Are zirconias of today different?

Background

The advantages of ceramic materials are generally considered to be their tooth-like translucent appearance, their good biological compatibility in direct contact with the gingiva and a wear pattern that is comparable to that of enamel. These criteria are usually met by lithium silicate ceramics, which are indicated for veneers, tabletops, single crowns and small anterior bridges. If we wish to expand the indication range and integrate larger restorations in the posterior region, this objective is only achievable with zirconia ceramics [7]. However, the higher fracture strength of zirconia is obtained at the expense of an opaque, less tooth-like appearance. This fact was initially not disturbing because the opaque framework was veneered with feldspathic ceramics. Since it has become technically possible, using the CAD/CAM process, to produce not only frameworks made of zirconia, but also complete restorations with occlusal surfaces, the high opacity of zirconia is no longer desirable from a clinical point of view. Developments in recent years have aimed to develop zirconias with the above-mentioned properties of silicate ceramics, which include combining translucency, biocompatibility, a tooth-like wear pattern with higher fracture strength and the possibility of CAD/CAM processing. These efforts have resulted in the development of different types of zirconia.

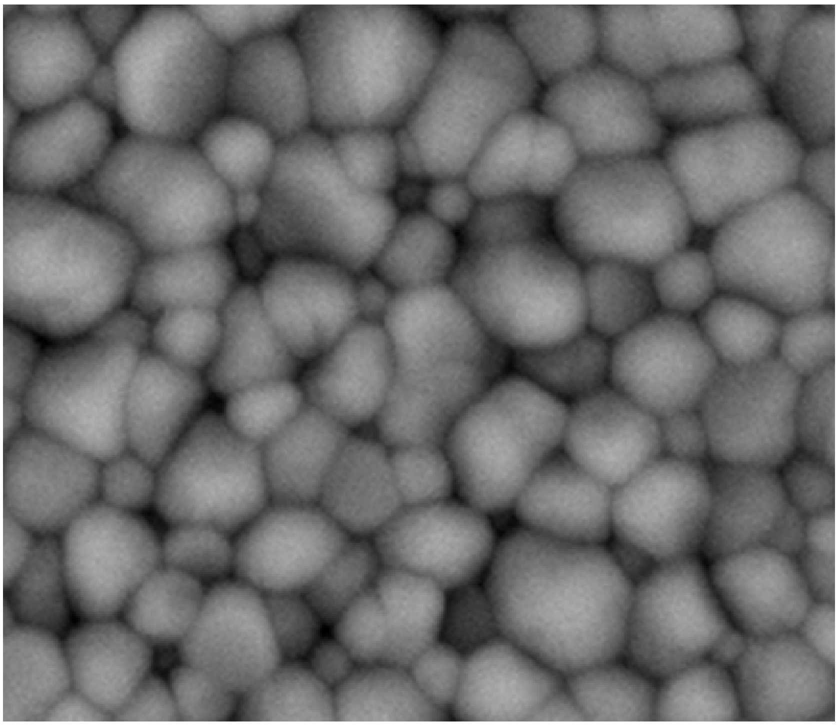

Figure 1 Scanning electron microscope imaging of the surface of 3Y-zirconia (magnification: 10,000x)

The crystal structure of zirconium dioxide (Fig. 1, Fig. 2) can be influenced by doping it with different amounts of yttrium and/or aluminum [13]. Zirconia exists in varying phases which depend on temperature; these are the cubic (> 2370°C), tetragonal (> 1170°C) or monoclinic (room temperature) phases; moreover, phase transitions are accompanied by a change in volume. In the case of opaque "conventional zirconia", for example, tetragonal fractions can be stabilized at room temperature by doping them with 3 mol% yttrium oxide (3Y-TZP, 3 mol% yttria stabilized tetragonal zirconia polycrystal). This allows a spontaneous phase transformation to take place within the monoclinic crystal structure in response to mechanical stress. The increase in volume that occurs can, for instance, counteract the propagation of cracks.

