Testing a Multistage Rating Scale for Clinical Evaluation of All-Ceramic Surfaces

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Purpose: This study tested the applicability of a multistage rating scale based on modified California Dental Association (CDA) criteria and the original criteria of the CDA for surface evaluation of all-ceramic restorations with the use of dental stone replicas, photographs, and scanning electron microscopy (SEM). ***Materials and Methods:*** Two examiners clinically evaluated 105 all-ceramic restoration units in the posterior region after a mean observation period of 42.2 months; the examiners employed the CDA criteria and a detailed six-stage rating scale. In addition, standardized photographs and gypsum stone and epoxy replicas based on impressions were analyzed blindly using the same rating scales and examiners. SEM images of gold-coated epoxy replicas enabled indirect ceramic surface evaluation, serving as the gold standard to control indirect evaluation and clinical findings. The Cohen kappa was applied to test for concordance; intraclass correlations and Spearman rank correlations were calculated. ***Results:*** Statistically significant rating correlations of the clinical situation, photographs, and stone replicas with the SEM photographs were generated from both evaluation systems. With the use of the multistage rating scale, the highest rating correlation was found for stone replica–SEM ($r = 0.61$, $P < .001$), and the lowest for clinical photography–SEM ($r = 0.5$, $P < .001$). ***Conclusions:*** A multistage rating scale based on modified CDA criteria is reliable for precise assessment of in vivo ceramic surface alterations. Stone replicas were found to be better-suited than photographs for the assessment of all-ceramic surface alterations and confirmation of clinical ratings. *Int J Prosthodont 2011;24:576–581.*

In recent years, clinicians and their patients have shown interest in tooth-colored and metal-free restorations. The rising demand for all-ceramic restorations may be attributed to their high biocompatibility and enhanced esthetics.[1] Framework fracture of all-ceramic core materials, particularly zirconia, is rather rare, while chipping of the veneering ceramic of zirconia-based crowns and fixed dental prostheses (FDPs) is the most frequently reported technical complication.[2–4] Therefore, the primary objective of clinical follow-up studies on all-ceramic restorations is to assess parameters such as surface texture and to detect porcelain chipping and attrition.[5,6] Suggestions that clinical evaluations of restorations should be based on precisely specified criteria with the use of simple nominal scales[7,8] led to the development of the United States Public Health Service criteria.[9,10] Modifications of these criteria have improved their limited sensitivity for modern restorative materials, for example, in the diagnosis of caries.[9,11] In 2007, new clinical criteria for the evaluation of restorations were published[6,12]; however, both systems of criteria focus on direct and indirect restorations, such as onlays and partial crowns.

Practitioners frequently use the standards of quality of dental care from the California Dental Association (CDA) for assessment of conventional prosthetic restorations.[4,13–15] Unfortunately, the CDA criteria lack the ability to differentiate between fracture and attrition of the ceramic veneering; consequently, the survival and success rates of all-ceramic restorations do not adequately reflect ceramic surface alterations during clinical function. This shortcoming is obvious when clinical studies on all-ceramic restorations are consulted, and the field lacks consensus on the choice of evaluation criteria for the assessment of ceramic surface alterations.[4,5,14,16–19] Therefore, commonly used detailed criteria for the clinical analysis of all-ceramic surfaces would be beneficial for direct comparison of clinical findings.

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Table 1 Quality Evaluation Criteria According to the CDA

Rating	Surface
Satisfactory	
Excellent (Romeo)	Surface of restoration(s) is smooth, no irritation of adjacent tissue is occurring
Acceptable (Sierra)	Surface of restoration is slightly rough or pitted, can be polished
Not satisfactory	
Reparable (Tango)	Surface is grossly irregular, not related to anatomy, and not subject to correction
Irreparable (Victor)	Surface is fractured, there are gross porositiesin the crown

Table 2 ACE Criteria Based on Modified CDA Criteria

Surface	Code
Satisfactory	
Excellent	
Excellent	1
Acceptable	
Slight occlusal roughness	2
Minor chipping (no alteration of anatomy, can be polished)	3
Not satisfactory	
Reparable	
Major chipping (not related to anatomy)	4
Pronounced occlusal roughness with alteration of occlusal anatomy	5
Irreparable	
New reconstruction is needed	6

Indirect methods that complement direct clinical examinations, validating findings and reducing bias, are recommended.[6] Photographs and replica casts of the restorations are often used for documentary purposes and follow-up comparisons.[6] However, the reliability of these indirect methods for accurate assessment of all-ceramic surface evaluations is not sufficiently demonstrated. Replicas for scanning electron microscopy (SEM) may be the most precise indirect appliance for monitoring intraoral processes, ceramic failure analysis of restorations, and routine examination of ceramic surface alterations.[5,14]

This study tested the applicability of a more detailed rating scale based on modified CDA criteria for all-ceramic surface evaluation (ACE) and compared this applicability with the widely used CDA evaluation system. Both systems were hypothesized to exhibit equivalent reliability. Furthermore, the added benefits of the inclusion of indirect methods, including dental stone casts, photography, and SEM using the replica technique, were assessed.

