Bogna Stawarczyk

Three generations of zirconia: From veneered to monolithic. Part II

Bogna Stawarczyk, PD Dr Dipl Ing (FH) MSc[1]/Christine Keul, Dr MSc[2]/Marlis Eichberger, CDT[3]/
David Figge, Dipl Ing (FH)[4]/Daniel Edelhoff, Prof Dr[5]/Nina Lümkemann, MSc[6]

This article presents the historical development of the different generations of zirconia and their range of indications, from veneered to monolithic zirconia restorations. While Part I concentrated on detailed information about the development of zirconia for dental use and the mechanical and optical properties, Part II deals with the resulting guidelines for working with the relevant generations by summarizing the correct cementation procedure. Furthermore, this part also focuses on translucency measurements for better characterization and understanding of the different materials. The results obtained from measuring light transmission and contrast ratio are compared and discussed in detail, with the aid of clinical photographs. Finally, the reader is given practice-relevant recommendations for different areas of clinical use of the zirconia generations along with advice on how to process them appropriately. *(Quintessence Int 2017;48:441–450; doi: 10.3290/j.qi.a38157. Originally published (in German) in Quintessenz Zahntech 2016;42(6):740–765)*

Key words: cementation, contrast ratio, flexural strength, full ceramic, monolithic zirconia restorations, reflectance, translucency, transmission, veneered zirconia restorations, zirconia

Full-ceramic restorations, in contrast to metal-ceramic restorations, should have no primary friction, because this can cause crack-inducing tensile stresses on the inside of the restoration. This also applies to zirconia. An important task of the cementation material is to compensate for the lack of primary friction to counteract retention losses. The cementation material should not be selected on the basis of preference but based on specific guidelines.[1]

CEMENTATION OF ZIRCONIA RESTORATIONS

In general, there are different classes of cementation material: traditional cements and composite resin cements.

A prerequisite for cementation using conventional acid-based cements (eg, zinc phosphate or glass-ionomer cement) is the extremely close fit between prepared tooth and restoration. This ensures, due to the hydrophilic properties of conventional cements, that the restoration fits precisely. Pretreatment to condition the dental hard tissue is not necessary with the trad-

---

[1] Head of Dental Materials Research, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Munich, Germany.

[2] Associate Professor, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Munich, Germany.

[3] Dental Technician in Dental Materials Research, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Munich, Germany.

[4] Engineer, Private Practice, Bensheim, Germany.

[5] Head and Chairman, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Munich, Germany.

[6] Fellow Researcher in Dental Materials Research, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Munich, Germany.

Correspondence: PD Dr Dipl-Ing (FH) Bogna Stawarczyk, Ludwig-Maximilians University Munich, Poliklinik für Zahnärztliche Prothetik, Goethestrasse 70, 80336 Munich, Germany. Email: bogna.stawarczyk@med.uni-muenchen.de

itional cements. Traditional cements should be used only for crown preparations involving a stump height of 4 mm or more that were prepared relatively steeply (6 degree to 15 degree convergence angle).[2] If retention loss of a crown occurred, this would be immediately visible. An increased rate of retention loss has been described for fixed partial dentures made from zirconia ceramic that were attached using conventional cements.[3] An one-sided retention loss at only one of the fixed partial denture anchors can lead to substantial problems. For this reason, the author's team basically prefers adhesive cementation for full-ceramic fixed partial dentures.

In contrast to this, for adhesive cementation with cementation composites, a force-fitted bond is created because of the "sticking together," which is consequently somewhat more tolerant in relation to fit. Although the use of adhesive cementation materials compared to traditional cementation materials decreases user friendliness and tolerance of humidity, a significant improvement in the mechanical and optical properties is evident. Furthermore, adhesive cementation materials show high resistance to abrasion and are in addition almost insoluble because of their hydrophobic properties.