Today we distinguish several generations or classes of zirconia [13]:

- 1st Generation 3Y-TZP-A → flexural strength > 1000 MPa → opaque
- 2nd Generation 3Y-TZP-LA → flexural strength 900 MPa 5 % → more translucent
- 3rd Generation 5Y-TZP → flexural strength 600 MPa 15 % → more translucent
- 4th Generation 4Y-TZP → flexural strength 750 MPa 10 % →
- more translucent

Translation from German: Cristian Miron
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- 5th Generation 3Y/4Y/5Y-TZP → flexural strength 550–1200 MPa 1–15 % → more translucent (Multilayer with translucency gradients)

In a first step to make 3Y-TZP more translucent, the aluminum content was reduced in the 2nd generation. Yet, only the 3rd and 4th generations of zirconia show considerably improved translucency. However, they achieve higher translucency at the expense of lower strength, with values being similar to those of lithium disilicate ceramics. The newest development in zirconias are "Multilayer"; they combine areas of "highly" translucent and opaque zirconium dioxide in several layers within the same milling block (Fig. 3). By skillfully aligning the digitally planned restoration in the milling block for the milling machine, larger bridges in the posterior region can also be fabricated with a more natural color gradient. However, it is important to note that the more translucent areas of the milling blocks have a lower strength than the opaquer areas. This can result in clinical failures if the mixed blank is incorrectly planned and set up in the milling machine, as though the same flexural strengths were present in all areas of the blank. Furthermore, initial investigations on the strength of various Multilayer zirconias showed that the strength in the transition layer (interphase) could be a weak point [5]. The strength of this "transition layer" was about 30 % lower than the strength of the "pure" 3Y-TZP or 5Y-TZP zirconia layers; thus, Kaizer, for instance, is of the view that the clinical indication for Multilayer should not be expanded, but rather limited [5].

Due to their opacity, 1st Generation zirconias are mainly used as framework materials. It is possible to veneer them with feldspathic ceramics in order to obtain a natural looking tooth-colored restoration. The recurrent problems with chipping, especially in combination with implant restorations [10], can be reduced through standardized and optimized processing protocols [14]. It is important to note that, in contrast to metal ceramics, the processing possibilities of zirconia are considerably smaller. For example, local temperature increases during the grinding of metal-ceramics is relatively well distributed by the metal lattice structure, whereby the lattice structure of the ceramic leads to high temperature gradients. Due to the large temperature differences within closely spaced crystal structures, ini-

