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Update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" – current evidence-based recommendations

Summary: In the update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" (AWMF Reg. No. 083-012) published in June 2021, new scientific evidence was incorporated into the guideline first published in 2014. The guideline established a broadly consented, evidence-based framework within which the use of tooth-supported all-ceramic restorations offers comparable long-term clinical outcomes to metal-based crowns and fixed dental prostheses (FDPs).

In the updated version (version 2.0), all chapters have been reviewed with regard to new research findings, backgrounds have been newly discussed, and numerous recommendations have been updated with regard to indications and localization. In the process, the recommendation grading of individual materials was adjusted on the basis of new literature. Recommendations on materials that are no longer on the market (alumina ceramics) were removed and recommendations on new materials and applications were added (zirconium oxide ceramics [3Y-TZP] monolithic; zirconium oxide ceramics [4Y-, 5Y-TZP and combinations with these]; resin-matrix ceramics; lithium silicate/phosphate glass-ceramics). Recommendations on endocrowns were also made for the first time. In addition, the questions regarding the treatment of bruxism patients with all-ceramic restorations as well as material-specific manufacturing recommendations were re-evaluated.

The main recommendations are listed in this article, the key innovations are emphasized, and the considerations of the guideline group in arriving at the recommendations are summarized. All recommendations as well as complete references can be found in the long version of the German S3 guideline [11].

Key words: guideline; prosthodontics; crowns; fixed dental prostheses; all-ceramics; survival rates; restorative materials

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Citation: Jerg A, Spitznagel F, Ahlers O, Beck J, Beuer F, Struck R, Christelsohn K, Reiss B, Güth JF, Kern M, Gierthmühlen P: Update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" – current evidence-based recommendations. Dtsch Zahnärztl Z Int 2021; 3: 248–256

DOI.org/10.3238/dzz-int.2021.0031

1 Introduction

The reasons for preparing and updating the guideline "All-ceramic single crowns and fixed dental prostheses" were the continuous further development in the field of all-ceramic materials and the continuing prevalence of severely destroyed and missing teeth requiring treatment with crowns and fixed dental prostheses (FDPs) [28]. The guideline focuses on tooth-supported crown and tooth-supported FDPs; partial crowns, inlays, onlays and repositioning onlays are not covered by the guideline.

All tooth-colored materials must compete with metal-based restorations, which are still considered as the gold standard for fixed restorations [42, 66, 88]. Since the clinical performance of tooth-colored materials strongly depends on the indication, the materials used and their processing [18, 39, 44, 68, 69], evidence- and consensus-based recommendations have been made which take these influencing factors into account.

The recommendations of the guideline refer to the survival and complication rates of all-ceramic crowns and fixed dental prostheses, which have been evaluated based on long-term clinical studies and thus serve as a decision criterion. This provides the patient and restorative treatment team with therapeutic safety, and complications can be avoided.

The recommendations of the present update were based on a new systematic literature search, which included 24 new studies. The content of the new literature was evaluated regarding the survival rates of the restorations and the complications that occurred, as well as methodologically with evidence levels (Table 1). Depending on the study quality, the number of studies and the study results, recommendations of varying strength (Table 2) emerged from this, which were adopted in a structured consensus procedure (for consensus strengths, see Table 3).

Evidence Assessment	
1++	High quality meta-analyses, systematic literature reviews of randomized controlled trial (RCT) articles, or RCTs with a very low risk of bias
1+	Well-conducted meta-analyses, systematic literature reviews, or RCTs with a low risk of bias
1–	Meta-analyses, systematic literature reviews, or articles on RCTs with a high risk of bias
2++	High quality systematic literature reviews or articles on case-control studies or cohort studies
2+	Well-conducted case-control studies or cohort studies with a low risk of influence or bias and a moderate probability that the associations are causal, and well-conducted case series with an acceptable risk of bias
2–	Articles on case-control studies with a high risk of influence or bias and a significant risk that the associations are not causal
3	Articles on non-analytical studies, e.g. case presentations or case series
4	Expert opinion

Table 1 Qualitative evidence assessment (LoE = Level of Evidence) modified and deviating from SIGN 50 (Scottish Intercollegiate Guidelines Network).