In contrast to traditional cementation, conditioning of the dental hard tissue and restoration plays a decisive role in adhesive cementation with cementation composites. The cementation composites can be further classified on the basis of their chemical constituents as:

- conventional cementation composites based on bisphenol glycidyl methacrylate (bis-GMA), triethylene glycol dimethacrylate (TEGDMA), urethane dimethacrylate (UDMA)
- cementation composites containing acid groups.

The latter can be further subdivided using the acid groups they contain, into:

- cementation composites with 10-methacryloyloxydecyl dihydrogen phosphate (MDP)
- self-adhesive cementation composites with multifunction methacrylates (eg, phosphoric acid esters, carbonic acid or amino acid derivatives).

In general, the self-adhesive cementation materials are easier to process and thus more efficient to handle than the conventional cementation composites, because the appropriate conditioning of the dental hard tissue is missing.

With regard to the restoration, the functional acid groups of the methacrylates and the MDP monomer can enter a direct interaction with the zirconia. The phosphate ester group of the bifunctional MDP monomer binds chemically to the zirconia, while the monomer-based methacrylate group ensures the polymerization and hardening of the cementation composite.

For adhesive cementation, therefore, the choice of cementation material is highly critical. The following combinations show good bonding strengths with zirconia:

- Self-adhesive cementation composites (eg, RelyX Unicem, 3M)
- Conventional composite resin cements in combination with an MDP primer or with acid phosphate and phosphorus group adhesive systems (eg, Multilink Automix with Monobond Plus, Ivoclar Vivadent; Panavia V5 with Ceramic Primer Plus, Kuraray Dental)
- Many of the new universal adhesives such as Scotchbond Universal (3M) contain acid monomers and can be used for adhesive cementation of zirconia restorations.

An important prerequisite of good and durable chemical bonding is the cleaning, activation, and roughening (increasing surface area) of the restoration's inner surface. In the case of zirconia, this cannot be achieved by chemical conditioning with hydrofluoric acid, but only through gentle mechanical surface treatment using a blasting unit. The recommended parameters are as follows: pressure 1 bar (14.5 psi), particle size ≤ 50 µm, nozzle-to-surface distance approximately 10 mm.

The following figures give an example of the clinical procedure. Airborne-particle abrasion is used in the inner surface of the crown in order to prepare it for adhesive cementation (Fig 1). The crown is bonded using Clip (Voco) to a brush holder. This makes handling easier. After cleaning the blasted inner surface, an extremely thin layer of bonding agent containing MDP (in this case Ceramic Primer Plus, Kuraray) is applied (Fig 2). A primary self-hardening adhesive cementation material is then applied (in this case Panavia V5, color Universal, Kuraray Dental) (Fig 3).

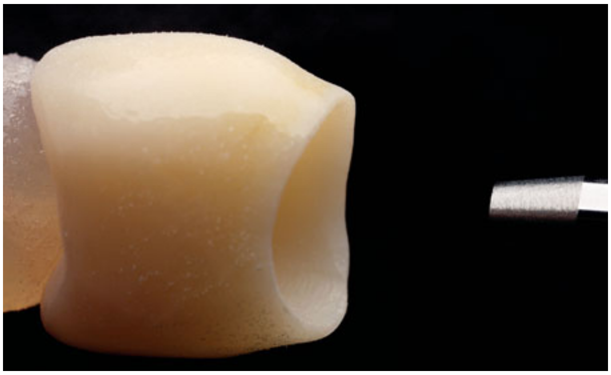

Fig 1 Radiation of the inner surface of the crown as a measure of the preparation for the adhesive attachment. The crown is attached to a brush holder using Clip (Voco). This facilitates handling.