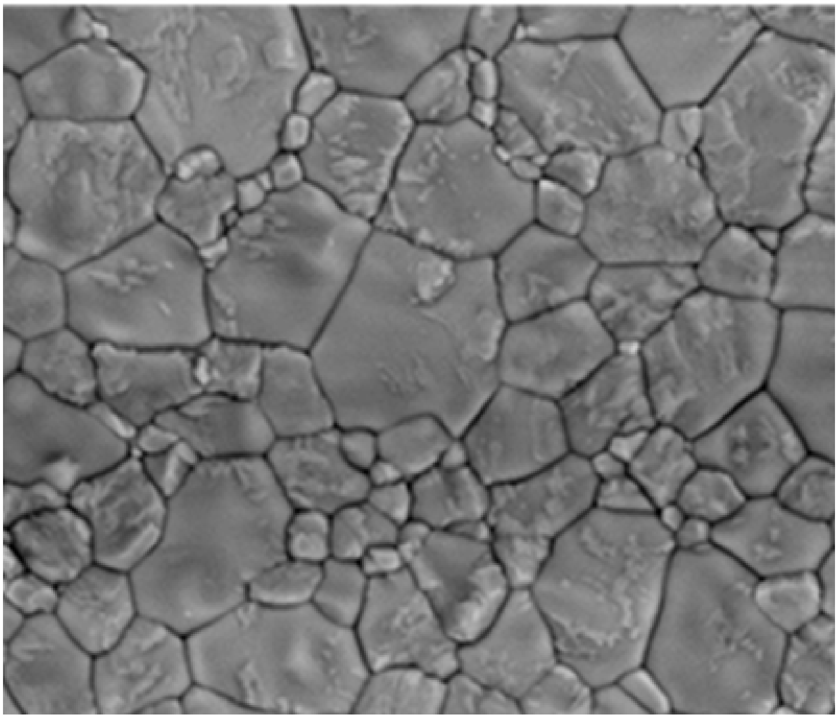


Figure 2 Scanning electron microscope imaging of the surface of 5Y-zirconia (magnification: 10,000x). Note the larger particle size compared to 3Y-zirconia (Fig. 1).

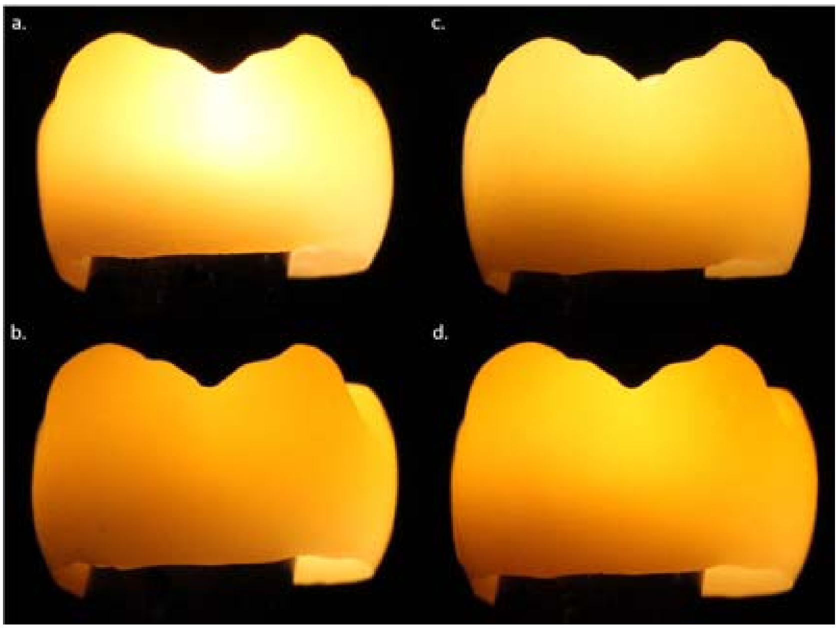
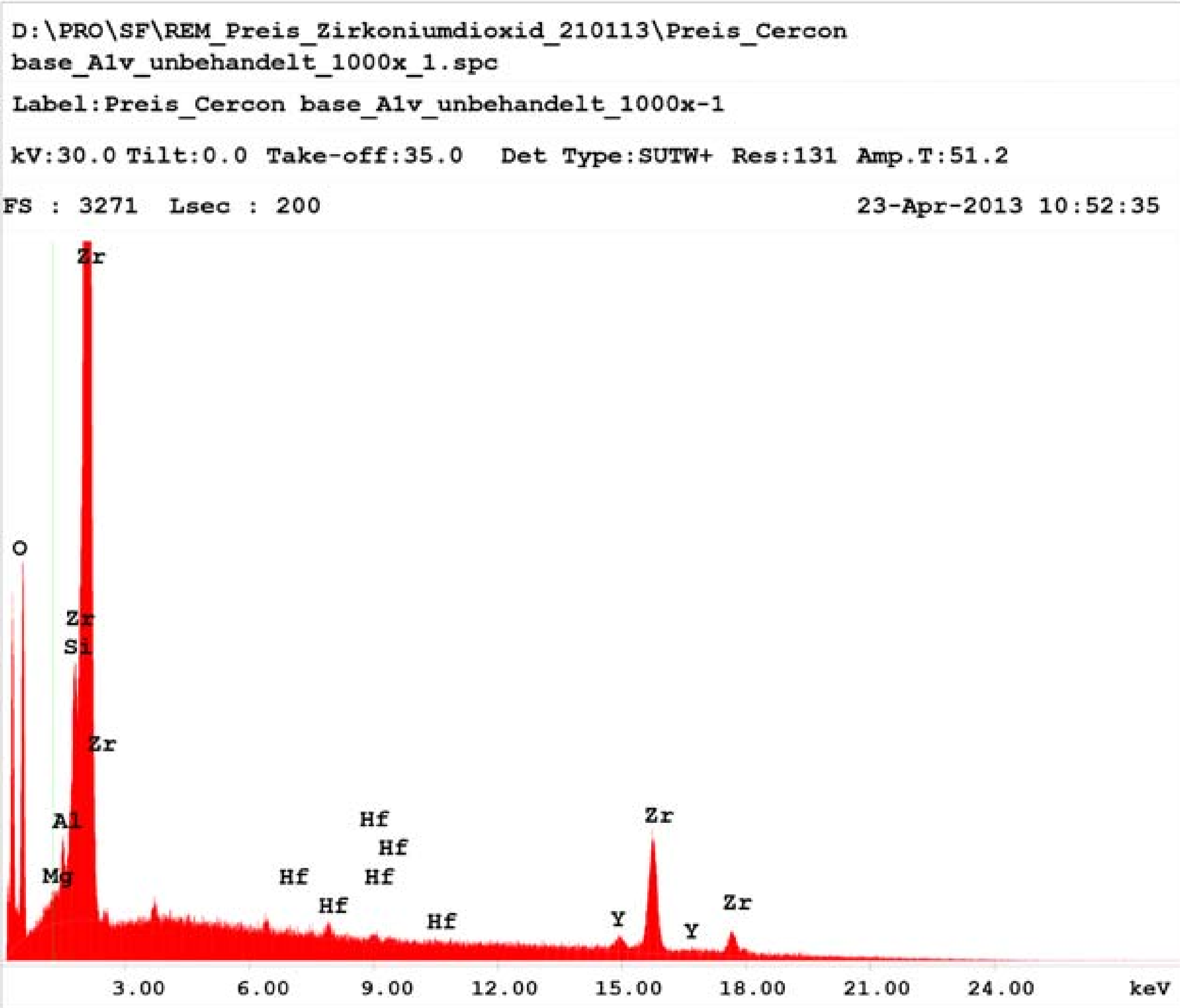