	Evidence strength	Recommendation	Recommendation against intervention	Description
A	high	should ↑↑	should not ↓↓	Strong recommendation
B	moderate	should ↑	should not ↓	Recommendation
0	low	may be used/ may be indicated =	may not be used =	Recommendation open

Table 2 Scheme of recommendation grading according to AWMF

2 Fundamentals of materials science

2.1 Material classes

Silicate ceramics consist of a glass matrix with embedded crystals. A classic representative is feldspar ceramic. Silicate ceramics can be used as veneering ceramics, but can also be pressed or milled from industrially manufactured blocks [18, 89]. Lithium disilicate ceramics and lithium silicate ceramics containing zirconium oxide have an increased flexural strength of up to 400 MPa compared to other silicate ceramics [25, 89].

Oxide ceramics do not have a glass matrix, but usually consist of zirconia polycrystals stabilized with yttria [8, 55]. The flexural strength of classic first-generation tetragonal zirconia doped with 3 mol% yttrium is significantly increased to over 1000 MPa, but light transmission is limited and these materials are thus more opaque, making them suitable primarily as framework materials for manual veneering [72, 73]. With the novel generations of zirconium oxides available on the market, greater translucency is to be achieved by varying the yttria content among other modifications [91]. This is also the reason for the designations 3Y-, 4Y- or 5Y-TZP used in the guideline (3 = 3 mol-%; 4 = 4 mol-%; 5 = 5 mol-%; Y = yttrium oxide; TZP = "tetragonal zirconia polycristal"). More translucent zirconium with an

Classification of consensus strength	
Strong consensus	Consent from >95 % of the participants
Consensus	Consent from >75–95 % of the participants
Majority approval	Consent from >50–75 % of the participants
No consensus	Consent from <50 % of the participants

Table 3 Classification of consensus strength according to AWMF

increased content of yttrium has a larger cubic phase fraction and is offered by many manufacturers for monolithic use [91]. It should be noted that these modifications are at the expense of the mechanical properties and thus the range of indications can differ significantly depending on the zirconium material, generation and manufacturer [22]. Recently, multilayer blocks with a color and translucency gradient have also been offered for monolithic use, in which, for example, combinations of mechanically more stable 4Y-TZP and 5Y-TZP, which is optically more translucent in the incisal region, are used [2].

Resin-matrix ceramics (RMC) can be divided into two subgroups: CAD/CAM composites with dispersed fillers as well as a predominantly organic phase and polymer-infiltrated ceramics with a dominant inorganic phase [9, 38]. Depending on the material, both groups are intended for various single-tooth restorations; they are not approved by the manufacturers for FDPs due to their limited flexural strength of 150–240 MPa [9, 36].

2.2 Material selection

In addition to a range of silicate ceramics, various types of zirconium ceramics (3Y-TZP, 4Y-TZP, 5Y-TZP) are available for all-ceramic single crowns and FDPs – each as an alternative to metal-based restorations. A trend towards monolithic materials can be observed, which allows less invasive preparation forms due to lower material thicknesses, preserves tooth structure, and expands the range of indications for all-ceramic restorations [4, 86].

The decision for a material depends on both material-related (esthetic potential, mechanical properties, abrasion behavior of the material and the antagonist) and clinical factors (degree of destruction of the tooth, cementation options, functional aspects). The clinical long-term success is closely linked to the correct indication, the experience and knowledge of the restorative team, as well as suitable cementation and an adequate occlusal concept.

3 Material recommendations

Table 4 provides an overview of the all-ceramic materials that are recommended or rejected for specific indications and localizations. Background information on the recommendations is provided briefly below and in detail in the long version of the guideline.

