali, 2017 [171]	Zenostar Zr Translucent (Wieland)	CeraMaster 5000 rpm 4.0 (0.4) CeraMaster 15,000 rpm 3.8 (0.2) CeraMaster 40,000 rpm 4.0 (0.4) Dialite ZR 5000 rpm 4.0 (0.4) Dialite ZR 15,000 rpm 4.1 (0.3) Dialite ZR 40,000 rpm 3.8 (0.2)	CeraMaster 5000 rpm: Medium polished 30 s 2.7 (0.1)/60 s 2.8 (0.2)/Fine polished 2.3 (0.2) CeraMaster 15,000 rpm: Medium 30 s 3.0 (0.8)/ 0 s 2.4 (0.2)/Fine 1.0 (0.3) CeraMaster 40,000 rpm: Medium 30 s 2.5 (0.1)/60 s 2.1 (0.1)/Fine 1.6 (0.1) Dialite ZR 5000 rpm: Medium 30 s 2.4 (0.3)/60 s 2.3 (0.3)/Fine 2.0 (0.2) Dialite ZR 15,000 rpm: Medium 30 s 2.3 (0.4)/60 s 1.5 (0.4)/Fine 0.6 (0.2) Dialite ZR 40,000 rpm: Medium 30 s 1.8 (0.5)/ 60 s 1.4 (0.2)/Fine 1.3 (0.3)			CeraMaster 15,000/40,000/Dialite ZR 5000 rpm: Glazed lower than fine polished 1.0/1.6 /2.0 CeraMaster 5000 rpm: Glazed similar as fine polished 2.3 Dialite ZR 15,000/40,000 rpm: Glazed higher than fine polished 0.6/1.3
Chun, 2017 [96]	Vita YZ HT (Vita Zahnfabrik)	Glazed, ground 0.61 (0.47)	Glazed, ground, polished 0.21 (0.11)			Glazed 1.12 (0.18) Ground, glazed 1.32 (0.33) Ground, polished, glazed 1.45 (0.42)
De Souza, 2020 [102]	Vipi Block Zirconn Translucent (Vipi)	0.87 (0.16)	Ground, polished 0.55 (0.12)			
Fratucelli, 2021 [86]	Prettau zirconia (Zirkonzahn)			Ra: 2.47 (0.91) Rz: 15.95 (4.62)		
Goo, 2016 [174]	Lava Plus High Translucency (3M ESPE)		White stone, Shofu 0.34 Shofu 0.39 Ceramisté 0.51 Ceramaster 0.42 Komet 0.25 *			
Hatanaka, 2020 [93]	Prettau (Zirkonzahn)	4.30 (3.50, 5.05) **	Ground, polished 2.12 (1.66, 2.41) **			Glazed 0.45 (0.35, 0.52) Ground, glazed 0.97 (0.75, 1.04) Ground, polished, glazed 0.50 (0.40, 0.67) **
Huh, 2016 [160]	Rainbow Trans (Genoss)	0.93 (0.17)	D&Z 60 s 0.15 (0.03)/120 s 0.14 (0.02) EVE Diacera 60 s 0.16 (0.02)/120 s 0.17 (0.05) CeraGloss 60 s 0.19 (0.03)/120 s 0.21 (0.06) StarGloss 60 s 0.14 (0.03)/120 s 0.12 (0.02) Luster 60 s 0.16 (0.03)/120 s 0.16 (0.03) DFS 60 s 0.24 (0.08)/120 s 0.23 (0.04)			
Huh, 2018 [161]	Zenostar T0 Zenostar sun Zenostar sun chroma (Ivoclar Vivadent)	3.00 * (independent of material)	T0 0.17, Sun 0.19, Sun chroma 0.15 * 0.10 * (independent of material)			
Incesu, 2020 [173]	Lava Plus Zirconia (3M ESPE)		Ra: Komet 0.24 (0.07) Luster 0.17 (0.03) Ceramisté 0.25 (0.06) OptraFine 0.10 (0.02) Rz: Komet 1.46 (0.42) Luster 0.96 (0.19) Ceramisté 1.52 (0.48) OptraFine 0.55 (0.14)			
Jum'ah, 2020 [168]	DD Bio ZX (DentalDirekt)	1.82 (0.33)	Identoflex 1.03 (0.24) Diacera Twist 1.44 (0.38) DiaShine 0.41 (0.10)			0.21 (0.05)
Khayat, 2018 [94]	Tizian Blank Translucent (Schütz)	1.70 (0.44)	Brasseler 1.00 (0.31) Komet 0.81 (0.26)			Glazed (to be ground) 0.80 (0.16) Glazed (to be polished Brasseler) 0.67 (0.06) Glazed (to be polished Komet) 0.70 (0.12) Glazed (control) 0.79 (0.20)
Lee, 2019 [172]	Prettau (Zirkonzahn)	Ground 1.07	Diamond, polishing 0.87 (0.11) Diamond, stone grinding, polishing 0.64 (0.10) Polishing 0.32 (0.06) Stone grinding, polishing 0.29 (0.07)			

Table 16. *Cont.*

Author, Year	Name of Material (Manufacturer)	Clinical Grinding Ra/Rz (µm) Mean (±SD)	Clinical Polishing Ra/Rz (µm) Mean (±SD)	Laboratory Grinding Ra/Rz (µm) Mean (±SD)	Laboratory Polishing Ra (µm) Mean (±SD)	Glazing Ra/Rz (µm) Mean (±SD)
Mai, 2019 [156]	Prettau (Zirkonzahn)	Jota Coarse 0.32 (0.02) Meisinger Coarse 0.74 (0.11) Edenta Coarse 0.50 (0.06)	Jota: Coarse, medium polished 0.16 (0.07)/Coarse, fine polished 0.24 (0.03)/Coarse, medium, fine polished 0.05 (0.07) Meisinger: Coarse, medium 0.09 (0.08)/Coarse, fine 0.41 (0.07)/Coarse, medium, fine 0.08 (0.03) Edenta: Coarse, medium 0.29 (0.03)/Coarse, fine 0.44 (0.07)/Coarse, medium, fine 0.09 (0.04)			
Manziuc, 2019 [169]	Katana HT (Kuraray Noritake) Vita YZ HT (VITA Zahnfabrik) Cercon HT (Dentsply Sirona)			Katana HT 0.09 Vita YZ HT 0.06 Cercon HT 0.12 *** (0.8, 1.5, 2.0 mm)		
Moqbel, 2019 [111]	Katana HT10 (Kuraray Noritake)		Ra: 0.01 (0.00) Rz: 0.03 (0.01)			
Pereira, 2016 [106]	Zirlux FC (Ivoclar Vivadent)	Ra: Coarse ground 1.32 (0.24) Extra-fine ground 0.64 (0.16) Rz: Coarse ground 6.74 (1.20) Extra-fine ground 4.29 (1.00)				
Pereira, 2016 [104]	Zirlux FC (Ivoclar Vivadent)	Ra: 1.04 (0.27) Rz: 6.51 (1.49)				
Prado, 2017 [107]	Zirlux FC (Ardent Dental)	Ra: 0.60 *** (0.5, 1.0 mm) Rz: 4.00 *** (0.5, 1.0 mm)				
Preis, 2015 [157]	Cercon HT (DeguDent)	1.23 *	0.20 *			
Schatz, 2016 [95]	Ceramill Zolid (AmannGirrbach) Zenostar Zr Translucent (Wieland + Dental) DD Bio zx2 (Dental Direkt)				Dry polished 0.31–0.41 Wet polished 0.01–0.01 ****	
Tachibana, 2021 [167]	inCoris TZI (Sirona)			Experiment 1–3 3.16/3.18/3.17	Experiment 1–3 0.02/0.02/0.03	
Zucuni, 2019 [105]	Zenostar T (Ivoclar Vivadent)	Ra: 1.21 Rz: 7.42	Ra: Ground coarse, Eve Diacera 0.33/Ground coarse, fine, extrafine, Eve Diacera 0.33 Ground coarse, Kg Viking 0.84 Ground coarse, fine, extrafine, Kg Viking 0.57 Ground coarse, Optrafine 0.63 Ground coarse, fine, extrafine, Optrafine 0.47 Rz: Ground coarse, Eve Diacera 2.33/Ground coarse, fine, extrafine, Eve Diacera 2.07 Ground coarse, Kg Viking 5.38 Ground coarse, fine, extrafine, Kg Viking 3.85 Ground coarse, Optrafine 4.16 Ground coarse, fine, extrafine, Optrafine 3.27			
Zucuni, 2017 [87]	Zenostar T (Ivoclar Vivadent)	Ra: 1.10 (0.16) Rz: 4.97 (0.86)	Ra: Ground, polished 0.29 (0.05) Rz: Ground, polished 1.80 (0.32)			Ra: Ground, glazed 0.24 (0.11) Ground, polished, glazed 0.17 (0.05) Rz: Ground, glazed 1.24 (0.60) Ground, polished, glazed 0.93 (0.37)
Zucuni, 2019 [92]	Vita YZ-HT (Vita Zahnfabrik)	Ra: 1.03 (0.18) Rz: 6.47 (1.21)				Ra: Brush-glazed 0.54 (0.07) Spray-glazed 0.83 (0.29) Ground, brush-glazed 0.62 (0.17) Ground, spray-glazed 1.16 (0.42) Rz: Brush-glazed 3.61 (0.68) Spray-glazed 5.39 (1.90) Ground, brush-glazed 3.81 (1.06) Ground, spray-glazed 7.46 (2.51)