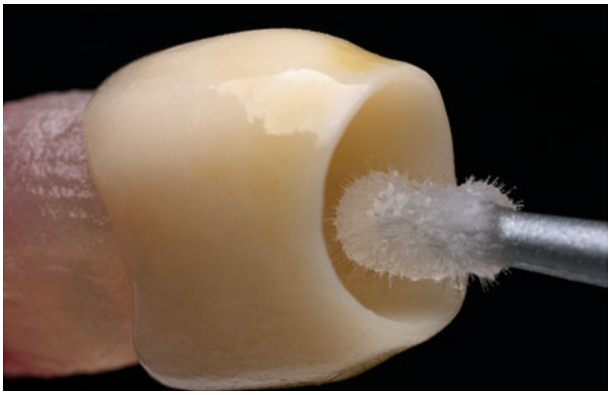

Fig 2 After cleaning the radiated inner surface, an MDP-containing adhesion promoter (Ceramic Primer Plus, Kuraray) is applied.

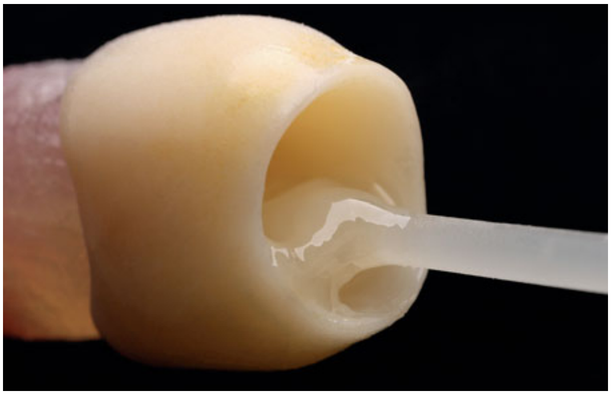

Fig 3 The application is then followed by the application of a primarily self-hardening adhesive material (Panavia V5, Universal color).

RANGES OF INDICATIONS FOR THE ZIRCONIA GENERATIONS

First- and second-generation zirconia is recommended, because of its high strength value (ISO 6872), as a restoration material for multi-unit fixed partial dentures. Figure 4 shows the flexural strength for the different generations. It must be emphasized that first-generation zirconia has the significantly highest strength values. Third-generation zirconia, in contrast, has the significantly lowest strength values.

Accordingly, third-generation zirconia is recommended only for single crowns and three-unit fixed partial dentures. The range of indications relate predominantly to monolithic restorations, which can also be veneered with conventional veneers because the coefficient of thermal expansion (CTE) has remained constant.

A DGPro Consensus Conference on the theme “Full ceramic crowns and bridges” was held in 2013. At this event, an S3 Guideline was drafted that was intended to help the practitioner to make decisions on prosthetic full-ceramic restorations.[4] All statements from this guideline are firmly based on the literature. The results of this conference and thus the S3 Guideline are summarized below.

After 6 years’ observation, single veneered zirconia crowns show survival rates between 88% and 99% in the anterior tooth region,[5-7] and between 79% and 99% in the lateral tooth area.[5,8] Therefore, these indications can be recommended for veneered zirconia crowns.

After up to 6 years’ observation, studies provide 5-year survival rates for three-unit veneered zirconia fixed partial dentures in the anterior tooth area of 89% to 100%,[5,9,10] and in the lateral tooth area of 90% to 97%.[5,9-13] At the consensus conference, therefore, an evidence-based recommendation was published for the potential range of indications for this material.

No clinical studies are available at this time on monolithic zirconia restorations.

In summary, the advantages and disadvantages of the three generations are presented in Table 1. Because the different zirconia generations can hardly be distinguished in the “white body” state (Fig 5), it is very important for dental technicians to know which material is being used and the indication range for each material.

IN-VITRO STUDY OF TRANSLUCENCY USING PLATE GEOMETRY

Preparation of test specimens and polishing

For the translucency study of the different zirconia generations (first to third generations) using transmittance and reflectance measurement, a total of 40 specimens (n = 10 test specimens per material) made of the materials priti multidisc ZrO_2 A2 Opaque, priti multidisc ZrO_2 A2 Translucent, and priti multidisc ZrO_2 A2 High Translucent (pritidenta) were milled with a computer-aided design/computer-assisted manufacture (CAD/CAM) machine (250i, imes-icore) and sintered in a sinter oven (HT Speed Sinter Oven, Mihm-Vogt) with the following sintering parameters: heating at room temperature with 8 K/minute to 1,450°C, 2 hours' holding period, cooling with 8 K/minute to room temperature.