Figure 3a–d Illustration of the different translucency degrees of different ceramic materials. This example uses a molar crown for tooth 46. View from lingual using light guide illumination. All crowns were made of different materials **(a–d)**, but with the aid of the same digital dataset using CAD/CAM, the crowns all have identical wall thicknesses. **(a)** Ivoclar emax CAD (Ivoclar-Vivadent, Schaan, FL); **(b)** Pritidenta multidisc ZrO_2 (Pritidenta, Leinfelden, D); **(c)** Ivoclar emax ZIRCAD Prime (upper position in Multilayer blank selected) (Ivoclar-Vivadent, Schaan, FL); **(d)** Ivoclar emax ZIRCAD Prime (lower position in Multilayer blank selected) (Ivoclar-Vivadent, Schaan, FL)



EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
O K	30.17	68.14	0.0445	1.1296	0.1305	1.0004
MgK	0.73	1.08	0.0026	1.0881	0.3218	1.0093
AlK	1.40	1.87	0.0065	1.0570	0.4343	1.0171
SiK	2.65	3.41	0.0156	1.0886	0.5248	1.0285
HfL	1.69	0.34	0.0148	0.8272	1.0592	1.0000
Y K	6.09	2.48	0.0551	0.9014	1.0030	1.0000
ZrK	57.26	22.68	0.5156	0.8973	1.0035	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
O K	45.34	2.81	1.11	16.11
MgK	5.28	6.50	5.72	0.81
AlK	14.03	6.93	2.66	2.03
SiK	32.77	8.12	1.51	4.04
HfL	4.21	8.17	7.61	0.52
Y K	6.23	4.13	4.32	1.51
ZrK	46.13	3.63	1.12	12.69