Materials and Methods

The clinical investigation was conducted at Dental Clinic 2-Prosthodontics and approved by the ethical committee of the Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany (ethical committee IRB no. 2832). Two examiners clinically evaluated the ceramic veneering of 18 three-unit and 9 four-unit all-ceramic FDPs, as well as 15 single crowns in the posterior region. The mean observation period for the zirconia-based restorations was 42.2 months. The ceramic surface of each FDP unit was rated separately; combined with the single crowns, a total of 105 restoration units were evaluated. The examiners possessed at least 5 years of experience in prosthetic dentistry and were not involved in the restorative treatment. Prior to quality assessment, both examiners were trained in the CDA and ACE criteria with standard sets of photographs and dental stone replicas as reference instruments for illustration of each rating.

Both evaluation systems were divided into two outcome options: satisfactory and not satisfactory (Tables 1 and 2). Two subratings are available within the two main categories in the CDA evaluation system (Table 1) and three subratings in the ACE rating scale (Table 2). A dental mirror and dental probe were used for clinical assessments. The surface was rated first according to the CDA quality evaluation criteria and second with the ACE rating scale. Examiner

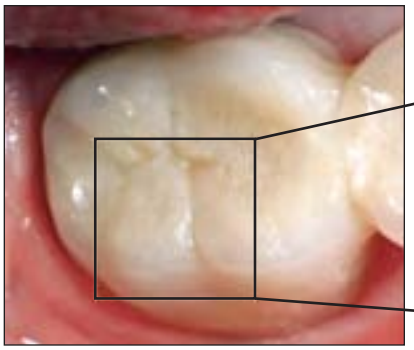

Fig 1a The rough surface of the ceramic veneering is hardly detectable with standardized photography. The ceramic veneering was assessed as Sierra (CDA) and code 2 (ACE).

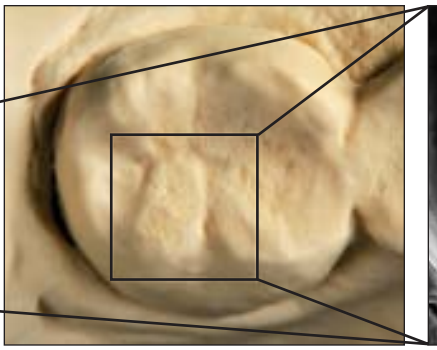

Fig 1b Dental stone replica with ceramic veneering rated as Sierra (CAD) and code 2 (ACE).

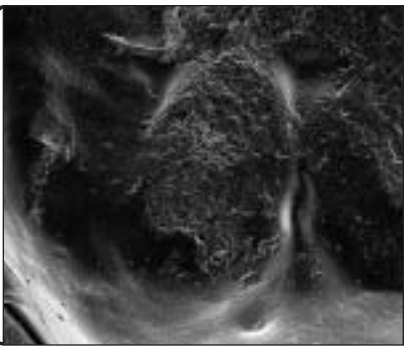

Fig 1c Corresponding SEM view with obvious occlusal roughness of the ceramic veneering rated as Sierra (CDA) and code 2 (ACE).

disagreement was resolved by reexamination and consecutive discussion. In the case of a rough surface and a chipping fracture in the same restoration, the chipping was predominant for the rating.

After air-drying the ceramic surfaces, standardized photographs (DG Macro, 105 mm, F 2.8, EX Sigma; Nikon D100, Nikon) of each restoration from the occlusal and lateral aspects were obtained (Fig 1a). For silicone impressions, ceramic surfaces were cleaned with alcohol, rinsed, and air dried. A preliminary silicone impression (Panasil binetics putty soft, Kettenbach) was made with single-use trays (Breciform D, Bredent Medical) and cut according to established procedures for the two-stage putty-and-wash technique.[20] A light-bodied silicone (Panasil initial contact x-light, Kettenbach) was dispensed onto the ceramic surfaces, and the preliminary impression was repositioned.

Impressions were poured with epoxy resin (Alpha Die top, Schuetz Dental) and gold-coated for SEM analysis. Two examiners, who were not involved in the previous examination of the restorations, independently rated the SEM-imaged surfaces with the CDA and ACE rating scales. These examiners had been trained with standard sets of SEM images to align each subrating. The rating of SEM images was regarded as the gold standard.

For dental stone replicas, a single-step putty-wash impression technique was performed. Coded photographs and dental stone replicas were evaluated with the CDA and ACE rating systems at 3-month intervals to minimize recognition of the restoration by the examiners. As with the clinical examinations, concordance of opinion was reached by reevaluation of the photographs, dental stone replicas, or SEM images, followed by consecutive discussion.