Rounded to two decimals. * Values indicated in figure. ** Median (25%, 75%). *** Arithmetic mean of the thicknesses. **** Only range presented.

Surface characterizations were qualitatively presented [87,89,91,92,94,95,144,151,168,171]. Grinding caused surfaces with grooves, scratches, and an irregular topography [87,91,92,94,168,171]. Meanwhile, glazing tended to show a more homogeneous surface than ground surfaces [87,92,144,168], with some bubbles within the glaze [91,100]. Polishing presented some striations from the polishing direction [144].

4YSZ

After polishing at the pre-sintered stage, a two-step polishing protocol using fine and rough laboratory diamond wheel polishers in the fully sintered stage generally reduced the surface roughness (Ra), but this did not affect the surface free energy (SFE) compared to a one-step protocol [97] (Table 17). Polishing with a laboratory polishing kit in two steps in the fully sintered stage resulted in a similar roughness to pre-sintered polishing with a felt wheel or goat hair brush with or without polishing paste followed by two-step polishing [97]. Laboratory polishing followed by glazing reduced the surface roughness (Ra) in comparison to clinical polishing protocols, in contrast to the HT 3Y-TZP material, where there was no difference between polished and glazed and the four-step protocol [168]. Glazing reduced the surface roughness [169]. Grooves were observed on ground surfaces but were reduced after polishing and glazing [168].

Table 17. The effect of clinical and laboratory grinding, polishing, and glazing on the surface roughness parameters Ra and Rz for 4YSZ.

Author, Year	Name of Material (Manufacturer)	Clinical Grinding Ra (µm) Mean (±SD)	Clinical Polishing Ra (µm) Mean (±SD)	Laboratory Grinding Ra (µm) Mean (±SD)	Glazing Ra (µm) Mean (±SD)
Jum'ah, 2020 [168]	DD cube ONE® (DentalDirekt)	2.87 (0.62)	Identoflex 1.55 (0.37 Diacera Twist 1.95 (0.42) DiaShine 0.99 (0.15)		0.45 (0.16)
Manziuc, 2019 [169]	IPS e.max ZirCAD MT (Ivoclar Vivadent)				0.07 * (0.8, 1.5, 2.0 mm)
Pfefferle, 2020 [97]	Ceramill Zolid HT+ (Amann Girrbach)			1 step: Felt wheel/polishing paste 0.29/0.10 Goat hair brush/polishing paste 0.35/0.12 Green-state finishing kit 0.28 Universal polisher 0.18 SiC polishing paper 0.07 2 step: Felt wheel/polishing paste 0.07/0.07 Goat hair brush/polishing paste 0.09/0.08 Green-state finishing kit 0.12 Universal polisher 0.10 SiC polishing paper 0.05 Polishing lab kit 0.07 **	

* Arithmetic mean of the thicknesses. ** Median.

5YSZ and Multilayer 4YSZ/5YSZ

Laboratory polishing followed by glazing showed a reduced surface roughness (Ra) compared to clinical polishing protocols [168] (Table 18). The combination of grinding, polishing, and glazing led to a lower surface roughness (Ra) than the combination of grinding and glazing followed by grinding and polishing [93]. In contrast, grinding and glazing showed a higher roughness (Ra) than polished or ground and polished surfaces [98]. For multilayer 4YSZ/5YSZ, there was no difference in the surface roughness (Ra, Rz) among the combinations of grinding, polishing, and spray glazing; grinding and spray glazing; and grinding and polishing—except for a lower Rz value of grinding and spray glazing [100].

Ground surfaces showed scratches and grooves [100,168], and glazing had a smoothening effect [98,100,168] but left some bubbles within the glaze [100]. Vila-Nova et al. [98] reported that the glaze layer did not cover the surface sufficiently, and Jum'ah et al. [168] stated that cracks and agglomerations were detectable in the glaze of 4- and 5YSZ, whereas HT 3Y-TZP exhibited a mirror-like surface.

Table 18. The effect of clinical and laboratory grinding, polishing, and glazing on the surface roughness parameters Ra and Rz for 5YSZ and multilayer 4YSZ/5YSZ.

Author, Year	Name of Material (Manufacturer)	Clinical Grinding Ra/Rz (µm) Mean (±SD)	Clinical Polishing Ra/Rz (µm) Mean (±SD)	Glazing Ra/Rz (µm) Mean (±SD)
Al Hamad, 2019 [112]	Zolid Fx (Amann Girrbach)		Ra: Prepolished 0.17 (0.04) Polished 0.114 (0.02) Super-polished 0.111 (0.02) Diamond paste 0.11 (0.03) Rz: Prepolished 0.97 (0.25) Polished 0.65 (0.10) Super-polished 0.65 (0.11) Diamond paste 0.65 (0.20)	
Hatanaka, 2020 [93]	Prettau Anterior (Zirkonzahn)	5.10 (4.57, 5.83) *	Ground, polished 2.29 (1.95, 2.74)	Glazed 0.36 (0.32, 0.44) Ground, polished, glazed 0.62 (0.48, 0.77) Ground, glazed 1.21 (0.94, 1.56) *
Jum'ah, 2020 [168]	DD cubeX2 (DentalDirekt)	3.57 (0.78)	Identoflex 1.54 (0.49) Diacera Twist 1.59 (0.39) DiaShine 1.46 (0.44)	0.68 (0.16)
Vila-Nova, 2020 [98]	Prettau Anterior (Zirkonzahn)	0.54 (0.15)	Ground, polished 0.05 (0.03) Polished 0.04 (0.03)	Ground, glazed 0.39 (0.30)
Zucuni, 2020 [100]	ZirCAD MT Multi (Ivoclar Vivadent) **	Ra: 1.26 (0.28) Rz: 7.72 (1.52)	Ra: Ground, polished 0.70 (0.18) Rz: Ground polished 4.72 (1.15)	Ra: Ground, glazed 0.55 (0.28) Ground, polished, glazed 0.79 (0.26) Rz: Ground, glazed 3.05 (1.15) Ground, polished, glazed 5.44 (1.66)

* Median (25%, 75%). ** Multilayer 4YSZ/5YSZ.

3.6.2. Clinical-Related Processing Factors

Factor: Chairside Sintering. Property: Surface Characterization

HT 3Y-TZP

Chairside sintering protocols, i.e., speed and super-speed, resulted in a smaller mean grain size and more heterogenous grain size distribution compared to regular laboratory sintering [101] (Table 8).

Factors: Clinical Grinding and Polishing. Properties: Surface Roughness, Characterization, and Surface Wettability

HT 3Y-TZP

Grinding evidently produced the highest surface roughness (Ra, Rz) [87,103–105] in comparison to as-sintered and polished surfaces [87,92–94,102–107,109,122,156,157,159–161,168,172] (Tables 9, 10 and 16). An increased grit size of the diamond bur was directly correlated to an increased surface roughness [106]. The final roughness (Ra) of a diamond-bur-ground surface was reported to decrease after the use of a stone grinding bur before polishing [172]. However, two publications reported a similar roughness of ground or glazed and ground, polished, and glazed surfaces [96,170]. Wet grinding created a rougher surface than dry grinding [109].