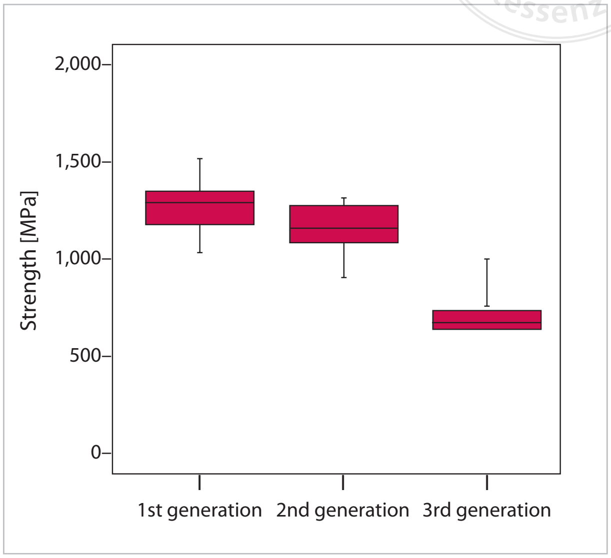

Fig 4 Graphical summary of the strength values as a function of the zirconia generation (data from pritidenta and prepared only for this post).

Fig 5 All three generations of the zirconia in the "white body" state. The blanks are difficult to distinguish from one another visually.

Table 1 Comparison of the three generations of zirconia (zirconia quality, wt%)

Zirconia	1st generation 3Y-TZP	2nd generation 3Y-TZP	3rd generation 5Y-TZP
$ZrO_2 + HfO_2 + Y_2O_3 + Al_2O_3$	> 99.9	> 99.9	> 90
Y_2O_3	4.5–5.6	4.5–5.6	< 10
Al_2O_3	0.25 ± 0.1	0.05 ± 0.02	< 0.01
SiO_2	< 0.02	< 0.02	Other oxides
Fe_2O_3	< 0.01	< 0.01	< 0.005
Na_2O	< 0.04	< 0.04	

Strength/fractional number
Translucency

Two lithium disilicate ceramics (LiSi$_2$) IPS e.max CAD LT A2 and IPS e.max CAD HT A2 (Ivoclar Vivadent) were used as control groups. The test specimens were separated from the lithium disilicate blanks using a cutting machine (Secotom 50; Struers). Crystallization firing followed (Programat EP 5000, Ivoclar Vivadent) using the program provided by the manufacturer.

All specimens were cut evenly to 20 µm and then polished so that after polishing their final dimensions were 140 × 120 mm with a thickness of 1.00 ± 0.03 mm. The ceramics used are summarized in Table 2.

Translucency measurements

The transmission and contrast ratio measurements were performed with the same specimens to ensure optimum comparability of the test methods.

Transmission measurements

The transmissions of the specimens were measured with a barium sulfate reflectance standard using a spectrophotometer (Lambda 35, Perkin Elmer) with an integrated Ulbricht sphere (Labsphere RSA-PE-20, Labsphere). Prior to this, the specimens were cleaned in ethanol (80%, Alkopharm 80, Brüggemann Alcohol) in an ultrasound bath (Sonorex RK 102 H, Bandelin Electronic) and left to air dry. The transmission measurement was made with the light source D65 at a wavelength spectrum of 400 to 700 nm at intervals of 1 nm.

Before the individual measurements, the spectrophotometer was calibrated without specimens in the light beam, to define the value for 100% transmission ($I_{\text{auto zero}}$). For measurement, the specimens were individually fixed in a special holding device in the incident light beam of the photometer. The light reflected and scattered by the specimens was registered using the barium sulfate standard in the Ulbricht sphere. The barium sulfate standard was used to reflect all non-linear light rays passing through the specimens onto the detector. The value registered by the detector ($I_{\text{test specimen}}$) was used to calculate transmission by applying the following formula:

Transmittance [%] = $I_{\text{test specimen}} / I_{\text{auto zero}} \times 100$.