3.1 All-ceramic single crowns in the anterior region

For the fabrication of all-ceramic single crowns in the anterior region, veneered lithium disilicate ceramics or veneered zirconium oxide ceramics (3Y-TZP) should be used. The recommendations have been strengthened compared to the first version of the guideline, as restorations made of these veneered materials, according to recent data, have very good survival rates of 86.1–100 % after 5–10 years for lithium disilicate ceramics [20, 74, 80, 83–86] and 88.5–100 % after 5 years for zirconium oxide ceramics [13, 21, 33, 45, 48, 50]. Chipping as a technical complication of veneered zirconium crowns has been reported with a frequency of 1.9–8.1 % after 5 years [21, 48].

An open recommendation is made for the monolithic use of lithium disilicate ceramics and zirconium oxide ceramics (3Y-TZP) due to the rather low level of evidence: The materials can be used. Short-term data after an observation period of 3 years show promising results with survival rates of 100 % for monolithic crowns made of zirconium oxide ceramic [4].

Monolithic (leucite-reinforced) silicate ceramics provide survival rates of 100 % and 98.9 % in the only two available studies after observation periods of 5 and 11 years, respectively [18, 90], so they should be used. Limited data are available for monolithic feldspar ceramics, so they can be used in the context of an open recommendation.

No statement can be made at present on newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP), RMC and lithium silicate/phosphate glass-ceramics due to a lack of clinical data.

3.2 All-ceramic single crowns in the posterior region

Veneered or monolithic lithium disilicate ceramics should be used for the fabrication of all-ceramic single crowns in the posterior region. Both chairside CAD/CAM-fabricated monolithic lithium disilicate ceramic crowns and laboratory press-fabricated monolithic lithium disilicate ceramic crowns and veneered lithium disilicate ceramic restorations show good long-term results after 8.7–11 years with survival rates of 83.5–98.2 % [20, 41, 60, 74, 80, 83–86]. Due to the recent good data the recommendation could be strengthened compared to the first version of the guideline.

Monolithic (leucite-reinforced) silicate ceramics and veneered zirconia ceramics should be used, monolithic feldspar ceramics and monolithic zirconium oxide ceramics can be used. The recommendations for veneered and monolithic zirconium oxide ceramics have been strengthened accordingly. Monolithic (leucite-reinforced) silicate ceramics showed survival rates of 97.5 % and 99 % after 5 years, respectively [18, 90]. New long-term data are available for veneered zirconium oxide ceramics with good 5-year survival rates of 94–98.1 % [21, 33, 46, 48, 62, 87] with moderate chipping rates of 1.9–10 % after 5 years [21, 46, 48, 62]. Monolithic feldspar ceramics had

Figure 1 Clinical case a) Initial situation with teeth 12, 22 and 23 to be extracted. b) Treatment completion with FDP 11 to 13 made of vestibular veneered zirconium oxide ceramic, single crown 21 made of lithium disilicate ceramic. 22 and 23 are restored implant-prosthetically with an implant crown 23 with mesial cantilever 22 made of vestibular veneered zirconium oxide ceramic.

posterior survival rates of 99.6 % and 94.7–95 % after 7 and 12 years, respectively, in a cohort study and a case series [15, 52].

Expert consensus was expressed for monolithic zirconium oxide ceramics based on short-term data with 100 % survival after 3 years [4].

Due to insufficient scientific long-term data for newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP), RMC and lithium silicate/phosphate glass-ceramics, no statement for a recommendation of their use in the posterior region can be made. Short-term studies with 2–3 years follow-up show survival rates of 92.9–96.8 % for polymer-infiltrated ceramics in the posterior region [7, 79].

3.3 All-ceramic endocrowns

Endocrowns were included in the guideline for the first time. Monolithic feldspar ceramics and monolithic as well as veneered lithium disilicate ceramics can be used. Initial data, however with a rather low level of evidence, show survival rates of 75–99.9 % after 7–12 years in the posterior region [3, 15, 51]. No evidence-based statement can yet be made on other all-ceramic materials when used as endocrowns.