Polishing either reduced (Ra, Rz) [87,93,102,105,157,160,161,168,171] or led to similar roughness (Ra) to that of ground surfaces [158,170]. Compared to as-sintered surfaces, polished surfaces generally had a lower surface roughness [105,111,159,161,168]. However, surfaces that were ground prior to polishing had mainly similar [87,96,102] or higher surface roughness [87,105] compared to as-sintered surfaces. Polishing produced similar [87,94,96,168,170,171,173] or higher [87,94,168,173] surface roughness (Ra) than glazing. The surface roughness was generally dependant on the polishing system or protocol used [94,105,112,156,158–160,168,171,173,174] (Tables 10 and 16). Multiple-step protocols [156,157,168] or the use of polishers specifically for zirconia [159,174] mainly reduced the roughness, whereas the polishing time did not have an effect [160]. The surface wettability was similar for all polishing systems and ground surfaces [112].

Furthermore, surface characterizations were qualitatively presented and varied between the surface treatments [87,91,92,94,98,100,102–110,112,157–161,168,171–175]. Grooves, scratches, and defects were identified on ground surfaces, mainly following the direction of the grinding [87,91,92,94,102–107,109,110,157–159,168,172]. Polishing tended to display a more uniform surface, but with striations from polishing procedures and some scratches and irregularities [87,94,102,105,108,112,157–161,168,171–174].

4YSZ

Grinding increased the surface roughness (Ra), whereas polishing reduced the roughness of 4YSZ as well [168] (Table 17). A four-step polishing protocol gave a lower surface roughness than one- and two-step protocols [168]. Grooves were observed on ground surfaces but were smoothed by polishing [168].

5YSZ and Multilayer 4YSZ/5YSZ

As with HT 3Y-TZP and 4YSZ, the grinding of 5YSZ and multilayer 4YSZ/5YSZ resulted in the highest surface roughness in comparison to as-sintered, polished, and glazed materials [93,98,100,168] (Table 18). Polishing reduced the surface roughness (Ra) compared to grinding and led to either higher [93,168,175] or lower [98] roughness than that of a glazed surface. Jum'ah et al. [168] found no difference in the surface roughness (Ra) between one-, two-, and four-step polishing protocols, but the roughness was reduced compared to as-sintered surfaces.

Morphological differences were observed between the surface treatments [175]. Ground surfaces displayed grooves, scratches, and defects, which were reduced after polishing [98,100,168,175]. Comparing HT 3Y-TZP with 4- and 5YSZ, SEM analyses revealed more noticeable surface flaws and material loss after grinding of the 4- and 5YSZ materials. The four-step polishing protocol almost entirely removed the grooves for all material types except for 5YSZ [168].

3.6.3. Time-Related Factors

Factors: Hydrothermal Aging and Mechanical Aging. Properties: Surface Roughness and Surface Characterization

HT 3Y-TZP

Hydrothermal aging in a reactor for 5 h [128] or in an autoclave for 5–20 h did not alter the surface roughness (Ra, Rz) of as-sintered, ground, glazed, or polished HT 3Y-TZP [93,102–104,106,107,111] (Table 11). However, the surface roughness (Ra, Rz) of ground or polished and heat-treated HT 3Y-TZP was reported to increase after hydrothermal aging in an autoclave for 1–20 h [102,104,123,163]. For polished and heat-treated HT 3Y-TZP, the roughness (Ra) increased with increasing aging time (1–10 h) [123,163]. According to Poole et al. [125], a HT 3Y-TZP material had a higher surface roughness (Ra) than a traditional 3Y-TZP material after aging, but the effect of aging was not reported. Aging with TC did not affect the surface roughness (Ra) of as-sintered or ground and polished HT 3Y-TZP but increased the roughness of the ground material [102].

Most publications reported that aging in an autoclave, in a reactor, or with TC did not promote any relevant alterations of the surface topography [89,91,102–104,106,107,110,122,129]. Some discontinuities of the grain boundaries, surface uplifts, and microcracks related to *t*–*m* phase transformation were observed after autoclaving or ML [27,110,123,163] (Table 12). Two publications [91,129] reported that the glaze layer was degraded and separated from the underlying zirconia after aging in an autoclave, after ML, or after a combination of ML and TC.

4YSZ

Choi et al. [123] reported an increase in the surface roughness (Ra), microcracks, and grain pull-outs of polished and heat-treated 4YSZ with increasing aging time (5, 10 h) in an autoclave. Pereira et al. [122] did not observe any relevant changes in the surface topography after aging in an autoclave for 20 h.

5YSZ and Multilayer 4YSZ/5YSZ

For 5YSZ, the surface roughness (Ra) was either increased with increasing aging time for polished and heat-treated materials (5, 10 h) [123]; not affected for polished materials (5, 10 h) [93,135]; or decreased for ground, glazed, ground and glazed, or ground, polished, and glazed materials (20 h) [93]. The surface roughness (Ra) of polished and heat-treated multilayer 4YSZ/5YSZ gradually increased from 5 to 10 h [123]. Autoclave aging and ML led to a more textured surface with elevated or less regular grain and grain boundaries and some microcracks [27,98,123] or did not affect the topography [122]. Compared to HT 3Y-TZP, 5YSZ was affected to a greater extent by ML, with larger wear craters, denser lateral cracks, and dislodging grains (micro pitting), thus leading to a rougher surface [138].

Factors: Three-Body and Two-Body Wear. Properties: Surface Roughness and Surface Characterization

HT 3Y-TZP

Three-body wear with an abrasive medium did not influence the surface roughness (Ra) after 50,000 [170], but it increased the roughness (Ra) after a total of 1×10^6 cycles [151] (Table 14). Two-body wear evaluated with ML did not affect the surface roughness (Ra) of as-sintered, ground, or polished surfaces [157,167], except for ground surfaces in one of the publications, where the roughness was reduced [157]. Two-body wear using a pin-on-block test did not change the surface roughness of the polished surfaces (Ra, Rz) [142].

Surface characterizations after wear were mainly qualitatively presented [34,131,144–147,151,157], and the surfaces were described as slightly affected with parallel wear striations [144,145,147,157]. However, partial cone cracks in the wear craters and dislodgment of the grain boundaries were also identified [34,157]. Abouelenien et al. [144] observed a seemingly intact glaze layer.

4YSZ

The surface roughness of polished surfaces (Ra, Rz) was not affected by ML (50 N and 1.2×10^6 cycles) with simultaneous TC, followed by a two-body wear test (50 N and 120,000 cycles) [142].

5YSZ and Multilayer 4YSZ/5YSZ

The surface roughness (Ra, Rz) of polished 5YSZ was not affected by two-body wear, as described above [142]. Vardhaman et al. [34] observed cracks in the end of the wear crater, loss of material, and dislodgment of grains in worn multilayer 4YSZ/5YSZ; hence, a more aggravated wear pattern and higher roughness than HT 3Y-TZP.

3.7. Optical Properties

Thirty-seven publications (the high-risk-of-bias publications excluded) evaluated optical properties, mainly the translucency parameter (TP), transmittance, and colour difference (ΔE) (Tables 2–15 and Figure 16). HT 3Y-TZP dominated the zirconia type evaluated (n = 31), followed by 5YSZ (n = 16) and 4YSZ (n = 13). The methods used in the publications are presented in Figure 17.

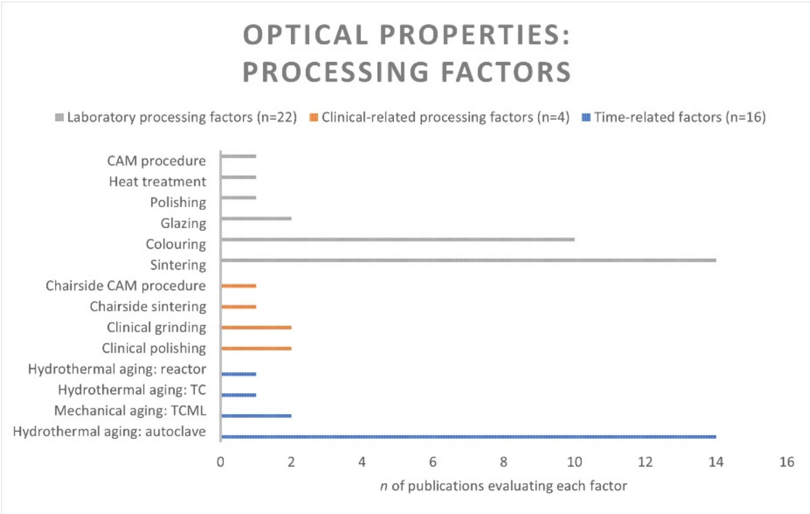

Figure 16. Laboratory and clinical-related processing factors and time-related factors evaluated for the optical properties (at the top: *n* of publications evaluating laboratory, clinical-, and time-related factors respectively; at the bottom: *n* of publications evaluating each factor; several factors can be included in one publication).