Contrast ratio measurements

The translucency values for the test specimens were also determined through opacity measurement using a reflectance spectrophotometer (CM-600d, Konica Minolta) in SCE mode (excluding gloss) with a MAV aperture diameter of 8 mm. The contrast ratio measurements were conducted with light source D65 in a wavelength range of 400 to 700 nm with lighting and observation angles of 8 degrees to the surface of the speci-

Table 2 Summary of the materials used

Material	Product	Batch number	Manufacturer	Composition
1st generation	priti multidisc $Zr0_2$ A2 Opaque	Z83 A2 18	pritidenta	ZrO_2/HfO_2, 94.0%; Y_2O_3, 4.5–5.4%; Al_2O_3, < 0.5%; other: < 0.5%
2nd generation	priti multidisc $Zr0_2$ A2 Translucent	A2Z33A218T		ZrO_2/HfO_2, 94.0%; Y_2O_3, 4.5–5.4%; Al_2O_3, < 0.5%; other: < 0.5%
3rd generation	priti multidisc $Zr0_2$ A2 High Translucent	5YZ-L65-280515-W-007-14-010; 5YZ-L65-280515-W-007-14-011		ZrO_2/HfO_2, 90.7%; Y_2O_3, 9.3%; Al_2O_3, < 0.1%; other: < 0.5%
$LiSi_2$ LT	IPS e.max CAD LT A2	U43692	Ivoclar Vivadent	SiO_2, 57–80%; Li_2O, 11–19%; K_2O, < 13%; P_2O_5, < 11%; ZrO_2, < 8%; ZnO, < 8%, Al_2O_3, < 5%; MgO, < 5%; coloring oxides, < 8%
$LiSi_2$ HT	IPS e.max CAD HT A2	U54553		SiO_2, 57–80%; Li_2O, 11–19%; K_2O, < 13%; P_2O_5, < 11%; ZrO_2, < 8%; ZnO, < 8%; Al_2O_3, < 5%; MgO, < 5%; coloring oxides, < 8%

men. An Ulbricht sphere coated with barium sulfate with a diameter of 40 mm in the reflectance spectrometer ensures evenly diffuse lighting and observation of the specimens placed on the aperture.

Before performing the measurements, the reflectance spectrophotometer was calibrated with a black light-proof aperture cover and a white calibration sample but no test specimens. When measuring the specimens, these aperture covers were also positioned over the specimens placed on the aperture. In contrast to the transmission measurement, the opacity values for the specimens were determined via the brightness values for the specimens measured with black covering ($I_{\text{test specimens black}}$) and with white calibration sample ($I_{\text{test specimens white}}$) and the SCI value calculated. In addition, the directed reflectance of the high-polish specimens was excluded by using a gloss trap (SCE mode).

Opacity values were calculated as follows:

Opacity [%] = $I_{\text{test specimens black}} / I_{\text{test specimens white}} \times 100$.

Translucency values were calculated using the following formula: Transmission [%] = 100% – opacity [%].

Statistical analysis

The translucency values measured (transmission and contrast ratio) were analyzed descriptively in a first step. In addition, the assumption of normal distribution was tested using Kolmogorov-Smirnov test. Because more than 95% of the groups showed normal distributions, the data were analyzed parametrically. A multifactorial analysis was conducted on this and the differences between the materials were calculated using single-factor variance analysis (one-way ANOVA) and the differences between the test methods were determined using an independent *t* test. All *P*-values below .05 were construed as statistically significant. The software SPSS version 23 (IBM) was used for the statistical analysis.

Results

All measuring methods showed significant differences between the materials ($P < .001$) (Fig 6). It was apparent that the first zirconia generation had the lowest translucency values, followed by the second and third generation in ascending order ($P < .001$). The highest translucency values were measured for $LiSiO_2$ HT, followed by lower translucency values in the $LiSiO_2$ LT group ($P < .001$).