(Fig. 1–4: M. Behr)

Figure 4 Plot of an EDX analysis (energy dispersive X-ray spectroscopy) of a 3Y-zirconia surface. The plot shows the chemical elements found in the sample: Zr, Al, Mg, Y, Hf, O, Si.

tial cracks form, which then propagate during the period of use, and can then contribute to premature failure, such as chipping.

Besides the clinical concerns regarding chipping, the new digital design possibilities for directly designing teeth with functional occlusal surfaces has also fuelled the desire to process esthetically appealing restorations with more translucent zirconia using a single class of materials by means of CAD/CAM. By doping zirconium dioxide with 5 mol-% yttrium oxide, abbreviated as "5Y-TZP", this requirement is fulfilled and the translucency partially reaches that of lithium disilicate ceramics [13]. However, this advantage of increased translucency is offset by the disadvantage of reduced flexural strength, which reduces the clinical indication range of this type of zirconia. In fact, the indication range for 5Y-TZP zirconia hardly differs from that of lithium disilicate ceramics [14]. Apart from single crowns in the anterior and posterior areas, it only includes three-unit bridges in the anterior and premolar region. Bridges in molar area and the replacement of more than one pontic are usually not permitted. With 4th Generation zirconias (4Y-TZP), the strength is further increased so that a few manufacturers have expanded the indication range to include that of the molar region. In this case, in the planning phase of a restoration, the differing specifications from the manufacturers should already be taken into account.

What all zirconias have in common is that their wear pattern differs significantly from that of enamel or previous restorative materials [12, 15]; they practically do not wear. Due to this fact, if wear-resistant monolithic restorations are distributed unfavorably in the dentition, occlusal changes that affect the position of the masticatory plane may result. Thereafter, functional interferences cannot be ruled out [2]. In order to avoid damage to the antagonist teeth, it is essential to always perfectly polish monolithic zirconia to a high gloss following occlusal corrections [8, 11]. If this measure is omitted, antagonist teeth will become disproportionately damaged through abrasion [12].

Moreover, the safety of zirconia as a material in clinical applications requires attention because the starting material for clinically used zirconia is the mineral "zircon", which is a carrier of natural radioactivity [1, 16]. Besides zirconium silicate, it contains hafnium oxide, thorium oxide and uranium oxide. These "impurities" must be removed from the material and this is achieved for thorium oxide and uranium oxide. The small traces of hafnium (Fig. 4), which usually remain detectable in zirconium dioxide, are nevertheless harmless. However, an unsatisfactory fact is that the Medical Devices Act [9] does not contain any regulations regarding the purity of zirconium dioxide used for medical purposes as of yet and that its treatment processes are not very transparent. Problems with hip joint prostheses from the 1990s show [3] that vigilance is required in this aspect.

Conclusion

Depending on their yttrium/aluminum doping ratio, dental zirconias show different properties. Zirconias with higher translucency have reduced mechanical strength compared to classical opaque zirconias. Due to this fact, their clinical indication range is limited. In fact, the clinical indications for translucent zirconias hardly differ from those of lithium disilicates. The restriction or broadening of the indication range to include the molar region must be carefully considered on a case-by-case basis in relation to the manufacturer, especially with respect to 4Y-TZP zirconias. Particularly confusing is the widely varying indication range for the new 5th Generation mixed zirconias with graded translucency within a milling block. For this generation, the indication range varies from only small three-span bridges in the anterior region [6] up to the approval of 14-unit bridges [4] (maximum of 2 teeth per dental gap replaced). Therefore, nowadays, the concept of "the zirconia" does not exist, but rather a multitude of material variants, which are created for individualized applications.

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