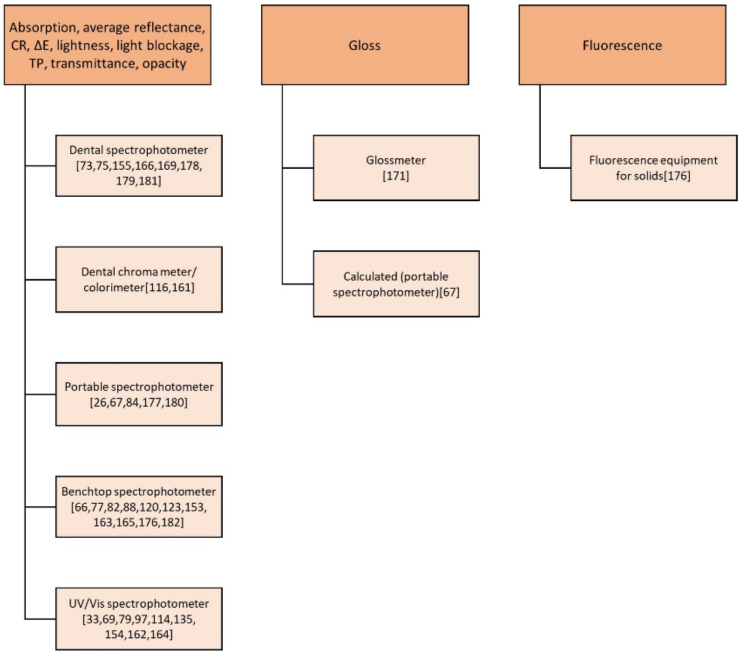

Figure 17. Methods/equipment used in publications for the evaluation of the optical properties.

3.7.1. Laboratory Processing Factors

Factor: CAM Procedure. Property: Transmittance

4YSZ and Multilayer 3Y-TZP/5YSZ

Milling with a laboratory procedure in combination with conventional sintering or chairside milling with high-speed sintering generally did not influence the transmittance [33] (Tables 2 and 8). Only the enamel layer of laboratory-milled multilayer HT 3Y-TZP/5YSZ showed a higher transmittance compared to that of laboratory-milled 4YSZ (multilayer shade) and that of chairside-milled 4YSZ [33].

Factor: Colouring. Properties: Transmittance, TP, CR, ΔE, Gloss, Lightness, Opalescence Parameter (OP), and Fluorescence

HT 3Y-TZP

Colouring with an immersion technique with colouring liquids in the pre-sintered stage had no [66,67,155] or a reducing effect [155] on TP, and it increased the CR [67] (Table 3). Sen et al. [66] reported that pre-coloured zirconia had a higher TP than immersion-coloured and non-coloured material sintered at 1350 °C. Immersion colouring with A4 colouring liquid reduced the transmittance compared to colouring with A1 liquid and not colouring [154].

HT 3Y-TZP immersed in fluorescent liquid in the pre-sintered stage had a higher fluorescence and colour difference (ΔE_{00}) in comparison to a combination of fluorescent and A2 colouring liquids, A2 colouring liquid alone, and non-coloured HT 3Y-TZP [176]. For the staining technique using a brush, the lower the A shade, the less material removal was required to receive a colour difference exceeding the acceptability threshold of colour difference (ΔE_{00} 1.8) [177]. Non-coloured zirconia had a higher lightness (ΔL) than fluorescent-, fluorescent/A2-, and A2-coloured zirconia [176].

4YSZ

Neither the colouring technique, i.e., staining or immersion, nor the number of applications and immersion time affected the TP when colouring in the pre-sintered stage, but coloured zirconia had lower TP than non-coloured [26]. The colour difference increased with a higher number of applications using the staining technique with brush, unlike increasing the immersion time, which had no effect [26]. Both staining and immersion led to a lower opalescence parameter (OP) compared to non-coloured zirconia [26].

5YSZ

5YSZ had a higher TP and lower CR than HT 3Y-TZP, irrespective of colouring [66,67]. Immersion in A2 colouring liquid reduced or did not affect the TP compared to non-coloured zirconia [66,67]. Colouring with an immersion technique with A2 increased the surface gloss for 5YSZ but had no effect on HT 3Y-TZP [67].

Factor: Sintering. Properties: Transmittance, TP, CR, ΔE, Gloss, OP, Reflectance, Opacity, and Absorption

HT 3Y-TZP

High-speed sintering, vacuum sintering, and fast cooling (50 °C/min) increased the TP and decreased or did not influence the CR [67,77,166] (Table 4). On the other hand, speed sintering and shortening the holding time were reported to reduce the transmittance and TP [73,79,153]. Rapid sintering did not affect the TP [75]. Moreover, increasing the final sintering temperature resulted in a TP higher than or similar to a regular sintering temperature [66,153,155].

The colour difference (ΔE) had a higher variation at a decreased final sintering temperature (1350 °C) and shortened holding time (60 min) compared to regular and increased final sintering temperatures (1450 °C and 1550 °C, respectively) and prolonged and regular holding times (180 and 120 min, respectively) [153]. The range of colour difference (ΔE) between conventional and rapid sintering was 0.5–1.4 [75]. Thermal tempering with different cooling rates did not influence the colour difference (ΔEw) [77].

Regular and increased final sintering temperatures, extended and regular holding times, and fast cooling increased the OP in comparison to decreased temperature, shortened holding time, and regular and slow cooling rate [77,153]. Vacuum sintering had no effect on the gloss [67].

4YSZ

High-speed sintering decreased [33,69,79,82] or did not affect [33,73] the transmittance and TP [33,69,73,79,82]. High-speed-sintered 4YSZ had a lower transmittance than both conventionally sintered HT 3Y-TZP, 5YSZ [69], and the enamel layer of multilayer HT3Y-TZP/5YSZ [33]. The TP was reported as higher in comparison to HT 3Y-TZP, irrespective of the sintering time [73]. Higher sintering temperatures (1450 °C and 1600 °C) increased the TP in comparison to a lower temperature (1350 °C) [178].

5YSZ

Rapid sintering and high-speed sintering decreased the TP [75,82], and vacuum sintering had no effect [67]. Increasing the final sintering temperature from 1350 °C to 1600 °C either increased or did not affect the TP and opacity percentage [66,84]. The average reflectance and absorption-scattering sum of light (S/A) were higher at a sintering temperature of 1450 °C than at 1600 °C [84].

The colour difference between the final sintering temperatures of 1450 °C and 1600 °C was below the acceptability threshold (ΔE_{00} 1.8) [84]. The colour difference (ΔE) between conventional and rapid sintering was 0.9 [75]. Vacuum sintering did not influence the gloss [67].

Factors: Polishing, Heat Treatment, and Glazing. Properties: Transmittance, TP, ΔE, and Gloss

HT 3Y-TZP

Rapid-cooling heat treatment did not influence the TP but improved the transmittance [88] (Table 6). Further, glazing did not influence the TP but resulted in varying degrees of colour differences (ΔE_{00}) that were brand-dependent [169]. Glazing and polishing were equivalent in terms of glossiness (GU) [171] (Tables 5 and 7).

4YSZ

The transmittance was higher after polishing at the pre-sintered stage compared to after polishing at the fully sintered stage [97]. A one-step (fine laboratory diamond wheel polisher) and two-step (fine and rough laboratory diamond wheel polisher) polishing procedure at the fully sintered stage resulted in similar transmittance [97]. Polishing with a felt wheel at the pre-sintered stage followed by polishing at the fully sintered stage with either the one-step or two-step procedure resulted in a higher transmittance than polishing with a felt wheel or goat hair brush (with or without polishing paste), a green-state finishing kit, a universal polisher, SiC polishing paper, or a lab polishing kit [97]. Glazing did not affect the TP but resulted in a colour difference (ΔE_{00}) [169]. Rapid-cooling heat treatment increased the transmittance and TP [88].

5YSZ

Rapid-cooling heat treatment increased the transmittance and TP [88].