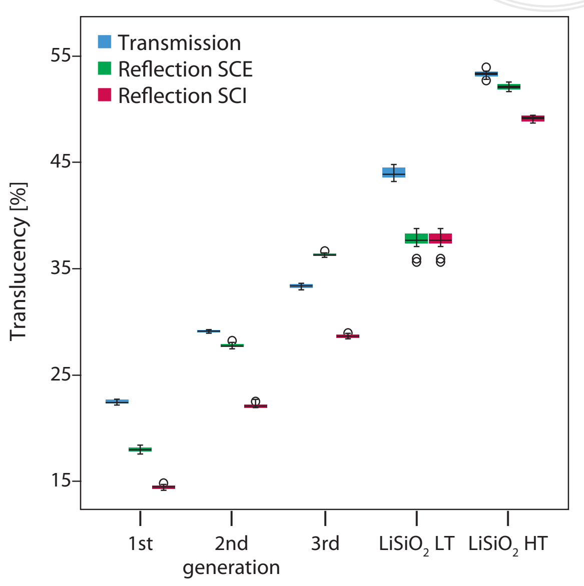

Fig 6 Graphical summary of the measured transmission as well as SCE and SCI reflection values for each material separately.

Within the first and second generation of zirconia and $LiSiO_2$, the method for measuring SCI contrast ratio showed significantly lower values than for measuring SCE contrast ratio ($P < .001$). The significantly highest translucency values were achieved with this class of materials in transmission measurement ($P < .001$). A different tendency in measurement methods was observed for the more translucent materials. In the third zirconia generation, SCI contrast ratio measurement led to significantly lower translucency values than the transmission measurement ($P < .001$). The highest translucencies were observed here with the SCE contrast ratio measurement ($P < .001$). With the $LiSiO_2$ LT, both the methods for measuring reflectance showed no effect on translucency ($P > .999$), but these values were significantly lower than those measured with the transmission measurement method ($P < .001$).

The descriptive statistics are summarized in Table 3 and Fig 6.

Table 3 Measured values for translucency measurements

Material	Transmission		Contrast ratio			
			SCE		SCI	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
1st generation	23 ± 0.1^{a}	(21–23)	18 ± 3.4^{a}	(16–20)	14 ± 0.6^{a}	(13–15)
2nd generation	29 ± 0.1^{b}	(28–30)	26 ± 3.0^{b}	(24–28)	22 ± 0.2^{b}	(21–23)
3rd generation	33 ± 0.2^{c}	(32–34)	33 ± 3.2^{c}	(30–35)	29 ± 0.1^{c}	(27–29)
IPS e.max CAD LT	44 ± 0.5^{d}	(43–45)	39 ± 3.2^{d}	(37–42)	38 ± 0.8^{d}	(36–39)
IPS e.max CAD HT	54 ± 0.3^{e}	(52–54)	52 ± 1.8^{e}	(49–53)	49 ± 0.2^{e}	(48–50)

CI, confidence interval.

VISUAL PERCEPTION OF REAL RESTORATIONS EX-VIVO AND IN-VIVO

Manufacturing the crown

For an in-situ implant in the region of the mandibular left second premolar (Bone Level NC 3.3 mm, Straumann), an individually milled implant abutment was manufactured on the basis of indirect digitalization after conventional interoral precision impression (Impregum Penta, 3M Espe) and plaster model production. A Cares Mono Scanbody (Straumann) was introduced into the laboratory analog of the plaster model for indirect digitalization of the situation on the part of the laboratory. This was scanned in as a wax-up in a laboratory scanner (D911L, 3Shape) and subsequently sent as a dataset to Straumann Cares for the manufacture of an individually milled titanium abutment. Virtual construction of the crown restoration was subsequently carried out. The three-dimensional (3D) construction dataset was sent in the form of a CAD dataset in STL format (Surface Tesselation Language) to pritidenta for manufacture of the ceramic crown. A monolithic crown was milled from first-generation, second-generation, and third-generation zirconia in the white body state and subsequently sintered analogously to the test specimens for the translucency measurement. The three zirconia crowns were then individualized according to color specification Vita A3 with glazing material and stains (Vita Akzent, Vita Zahnfabrik) under the same conditions.