3.4 All-ceramic 3-unit fixed dental prostheses in the anterior region

Veneered zirconia ceramics (3Y-TZP) should be used for the fabrication of all-ceramic 3-unit FDPs in the anterior region (Figure 1). This recommendation has been strengthened compared to the previous version of the guideline due to the large amount of new data. For example, after up to 7 years of follow-up, survival rates are 88.8–100 % [5, 33, 37, 43, 75, 90]. Data on technical complications are heterogeneous with chipping rates of 24.2 % at 5 years [5] and 7.4 % at 7 years [75].

Monolithic zirconium oxide ceramic (3Y-TZP) can be used and is thus recommended for this indication for the first time, but only on the basis of expert consensus. Clinical data after an observation period of 3 years show promising results with survival rates of 96.7 % for monolithic FDPs in the anterior and posterior region [23].

Monolithic and veneered lithium disilicate ceramics can also be used, since clinical data for veneered lithium disilicate ceramics in the newly considered literature show survival rates of 89.7 % and 86.1 % after 5–10 years, respectively [83]. In one study monolithic lithium disilicate ceramics have been followed up for longer with survival rates of 87.9 % after 10 years [32], that diminished however to only 48.6 % after 15 years [19].

No statement can be made on newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP) due to a lack of clinical data.

3.5 All-ceramic 3-unit fixed partial dentures in the posterior region

Veneered zirconium oxide ceramics (3Y-TZP) should be used for the fabrication of all-ceramic 3-unit FDPs in the posterior region. This recommendation has been strengthened compared to the previous version of the guideline. After 5 years, survival rates are 90–97 % [5, 33, 43, 58, 69, 77, 90], and after 10 years, survival rates are 70.3–91.3 % [27, 53, 63, 64]. Since ceramic fractures such as chipping occur in up to 31 % of veneered zirconium oxide ceramic FDPs after 10 years, FDPs made of monolithic zirconium oxide ceramics are an alternative that can be used. Short-term data, a documented case series and initial empirical experience (case study in Figure 2) with monolithic and solely vestibular veneered FDPs made of zirconium oxide ceramics are promising: They show a survival rate after 3 years of 96.7 % for monolithic and 93.8 % and a chipping rate of 8.8 % for purely vestibular veneered FDPs [23], but still only receive a recommendation as an expert consensus.

Veneered and monolithic FDPs made of lithium disilicate ceramics show lower survival rates of 48.6–51.9 % after 10–15 years and 63.0–51.9 % after 5–10 years, respectively [19, 83], but can also be used within the manufacturer's indication. This rules out replacement of the 2nd premolar as well as the molars.

3.6 All-ceramic multi-unit/span fixed dental prostheses

The clinical data is not sufficient to recommend multi-unit/span all-ceramic FDPs. This was already the case when the first version of the guideline was prepared. The few existing studies on veneered zirconium oxide ceramics (3Y-TZP) report that there are increased chipping rates [63] at 35 % after 10 years and increased failures [71] with long-span FDPs. Survival rates are 75 % after 10 years for FDPs with up to 4-units [63] and 88.8 % after 7 years for FDPs with up to 6-units [75].

Indication	Localization	Material	LoE	Recommen-dation level	Recommen-dation level
Single crown	Anterior tooth region	Silicate ceramic (leucite reinforced), monolithic	2+	↑	B
		Feldspar ceramic, monolithic	4	=	0
		Lithium disilicate ceramic, veneered	2+	↑↑	A
		Lithium disilicate ceramic, monolithic	4	=	0
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region	Silicate ceramic (leucite reinforced), monolithic	2+	↑	B
		Feldspar ceramic, monolithic	2+	=	0
		Lithium disilicate ceramic, veneered	2+	↑↑	A
		Lithium disilicate ceramic, monolithic	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑	B
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
Endocrown	Posterior tooth region	Feldspar ceramic, monolithic	2+	=	0
		Lithium disilicate ceramic, veneered/ monolithic	4	=	0
3-unit FDP	Anterior tooth region	Lithium disilicate ceramic, veneered	2+	=	0
		Lithium disilicate ceramic, monolithic	4	=	0
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region	Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑	B
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region, replacement of the 1st premolar	Lithium disilicate ceramic, veneered/ monolithic	2+	=	0
	Posterior tooth region, replacement of the 2nd premolar and molar replacement	Lithium disilicate ceramic, veneered/ monolithic	2+	↓↓	A
Resin-bonded FDP	Anterior tooth region	Zirconium oxide ceramic, veneered	2+	↑↑	A
Inlay-retained FDP	Posterior tooth region	Lithium disilicate ceramic, monolithic	2+	↓↓	A
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↓↓	A