3.7.2. Clinical-Related Processing Factors

Factors: Clinical Grinding and Polishing. Properties: ΔE, Lightness, and Gloss

HT 3Y-TZP

Polishing decreased the lightness (CIE L*) compared to grinding, as it decreased the surface roughness; furthermore, pre-coloured zirconia was more easily polished than non-coloured [161] (Tables 9 and 10). A high gloss was achieved through polishing at 15,000 rpm, and each step in the polishing procedure sequentially improved the gloss [171].

3.7.3. Time-Related Factors

Factors: Hydrothermal Aging and Mechanical Aging. Properties: Transmittance, TP, CR, ΔE, Lightness, OP, Fluorescence, and Light Blockage

HT 3-YTZP

The effect of hydrothermal aging in an autoclave on the transmittance and TP of HT 3Y-TZP [69,73,114,116,120,123,162–164,179–181], 4YSZ [69,73,114,123,164], and 5YSZ [69,114,116,123,135,181] is presented in Table 11 and Figures 18–20. Kim and Kim [163] showed that the TP of a multilayer (shade-gradient) HT 3Y-TZP material increased after shorter aging periods (1, 3, and 5 h) compared to non-aged material. After 10 h, the translucency was reduced and there was no longer a difference compared to the non-aged material. The CR mainly increased with increasing aging time in an autoclave for 5–100 h [73,123,180,181], but it decreased [123] or showed no effect [120] after 10 and 20 h, respectively. Five hours of aging using a hydrothermal reactor did not affect the CR [128]. However, after 20 h of aging in a hydrothermal reactor, the TP increased and the CR decreased compared to non-aged and autoclave-aged material [120]. TC for 10,000–50,000 cycles increased the TP [165].

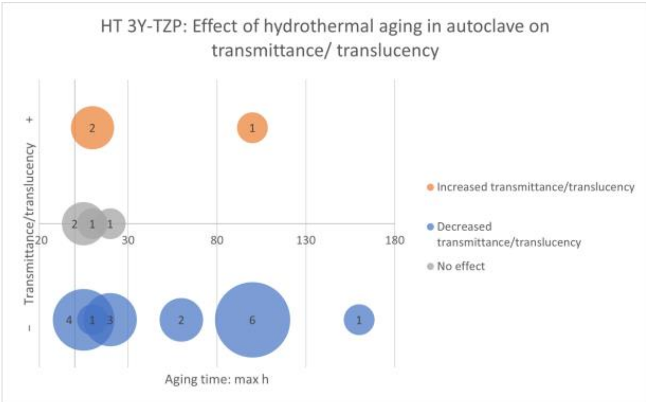

Figure 18. The effect of hydrothermal aging in an autoclave on transmittance/translucency (TP) for HT 3Y-TZP: decreasing [69,73,116,123,162,180,181]/increasing [123,164]/no effect [114,120,163,179] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles.

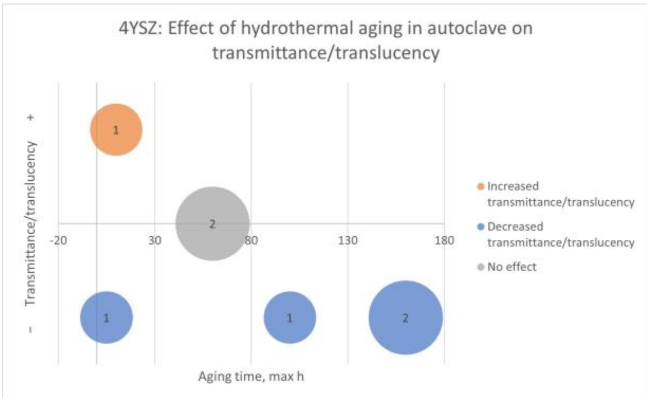

Figure 19. The effect of hydrothermal aging in an autoclave on transmittance/translucency (TP) for 4YSZ: decreasing [69,114,164]/increasing [123]/no effect [73] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles.

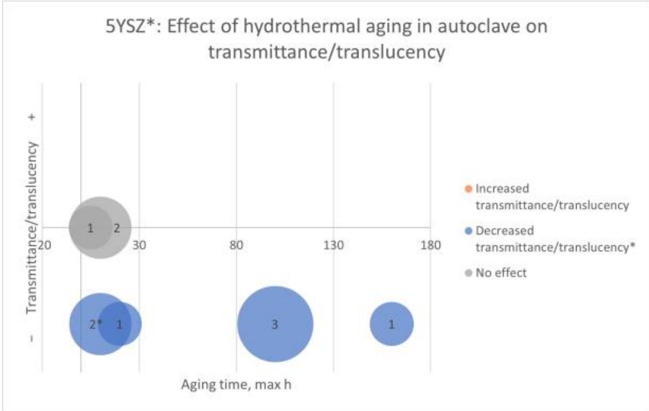

Figure 20. The effect of hydrothermal aging in an autoclave on transmittance/translucency (TP) for 5YSZ and multilayer 4YSZ/5YSZ: decreasing [69,116,123,164,181]/increasing/no effect [114,135] (not exact values). Aging time was determined based on the longest time reported and categorized into 5, 10, 20, 60, 100, or 160 h. The number of materials evaluated is presented in the bubbles and by the size of the bubbles. * Including one multilayer 4YSZ/5YSZ, 10 h aging time [123].

The colour difference (ΔE_{00}) was affected already after 1 h of hydrothermal aging in an autoclave [163,176]. Generally, an increasing colour difference of HT 3Y-TZP that was either pre-coloured or coloured with an immersion technique (ΔE^*_{00} and ΔE) was observed with increasing aging time for up to 100 h [163,176,181]. TC for 10,000 to 50,000 cycles gradually increased the colour difference [165]. Unlike chroma and hue differences, the lightness difference (ΔL) was affected by aging in an autoclave and was higher after 5 h of aging [176]. In general, the OP decreased when the aging time in the autoclave increased up to 100 h [181]. Hydrothermal aging in an autoclave for 5 h did not have an effect on the fluorescence [176].

The TP, CR, and light blockage percentage were numerically increased with TCML for 1.2 million loading cycles [182] (Table 13). The transmittance decreased after 2.4 million cycles in comparison to non-aged material and TCML for 1.2 million cycles [114].

4YSZ

Two publications [69,164] concluded that the transmittance was reduced with increasing aging times (2–160 h and 5–100 h). The CR was shown to be similar to that of non-aged 4YSZ after 60 h of aging [73]. The transmittance of 4YSZ gradually increased from non-aged to 1.2 and 2.4 million loading cycles and TC [114].

5YSZ

The TP decreased with increasing aging time in an autoclave, but the magnitude of the decrease was either lower than for HT 3Y-TZP [181] or in a similar range [116]. Five hours of aging in a hydrothermal reactor did not affect the CR of 5YSZ [128]. Aging with TC increased the TP up to 30,000 cycles, but the effect diminished between 30,000 and 50,000 cycles [165].

Aging in an autoclave for 20 h caused an increased colour difference (ΔE^*_{ab}) [181]. In comparison to the colour difference of HT 3Y-TZP materials, a 5YSZ material coloured using an immersion technique was the only one displaying a difference below the acceptability threshold (AT) of ΔE^*_{ab} 2.7 according to CIE76 after 100 h of aging [181]. Correspondingly, TC increased the colour difference from 10,000 to 50,000 cycles. Hydrothermal aging in an autoclave caused a decrease in the OP until 80 h of aging, after which there was no difference compared to non-aged material [181].

Moreover, TCML for 1.2 million loading cycles resulted in a higher TP and lower CR and light blockage in 5YSZ compared to HT 3Y-TZP [182]. The transmittance was higher after TCML for 1.2 and 2.4 million cycles compared to non-aged material [114].

4. Discussion

To be able to navigate among the various zirconia materials, it is essential to have knowledge of the material properties. The dental team needs to understand how the entire spectrum of properties might be affected by every single processing factor, directly or indirectly by modifications of the micro/atomic structure, to be able to make well-informed decisions regarding material in the treatment planning and during the production of restorations. This, together with the possibility for generalization and identification of interventions in need of more research, was the reason for the broader research question.

This review has identified some processing factors—such as colouring, chairside sintering, and laboratory grinding and polishing—where the literature is scarce regardless of zirconia type. These processing factors are highly relevant to investigate since they are employed on a daily basis in the laboratory and in the clinic. Glazing is another processing factor frequently used in the laboratory about which the number of publications is limited or even missing. Choosing the most appropriate procedure is crucial for a successful and predictable patient treatment, and further research is required.