Analogously to the translucency measurements, two crowns were produced from lithium disilicate and crystallized according to the manufacturer's instructions (Programat EP 5000, Ivoclar Vivadent). The lithium disilicate crowns were individualized analogously to the zirconia crowns with stain according to color specification Vita A3 and glazed (e.max CAD Crystall/Shades and Glaze, Ivoclar Vivadent).

Digital photographs were produced on a light table from the perspective giving a view of the occlusal surface of the finished crowns (D90 camera, Nikon; AF-S Micro Nikkor 105 mm 1:2.8G macro lens, Nikon; Metz 15MS-1 flash, Metz mecatech). These photographs are identified by "ex vivo" in the further course of the article. Furthermore, intraoral photographs were taken after the try-in of the crowns on the integrated titanium abutment (Nikon D90, Metz 15MS-1), which are identified below as "in vivo" photographs and are discussed in comparison with the "ex vivo" photographs.

Results

In the ex-vivo comparison of the crowns on the light table, the first generation zirconia appeared the least translucent (Fig 7). Translucency increased through the second generation to the third generation of zirconia. The crown made from LT lithium disilicate ceramic even appeared slightly less translucent than the third-generation zirconia. The highest translucency was shown by the HT lithium disilicate ceramic.

Fig 7 Comparison of the different zirconia generations compared to $LiSiO_2$ ceramics (left to right: 1st generation, 2nd generation, 3rd generation, $LiSiO_2$ LT, and $LiSiO_2$ HT).

In the lateral photographs of the in-vivo comparison, the first-generation zirconia proved to be the most opaque material. The gray color of the titanium abutment shone through the least. With regard to the crowns made of zirconia, opacity reduced from the second to the third generation. Both crowns made from lithium disilicate showed barely visible differences with regard to opacity. However, the gray color of the titanium abutment was visible (Fig 8).

DISCUSSION

When contrast ratio parameters are measured, measurement of SCE values can be distinguished from measurement of SCI values.[14] When measuring SCE values, only the diffuse reflectance of the specimen was measured. By activating what is known as the “gloss trap” of the reflectance spectrophotometer, the directed reflectance of the light beam from the test specimen is not included in the measured values. In contrast to this, both the directed and diffuse reflectance are included in the SCI values by the “deactivation” of the gloss trap.

In the present study, the SCI measurements for all groups yielded lower values than the transmission measurements. However, a similar tendency can be seen in the results obtained for both measuring methods. In contrast to this, the same tendency in the values is yielded for the SCE measurement only for the two $LiSiO_2$ and for the first- and second-generation zirconia. In the case of third-generation zirconia, however, contrast ratio measurement achieved higher translucency values than the transmission measurement. Earlier studies also resulted in different correlations between the translucency values from reflectance measurement and from transmission measurement.[15]

In comparison of SCI values for consistency with the photography of the clinical crown in vivo, it was evident that the visual appearance of the different classes of material on the titanium abutment also showed the same tendency as the measured values in themselves. For the photographs of the clinical crowns ex vivo, a tendency towards consistency with the SCE values was found. However, it should be mentioned that third-generation zirconia appeared even more translucent than the LT lithium disilicate. In this regard, the coloring process of the different classes of material also represented an unknown component. However, previous studies have shown that the color component itself has an effect on the translucency of a material.[16] Thus a pure comparison of the translucency properties between the individual materials is possible only to a limited extent.