Table 4 Evidence- and consensus-based material recommendations. LoE = Level of Evidence, FDP = fixed dental prostheses

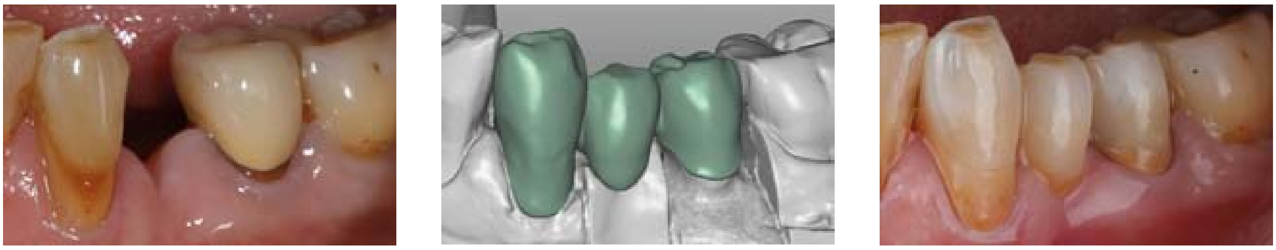

Fig. 1 + 2: P. Gierthmühlen

Figure 2 Clinical case of an all-ceramic 3-unit posterior FDP made of monolithic zirconia. a) initial situation, b) fully anatomical digital design, c) treatment completion

3.7 All-ceramic single retainer resin-bonded fixed dental prostheses in the anterior region

For the replacement of missing anterior teeth with all-ceramic single retainer resin-bonded FDPs, veneered zirconium oxide ceramics should be used, since these restorations show survival rates of 98.2 % after 10 years [31] and thus appear to be superior even to metal-ceramic resin-bonded FDPs [47, 57]. The recommendation was strengthened compared to the first version of the guideline.

3.8 All-ceramic single retainer resin-bonded fixed dental prostheses in the posterior region

Since no clinical data is available for the use of all-ceramic single retainer resin-bonded FDPs in the posterior region, their use cannot be recommended. This was already the case in the previous version of the guideline.

3.9 All-ceramic inlay-retained fixed dental prostheses in the posterior region

Lithium disilicate ceramics and veneered zirconium oxide ceramics should not be used for the fabrication of inlay-retained FDPs in the posterior region, since clinical data show low survival rates of 22 % after 15 years for lithium disilicate ceramics [1] and 12.1 % after 10 years for veneered zirconium oxide ceramics [59]. The negative recommendation for inlay-retained FDPs made of veneered zirconium ceramics was made for the first time on the basis of the new data. Approaches to design inlay-retained FDPs of veneered zirconium oxide ceramic with an additional wing resulted in a better survival rate of 95.8 % after 5 years [6]. Nevertheless, the data for other preparation forms and materials are not sufficient for a recommendation.

4 Bruxism and all-ceramics

The following strong expert consensus (100 % agreement) was reached on the question of whether all-ceramic restorations show comparable long-term results to metal-ceramic restorations in bruxism patients requiring crowns and FDPs:

Based on the current clinical study situation, the question cannot be conclusively evaluated [70], as a large number of studies explicitly excluded patients with bruxism [1, 5, 13, 15–17, 19, 20, 24, 27, 34, 35, 39, 46, 48, 53, 54, 59–65, 67, 69, 76, 78, 83, 84] and only a few studies explicitly included bruxism patients [2, 45, 49, 56, 74].