4.1. Available Data for Each Zirconia Type

For HT 3Y-TZP, there was a relatively large number of publications regarding the effect of hydrothermal aging with an autoclave, sintering, and clinical grinding and polishing on several property categories and publications regarding the effect of glazing, wear, ML, and TCML mainly on the mechanical properties (Figure 21). Even so, the evidence of all other processing and time-related factors' effect on the different properties is still limited, emphasizing somewhat unexpected knowledge gaps.

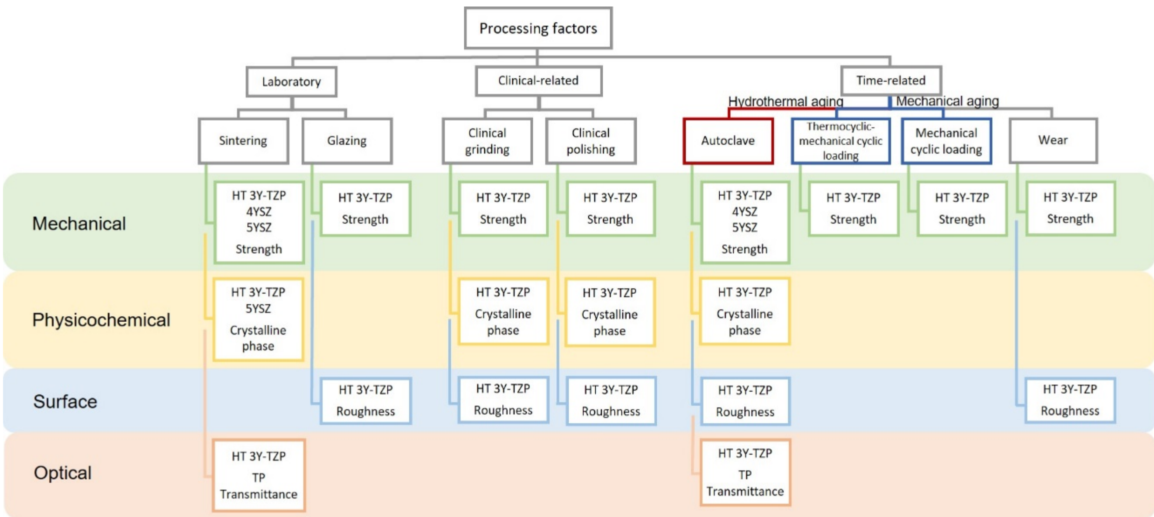

Figure 21. Overview of the properties of zirconia types where evidence of the effect of the laboratory and clinical-related processing factors and time-related factors was found.

For 4YSZ, data were missing or insufficient for all combinations of processing or time-related factors and property categories, except for sintering or hydrothermal aging with an autoclave in relation to mechanical properties (Figure 21). Data on 5YSZ were more comprehensive but still limited, except for the same combinations as 4YSZ and, additionally, for sintering related to physicochemical properties (Figure 21).

Only five publications included composition-gradient multilayer zirconia. Therefore, the data are far too limited to draw any conclusions regarding the influence of any processing factors on the properties of this zirconia type. Multilayer zirconia can be anticipated to demonstrate a behaviour distinguished from the individual zirconia types combined, since there are also one or more interfaces within the material. Consequently, the results from studies of the individual zirconia types included in the multilayer cannot be directly transferred and applied on multilayer zirconia. Due to the different compositions, crystal structures, and properties of 3Y-TZP and 5YSZ, there is an imminent risk of stresses arising at the interface within a multilayer material combining these zirconia types, especially when subjected to time-related factors such as aging. For instance, a *t*–*m* phase transformation in the 3Y-TZP layer and, consequently, an increased crystal grain volume will probably cause stresses at the interface. The composition and crystal structure of the interfaces and eventual transition zones have not been thoroughly evaluated. In addition, several publications evaluating shade-gradient multilayer zirconia neglected to specify from which layer(s) the specimens were produced, leading to uncertainty in the interpretation of the results.

4.2. Processing Factors and Methods

There was a high heterogeneity of study designs and methods between publications, reflected in the high heterogeneity of the meta-analyses, complicating comparisons and the synthesis of the results. The heterogeneity and need for more research and standardized methods were confirmed in other reviews [183,184]. In general, the effect of sintering or hydrothermal aging with an autoclave on the mechanical properties were evaluated the most regardless of zirconia type.

Aging with an autoclave was both the most common aging method and the most common factor of all. However, the clinical relevance of the method and applicability of the results in the clinical situation may be questioned. The aggravated environment—with temperatures of 134 °C, pressure, and aging times up to 200 h—provokes the material to a much greater extent than the oral environment. Consequently, the microstructure and properties might be affected in a way not comparable to the clinical situation and results are likely to be misinterpreted and under- or overestimated.

Estimating how the time of an artificial aging method corresponds to the time for a restoration in clinical service should be performed with utmost caution. Nonetheless, several publications stated that autoclave aging for 1 h represented 3–4 years at 37 °C, which is based on *t*–*m* phase transformation extrapolations in previous studies and is generally accepted [185–187]. The longest identified aging time of 200 h [118,124] would then correspond to 600–800 years, an unrealistic time frame for a restoration. The authors highlight the possibility of errors in such estimations [118,124]. It has also been reported that the aging, in fact, might be even faster than the previously proposed extrapolation based on the *t*–*m* phase transformation, which further questions the clinical relevance [39,52,188].

TC for 10,000 cycles has been estimated to represent one year in clinical service [102,129,165,189]. The number of thermocycles in the publications varied from 3500 to 200,000 cycles, i.e., corresponding to up to 20 years [102]. In a systematic review, zirconia-based crowns subjected to TCML were reported to have a five-year cumulative survival rate representative of clinical outcomes [190]. Therefore, aging methods exerting both thermal and mechanical stresses might be a relevant alternative to ensure results that are more congruent with the actual aging behaviour of zirconia, although the time required is longer than when autoclaving. Since 4YSZ and 5YSZ are not as prone to LTD and have a lower initial strength, aging methods involving thermal and mechanical factors are even more strongly recommended than autoclaving.

The intensity of aging was reflected in the results of the crystalline phase for HT 3Y-TZP. Aging in a reactor, where the temperature and pressure are constant during the entire aging time, resulted in higher amounts of *m* phase compared to autoclaving, where the temperature and pressure vary in cycles, with reservation for the limited data. Accordingly, autoclaving promoted more *m* phase than ML and dry or water storage; similarly, TC in combination with ML resulted in more *m* phase than TC alone. ML and TC individually did not trigger a *t*–*m* phase transformation, indicating a synergy effect when thermal and mechanical aging is combined. However, dry and water storage led to *m* phase, demonstrating that time is an even more crucial factor for inducing a phase transformation [110,133]. Performing artificial aging in in vitro studies is essential to prevent unrealistically high values not comparable to the clinical situation or between studies.

4.3. Properties

Mechanical properties, specifically the flexural strength, were more extensively evaluated. However, the fracture toughness was not investigated to the same extent. Moreover, indentation fracture toughness was the method most often employed—a method criticized for inaccuracy and high variability, partly due to the uncertainty in measuring the crack length appropriately [191,192]. Further research using more reliable methods appropriate for zirconia, such as single-edge pre-cracked beam (SEPB), surface crack in flexure (SCF), or chevron-notched beam (CNB), is recommended for all zirconia types [191,193–195].

4.4. Effect of Laboratory and Clinical-Related Processing and Time-Related Factors

4.4.1. Laboratory Processing Factor: Sintering

In general, neither the strength, the crystalline phase, nor the surface roughness of HT 3Y-TZP was affected by modification of the sintering parameters. However, there was a large diversity in the achieved transmittance and TP, possibly connected to the microstructure in terms of the grain size, which correspondingly varied depending on the sintering parameters. The sintering temperature and time influence the diffusion and grain growth during the sintering process and, consequently, the density [10,29,196,197]. Higher temperatures, primarily, and longer sintering protocols tended to increase the grain size [75,79,153,155]. Larger grains imply fewer grain boundaries where the light is scattered; thus, the translucency is increased [10,18,196,197]. Accordingly, an increased final temperature increased both the grain size and in turn the TP in some publications [153,155]. Porosities in the bulk of the material scatter the light due to the different refractive indexes of air and zirconia. A porosity amount of only 0.05% can reduce the translucency, and porosities in the size of visible light wavelengths are the most disadvantageous [18,21,197]. Only one publication evaluated the density in relation to sintering time, reporting no difference [73]. Nevertheless, the translucency is not defined by one single factor but determined by the entirety of the individual factors.