CONCLUSION

New generations of zirconia have higher translucency but this is generally associated with the side effect of lower strength. Therefore, an increase in translucency cannot always be considered to be advantageous. In

Figs 8a to 8e In-vivo presentation of the various restorations on the mandibular right second premolar: *(a)* 1st generation, *(b)* 2nd generation, *(c)* 3rd generation, *(d)* 4th generation, *(e)* $LiSiO_2$ LT and $LiSiO_2$ HT.

the case of colored tooth stumps in particular, a reduced masking potential of the restoration can also be a negative result. It is important, therefore, to select and use the correct material according to the range of indications.

ACKNOWLEDGMENTS

Translucency measurements were financed by pritidenta. The crowns for the clinical photographs were also produced by pritidenta and made available to the university staff for these photographs. The authors are responsible for the contents of this article and were in no way influenced by pritidenta.

REFERENCES

1. Edelhoff D, Özcan M. To what extent does the longevity of fixed dental prostheses depend on the function of the cement? Working Group 4 materials: cementation. Clin Oral Implants Res 2007;18:193–204.
2. Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D. Clinical results of lithium disilicate crowns after up to 9 years of service. Clin Oral Investig 2013;17:275–284.
3. Rinke S, Gersdorff N, Lange K, Roediger M. Prospective evaluation of zirconia posterior fixed partial dentures: 7-year clinical results. Int J Prosthodont 2013;26:164–171.
4. Meyer G, Ahsbahn S, Kern M, et al. S3 Guideline 083/012: Vollkeramische Kronen und Brücken. [Full ceramic crowns and bridges] Current status 08/2014. Available at: http://www.awmf.org/leitlinien/detail/ll/083-012.html. Accessed 6 February 2017.
5. Kerschbaum T, Faber FJ, Noll FJ, et al. Komplikationen von Cercon-Restaurationen in den ersten fünf Jahren. Dtsch Zahnarztl Z 2009;64:81–89.
6. Monaco C, Caldari M, Scotti R. Clinical evaluation of 1,132 zirconia-based single crowns: a retrospective cohort study from the AIOP clinical research group. Int J Prosthodont 2013;26:435–442.

7. Örtorp A, Kihl ML, Carlsson GE. A 5-year retrospective study of survival of zirconia single crowns fitted in a private clinical setting. J Dent 2012;40:527–530.
8. Kokubo Y, Sakurai S, Tsumita M, Ogawa T, Fukushima S. Clinical evaluation of Procera AllCeram crowns in Japanese patients: results after 5 years. J Oral Rehabil 2009;36:786–791.
9. Molin MK, Karlsson SL. Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 2008;21:223–227.
10. Wolleb K, Sailer I, Thoma A, Menghini G, Hammerle CH. Clinical and radiographic evaluation of patients receiving both tooth- and implant-supported prosthodontic treatment after 5 years of function. Int J Prosthodont 2012;25:252–259.
11. Raigrodski AJ, Yu A, Chiche GJ, Hochstedler JL, Mancl LA, Mohamed SE. Clinical efficacy of veneered zirconium oxide-based posterior partial fixed dental prostheses: five-year results. J Prosthet Dent 2012;108:214–222.
12. Schmitt J, Goellner M, Lohbauer U, Wichmann M, Reich S. Zirconia posterior fixed partial dentures: 5-year clinical results of a prospective clinical trial. Int J Prosthodont 2012;25:585–589.
13. Sorrentino R, De Simone G, Tete S, Russo S, Zarone F. Five-year prospective clinical study of posterior three-unit zirconia-based fixed dental prostheses. Clin Oral Investig 2012;16:977–985.
14. Farbe und Glanz. Konica Minolta Sensing. Available at: http://www2.konicaminolta.eu/eu/Measuring/pcc/de/part3/02.html. Accessed: 5 March 2016.
15. Della Bona A, Nogueira AD, Pecho OE. Optical properties of CAD-CAM ceramic systems. J Dent 2014;42:1202–1209.
16. Ilie N, Stawarczyk B. Quantification of the amount of light passing through zirconia: the effect of material shade, thickness and curing conditions. J Dent 2014;42:684–690.