However, the clinical determination of whether patients suffer from bruxism has only been systematized in recent years. According to the S3 guideline Diagnostics and treatment of bruxism (AWMF register number 083–27), reliable detection of bruxism has so far only been possible by means of polysomnographic examinations [10]. Therefore, in practice, diagnosis remains limited to procedures that allow the diagnosis of "probable bruxism" but are associated with residual uncertainty [10]. In addition, the diagnosis of "bruxism" may change over the service time of the restorations.

Basically, the increased mechanical stress in patients with sleep and/or awake bruxism is a risk factor for all dental restorations, and therefore restorative treatments are associated with increased biological and technical risks [10].

In patients with probable bruxism, it is useful to check whether the treatment with metal restorations is possible and acceptable. If all-ceramic restorations are used, treatment with monolithic restorations is also an alternative. It is also important to inform the patient about the increased risk of loss due to bruxism and any restrictions on the indication provided by the manufacturer.

Protection against mechanical failure of the restorations can be provided by strict treatment protocols, careful analysis of function, and inclusion of an occlusal/stabilization splint.

5 Material-specific manufacturing recommendations

The following expert consensus was reached on the question of which material-specific manufacturing recommendations can be made: The preparation for all-ceramic crowns and FDPs with crown anchors should follow the proven preparation guidelines of the retention and resistance form [30] (consensus).

Minimally invasive preparation designs with 1 mm occlusal reduction were evaluated in only 2 studies: for monolithic and partially veneered crowns made of zirconium oxide ceramics in the anterior and posterior regions, an occlusal reduction of at least 0.5 mm was prepared in one study, with short-term survival rates of 98.5–100 % after 3 years [4]. For lithium disilicate ceramic crowns, an occlusal or incisal reduction of 0.2–2 mm was performed, and the survival rate in this study was 96.1 % after 9 years [86]. However, since no data beyond this are available for minimally invasive preparation forms for crowns and FDPs, no recommendation can be given (strong consensus).

Manufacturer's instructions and specifications of the Medical Devices Regulation must be strictly followed without fail (strong consensus). In addition, minimum layer thicknesses, connector cross-sections, framework design, processing, material treatment and the type of cementation must be observed (strong consensus). For example, subsequent grinding, surface roughness or temporary cementation may have a negative impact on the long-term survival of the restorations.

"A large proportion of failures were due to inadequate material dimensioning or other material failure such as chipping [12, 15, 21, 27, 46, 48, 53, 59, 62–64] and complete ceramic fractures [1, 17, 19, 26, 29, 39, 40, 45, 46, 59, 68, 69, 82]. Due to the potential risk of chipping, special attention should be paid to the type of veneer (full/partial)" [11].

6 Notes on the materials

- The manufacturer-dependent differences in composition within a material class as well as production-related features can lead to clinically relevant differences in the quality of results, without this necessarily being reflected in the literature.
- Regarding technical complications and the invasiveness of the preparation, the following should be considered: full veneering, purely vestibular veneering (watch glass setting) and veneering only in the incisal area ("cut-back").
- After any grinding measures on all-ceramic restorations, they must be polished again to a high gloss. This applies to all all-ceramic restorations. Otherwise, the adjusted area may be a predilection site for a subsequent ceramic fracture and promote wear of the antagonist [14, 81].

7 Conclusion

All-ceramic single crowns and FDPs provide good long-term results in terms of survival and freedom from complications if the indications are correct, the appropriate materials are selected and the procedure is carried out correctly. In particular, lithium disilicate ceramics and veneered zirconium oxide ceramics have proved very successful for anterior and posterior single crowns, 3-unit anterior FDPs and anterior resin-bonded FDPs. Monolithic zirconium oxide ceramics (3Y-TZP) can be used, but no statement can yet be made on newer materials such as translucent zirconia ceramics due to a lack of long-term data. All-ceramic multi-unit/span FDPs and all-ceramic inlay-retained FDPs are not recommended.

Conflict of interest

For possible conflicts of interest, see pp. 152–154 of the Guideline Report at: https://www.awmf.org/uploads/tx_szleitlinien/083–012m_S3_Vollkeramische_Kronen_Brücken_2021–06.pdf

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