High-speed sintering of 4YSZ either increased or did not affect the strength [33,73,74,79,82,83], but it tended to decrease the transmittance and TP of both 4YSZ and 5YSZ [33,69,75,79,82]. 5YSZ was mainly unaffected by modifying the sintering parameters. However, it is not possible to claim that either is the preferable option, because programs (and what is regarded as, e.g., speed or high-speed) differ between studies. Furthermore, sintering programs are complex, including several temperature and time parameters with various effects, and have been developed specifically for each brand. Given the complexity and the high heterogeneity between studies regarding the study design, parameters, and control group, it is not possible to give general recommendations on how to modify the sintering parameters. Therefore, to achieve the intended material properties, the sintering programs provided by the manufacturer should be followed.

4.4.2. Laboratory and Clinical-Related Processing Factors: Grinding, Polishing, and Glazing

The results regarding how clinical polishing or glazing affects the strength of HT 3Y-TZP were conflicting. In the individual publications, glazing generally led to lower strength compared to clinical grinding or polishing, indicating that polishing is a preferable surface-finishing procedure. However, the meta-analysis showed a tendency towards higher strength for glazing compared to clinical polishing, with reservation for the high heterogeneity. If glazing is chosen, the zirconia surface can advantageously be polished before to increase the strength [87,93]. The primary reason for a strength reduction when glazing appears to be the application of the actual glaze paste, rather than the heat during the glaze firing, with reservation of the very limited data [90]. This is in accordance with previous studies, where moist porcelain was reported to generate textured and faceted zirconia grains at the interface [198–200]. During the initial part of the firing program in the temperature range of 100–250 °C, when the moisture is evaporating, zirconia is particularly susceptible to a *t*–*m* phase transformation, causing stresses due to the formation of martensite plates within the partially transformed grains [16,198,199]. At higher temperatures, some dissolution of the grains can occur, exacerbated by the residual stresses [198]. Furthermore, the findings of fracture origins localized at the interface between zirconia and the glaze layer and the separation of the glaze from the zirconia surface after aging [91] indicate that the interface might constitute a weak link. The deficiencies identified in the glaze layer, such as bubbles [91,100], cracks [168], and insufficient coverage [98], might also have contributed to the reduced strength. The cracks and agglomerations in the glaze of 4YSZ and 5YSZ were associated with the initial higher roughness and more extensive flaws compared to HT 3Y-TZP, as a result of brittle material removal during the milling procedure. The compatibility between the different zirconia types and the glaze system and sintering parameters, due to different microstructure and grain size, might also have contributed to or aggravated the flaws in the glaze.

Notably, there were no or only a few publications evaluating the effect of glazing and polishing on the strength of 4YSZ and 5YSZ. Overall, clinical polishing showed a higher strength than glazing for 5YSZ, but only approximately half the strength for HT 3Y-TZP. In relation to the ISO classification for ceramic materials [192], both glazed and polished 5YSZ tended to exceed the limit of 300 MPa for a class 3 material, indicated for use as three-unit FDPs not involving molars. Glazed HT 3Y-TZP tended to exceed 800 MPa in the meta-analysis, i.e., a class 5 material indicated for FDPs longer than four units. However, polished HT 3Y-TZP did not reach that value; therefore, it should be used with caution and preferably be limited to three-unit FDPs involving molars according to class 4 (500 MPa). Nonetheless, since the fracture toughness is unknown and the studies are heterogenous, this only gives an indication. In addition to the mean, the dispersion of the data should also be considered. The Weibull modulus, describing the variability of the strength of brittle materials, and thus their reliability, might be more representative than a single strength value since fractures in brittle materials originate from flaws that can be more or less evenly distributed. The Weibull modulus did not always correlate with the strength in the publications; for instance, glazing increased the Weibull modulus but simultaneously led to a reduced strength compared to grinding or grinding and polishing [91,93], which could imply that glazed restorations are more reliable for clinical use [91,93,106]. Accordingly, clinical polishing tended to display a broader confidence interval than glazing for both HT 3Y-TZP and 5YSZ in the meta-analysis, indicating a lower reliability. One explanation might be that the polishing procedure is more technique- and operator-sensitive. Given that these procedures are used daily, further research on the processing factors is of great importance.

Overall, the surface roughness was similar or slightly higher for clinical polishing compared to glazing [87,94,96,168,170,171,173], although it was partly dependent on the polishing system or protocol used. When polishing after clinical adjustments, care should be taken in choosing a zirconia-specific polishing system, preferably with a multiple-step protocol, and all steps should be implemented sequentially to ensure a sufficiently low surface roughness [156,157,159,168,171,172,174]. Overall, 5YSZ showed a higher roughness (Ra) after grinding, polishing, and glazing, respectively, compared to HT 3Y-TZP. An acceptable threshold for surface roughness (Ra) of 0.2 and 0.5 µm, respectively, has been suggested based on bacterial adhesion and what can be perceived by the tongue [201,202]. However, there was a large deviation among the reported mean values (Ra) of HT 3Y-TZP in the publications, with a range of 0.1–2.8 µm for polishing and 0.2–1.5 µm for glazing. This deviation was confirmed by the high heterogeneity in the meta-analysis, where the results were clearly connected to the individual studies, implicating a low reliability and comparability between studies. The roughness of restorations may vary on a large scale depending on the chosen finishing procedure and system, which reduces the predictability of treatments. Accordingly, extra effort on the finishing procedure is recommended to achieve an acceptable roughness. Differences in finishing and evaluation methods, as well as challenges to standardizing polishing procedures, might partly explain the variations.

Glazed HT 3Y-TZP surfaces appear more susceptible to aging in terms of strength reduction, whereas ground or ground and polished surfaces can exhibit an increased strength after aging. The tendency for higher wear of glazed surfaces compared to polished ones implies a polished surface is preferable, but this is based on a limited number of publications [117,146]. In the clinical study [152], wear of the glaze was identified on the majority of surfaces after six months, which is in accordance with previous results [152,203–205]. Wear of zirconia restorations has been reported to be lower than the wear of antagonist enamel, and in a systematic review, the mean maximum wear of zirconia restorations was 58 µm [206,207]. In comparison, natural wear of enamel has been reported to be 15–40 µm per year [206,208]. Hence, that the glaze layer is worn after six months appears consistent with the results. The surface finish of the underlying zirconia is thus essential for the subsequent wear behaviour, and polishing before glazing can be beneficial. However, the majority of publications evaluated clinical polishing rather than laboratory polishing, possibly affecting the confidence in cumulative evidence since the procedures might differ, making the results not directly comparable. On the other hand, the glazed surface is most often subjected to some occlusal or approximal adjustments, necessitating clinical polishing as the final step. Nevertheless, laboratory polishing should be evaluated and compared to glazed and clinically polished zirconia in future studies.

Grinding increased the strength of HT 3Y-TZP and can be associated with the accumulation of compressive residual stresses caused by a *t*–*m* phase transformation or the development of orthorhombic or rhombohedral phase [11,106,203,209–213]. The rhombohedral phase has been associated with a distortion of the *c* or *t* phase [11,203,209–216]. In addition, grinding can promote ferroelastic domain switching, a toughening mechanism caused by external stresses involving domain reorientation without changing the crystal phase [11,88,203,210]. The domain switching occurs to relieve internal stress because the *t*–*m* transformation is constricted by adjacent non-transformed grains and the pressure of the abrasive medium. Surface uplifts are impeded from accommodating the transformation, which is the case in hydrothermal degradation [210]. Grinding itself, or in combination with local elevated temperatures due to the low thermal conductivity of zirconia, can cause plastic deformation and lattice deformation by dislocation slip [11,188,210]. However, polishing of ground HT 3Y-TZP was reported to induce a reverse *m*–*t* phase transformation, possibly due to locally increased temperature or merely the removal of the superficial layer [87,105,157,213]. The decreased strength of ground and glazed zirconia might be explained by the relaxation of the residual stresses during the glaze firing. Although grinding increased the strength, the high surface roughness, the resulting grooves and defects, and, in some cases, the lower Weibull modulus make it inappropriate in the clinical situation. Consequently, some surface finishing procedure is mandatory. Grinding did not have the same strengthening effect on 5YSZ, probably due to the limited *t*–*m* phase transformation ability.

4.4.3. Time-Related Factors: Hydrothermal and Mechanical Aging and Wear

All hydrothermal aging methods, with a few exceptions, triggered a *t*–*m* phase transformation of HT 3Y-TZP. The strength and surface roughness were, however, generally not affected. The mechanical properties of a restoration might not be affected even if *m* phase is detected. An upper limit of 25% of *m* phase has been stated for using zirconia as implants [217], and the flexural strength is only affected at levels over 50% [11,106,218], leaving a certain safety margin. Furthermore, the Garvie and Nicholson method modified by Toraya, used in most of the publications, has been reported to overestimate the *m* phase since the presence of *c* phase is not considered, unlike the Rietveld method [219–222]. The increased strength and roughness found in some publications might be due to the *t*–*m* phase transformation, where the higher volume of the *m* phase in partially transformed grains creates surface uplifts and compressive stresses, increasing the strength momentarily [27,88,102,104,110,123,163,203]. However, the phase transformation will probably affect the fracture toughness negatively, and consequently, the material will degrade over time.

Overall, aging in an autoclave decreased the transmittance and TP and increased the CR, confirming the inverse relationship between the parameters. The reduction is likely related to the microstructural *t*–*m* phase transformation and increased amount of *m* phase induced by the aging. *M* crystals are anisotropic and birefringent like the tetragonal, but they cause even more light scattering owing to microtwinning [73,196,223]. The presence of two or more crystal phases with different refractive indexes and orientations at the grain boundaries also scatters the light, reducing the translucency. Even though the surface roughness was generally not affected, aging-induced surface alterations might have influenced the translucency. Hydrothermal degradation occurs by diffusion of OH^- ions into the material, filling the oxygen vacancies and thereby destabilizing the *t* phase [15,16,185,186]. The formation of single martensite plates within the *t* grains generates shear strain and surface uplifts. The transformation continues until it is impeded by a grain boundary, thus inducing residual tensile stresses at grain boundaries and on neighbouring grains and causing intergranular microcracks. The microcracking releases the constraint, allowing further intragranular transformation, and the transformation propagates into the bulk by the stresses asserted by the martensite plate in partially transformed grains on neighbouring grains [16,224]. The surface roughness is increased by the surface uplifts, as confirmed by some publications [27,88,102,104,110,123,163], and grain pull-out can occur, affecting the reflection and transmission of the incident light. Colour pigments might also affect the translucency after aging, depending on the location and amount of pigment being absorbed due to the grain boundary dimensions and microstructure [26,37,69]. The significance of the results is that a deterioration of the aesthetic appearance of HT 3Y-TZP might be expected over time, but with maintained strength. However, even though a translucency reduction is identified, the change might not be clinically relevant if it is not perceivable by the human eye.

The surface finish influenced the susceptibility to hydrothermal aging. Grinding or grinding and polishing seem to have a protective effect since the *t*–*m* phase transformation was limited or lower than that for as-sintered materials and the strength even increased [91,93,104,106,110]. Glazing appears more prone to aging given the strength reduction and lower Weibull modulus [89,91]. One explanation is that a *t*–*m* phase transformation was induced already during the grinding, and the subsequent aging procedure was unable to trigger a degradation. Polishing has been proposed to reduce the roughness and generate an almost amorphous layer at the surface, protecting zirconia from the penetration of OH ions and chemicals, thus limiting the degradation [11,69].

The strength of 4YSZ and 5YSZ was, generally, not influenced by autoclave aging. However, somewhat unexpectedly, *m* phase was detected in both zirconia types, decreasing with increasing yttria amount, although to a lesser extent compared to HT 3Y-TZP. Because *c* grains are enriched with yttria, a depletion of the adjacent *t* grains might occur, destabilizing and making them more prone to *t*–*m* phase transformation [15,225,226]. Nevertheless, the theory has mainly been proposed for 3Y-TZP. In contrast to HT 3Y-TZP, other hydrothermal and mechanical aging methods did not induce a *t*–*m* phase transformation, indicating that accelerated conditions, dissimilar to those in the oral environment, are required to trigger a phase transformation. The surface finish had a certain impact on the strength and roughness of aged 5YSZ, but the results were inconsistent. If 5YSZ is to be glazed, it might be safer to polish before adding the glaze to maintain the strength and roughness [93,98,135]. The tendency for lower transmittance and TP after autoclave aging was the same for 4YSZ and 5YSZ as for HT 3Y-TZP, with the exception that no publication indicated an increased translucency of 5YSZ. The number of publications was, however, limited.

The strength of HT 3Y-TZP was mainly not affected by either ML or TCML, whereas there was a tendency towards a reduction in strength for 4YSZ and 5YSZ, with reservation for the less extensive data. Moreover, the inferior mechanical properties were confirmed by the more aggravated wear patterns [34,138]. The initial lower flexural strength and the inability of *t*–*m* phase transformation of 4YSZ and 5YSZ might be a reason for the increased occurrence of cracks and grain dislodgment since neither the existing defects and initiated cracks are inhibited nor are compressive stresses generated as in the case of HT 3Y-TZP. In addition, *c*-phase-containing zirconia has been attributed with a more brittle material removal behaviour, leading to a higher roughness and more defects, whereas HT 3Y-TZP has a more ductile behaviour, which might explain the differences in wear patterns [227,228]. The larger grain size, and thus fewer grain boundaries, and less homogenous grain size distribution [27,51,68,75,114,116,121,164,165] might lead to bigger grain dislodgement and pull-outs. 4YSZ and 5YSZ might be more susceptible to strength reduction when subjected to thermal and/or mechanical loading due to the limited ability of *t*–*m* phase transformation. Therefore, the choice of zirconia type should be made after careful consideration and based on the needs and conditions in the specific patient case.

4.5. Comments on Methodology and Limitations

The classification of zirconia types into HT 3Y-TZP, 4YSZ, 5YSZ, and composition-gradient multilayer was based on the information presented or received after contact with the authors of the publications and manufacturers. Few publications reported the content and type of zirconia material, and far from all manufacturers present the content of the individual materials. In addition, some brands are no longer produced or have been renamed. Consequently, the classification is a generalization, not representative of each individual zirconia material, and may contain errors, but it was deemed necessary to be able to present the extensive amount of data.

The results of publications with a high risk of bias were excluded from the qualitative synthesis to avoid affecting the strength of evidence. More accurate reporting of the performed studies is necessary to avoid misinterpretations and the implementation of laboratory and clinical procedures based on weak evidence. In the absence of an externally validated quality assessment tool for in vitro studies, a tool was constructed, pilot tested, and calibrated. The year limitation was implemented to increase the precision in Scopus and Web of Science, and it was based on the time of introduction of high translucent zirconia and validated by PubMed searches, where no relevant publications were identified before 2013. The exclusion of non-English and unpublished data might have given rise to publication bias, but it was necessary due to limited resources. Nevertheless, the geographical spread was relatively large.

5. Conclusions

Within the limitations of the present review, the following can be concluded:

In the laboratory, HT 3Y-TZP restorations should be sintered according to the manufacturer's recommendation and polished before glazing to favour flexural strength, surface roughness, and wear behaviour. Laboratory polishing needs to be further evaluated.

In the clinic, meticulous polishing of HT 3Y-TZP restorations is necessary to favour surface roughness and aging resistance if adjustments by grinding are performed, although grinding increases the flexural strength. For 4YSZ and 5YSZ, the evidence of laboratory and clinical-related factors' effect is too limited for conclusions to be drawn.

Over time, when using hydrothermal aging, a *t*–*m* phase transformation and reduced transmittance and translucency of HT 3Y-TZP can be expected, without the flexural strength and surface roughness being affected. The flexural strength of 4YSZ and 5YSZ is not affected. However, the time-related conclusions are based on methods of questionable clinical significance.

The evidence of all other laboratory and clinical-related processing factors' or time-related factors' effect on the properties of high translucent zirconia is lacking or limited; thus, the factors are of relevance for future research. There is a high heterogeneity of study designs and methods, and the results are dependent on the brand.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ceramics6010045/s1, Table S1: Search strategies for each database; Table S2: Risk of bias (quality) assessment tool; Table S3: Reasons for exclusion for publications.

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