Statistical analysis was performed using SPSS (2003, IBM), SAS (2005, SAS), and R (R-Cran, R Development Core Team) software. To test for concordance, the Cohen kappa was applied (exact calculation)[21]; 95% confidence intervals were also determined.[22] Accordingly, kappa values below 0.20 were evaluated as "slight," kappa values between 0.21 and 0.40 as "fair," and kappa values between 0.41 and 0.60 as "moderate." Kappa values above 0.60 were labeled as "substantial concordance." In addition, intraclass correlations and their 95% confidence intervals were calculated for descriptive reasons,[21] as were Spearman rank correlations.[23] Comparison of correlation coefficients within dependent samples was performed.[21] P values ≤ .05 were considered to denote an exploratory significant difference or concordance.

Results

Statistically significant rating correlations were detected for both evaluation systems of the clinical situation, photographs, dental stone replicas, and SEM (Table 3). For both evaluation systems, the correlation of photographs with the SEM was lowest (CDA: $r = 0.51$, $P < .001$; ACE: $r = 0.50$, $P < .001$). Clinical examination paired with SEM resulted in the highest absolute concordance for both the CDA (69.5%) and ACE (67.6%) evaluation systems. The photographs and dental stone replicas were least correlated with the gold standard (63.8%) in regard to absolute concordance. When comparing the correlations resulting from the CDA and ACE methods, no significant differences were identified for the clinical situation (CDA: $r = 0.62$, ACE: $r = 0.65$; $P = .191$), photographs (CDA: $r = 0.53$, ACE: $r = 0.49$; $P = .847$), or the dental stone replicas (CDA: $r = 0.65$, ACE: $r = 0.67$; $P = .256$).

Table 3 Rating Correlations and Concordance Among Clinical Examinations, Dental Stone Replicas, Photographs, and SEM

	CDA		ACE	
Correlation with SEM	Correlation	Concordance	Correlation	Concordance
Clinical examination	$r = 0.59$ ($P < .001$)	69.5%	$r = 0.58$ ($P < .001$)	67.6%
Dental stone replica	$r = 0.60$ ($P < .001$)	65.7%	$r = 0.61$ ($P < .001$)	63.8%
Photography	$r = 0.51$ ($P < .001$)	64.8%	$r = 0.50$ ($P < .001$)	63.8%

Table 4 Concordance Test for Dental Stone Replicas and SEM as Evaluated by the CDA System*

Dental stone replica	SEM				
	Romeo	Sierra	Tango	Victor	Total
Romeo	45	26	0	0	71
Sierra	3	15	3	0	21
Tango	1	3	9	0	13
Victor	0	0	0	0	0
Total	49	44	12	0	105

Outlined boxes indicate the number of ratings with absolute concordance (n = 69).
*See Table 1 for CDA rating explanation.

Table 5 Concordance Test for Dental Stone Replicas and SEM as Evaluated by the ACE System*

Dental stone replica	SEM						
	1	2	3	4	5	6	Total
1	45	26	0	0	0	0	71
2	3	12	1	0	2	0	18
3	0	1	1	1	0	0	3
4	0	0	0	6	0	0	6
5	1	3	0	0	3	0	7
6	0	0	0	0	0	0	0
Total	49	42	2	7	5	0	105

Outlined boxes indicate the number of ratings with absolute concordance (n = 67).
*See Table 2 for ACE rating explanation.

Discussion

The CDA and ACE evaluation systems both resulted in similar statistically significant rating correlations between the SEM images and the clinical situation, photographs, and dental stone replicas. Therefore, the modified rating scale was as applicable to the clinical evaluation of all-ceramic restorations as the CDA scale.

The calibration of evaluators, choices of relevant criteria, and use of simple nominal scales are essential for clinical evaluation of restorations.[7] The possible interexaminer variations in diagnostic judgment limit the utility of clinical surveys and complicate the evaluation of clinical performance of all-ceramic restorations. Therefore, well-trained examiners are essential if the subjects are to be rated with any degree of consistency.[6,7] The clinical assessment of restorations should ideally be carried out by at least two independent and calibrated examiners who were not involved in the placement procedures.[6,9] To obtain a reliable reference and gold standard, SEM images of all restoration units were rated by two independent and trained examiners, as were the clinical, photography, and dental stone–based evaluations. Although the calibration of evaluators is highly recommended, correct implementation is difficult to achieve, costly, and time-consuming.[24,25]

Many studies lack a nominal rating scale, and ceramic surface alterations are inconsistently described with a range of precision: fractured veneering porcelain, minor or major chipping, or a precise description of the chipping extent and location.[5,19,26] Criteria of success are heterogenous. For example, Roediger et al[26] defined veneers as successful if they remained event-free without any clinical intervention during the evaluation period, while according to the United States Public Health Service criteria,[18] small chippings that can be polished are clinically acceptable. The absence of a common consensus on evaluation criteria compromises the comparability of clinical studies. The ideal rating system for the evaluation of ceramic surface alterations should include precise definitions of ceramic chippings and surface texture of the veneering, arranged in a staged scale that defines restoration success.

The CDA criteria are limited by a lack of differentiation between a rough occlusal surface and veneering fracture. On the other hand, the ACE rating scale (based on modified CDA criteria) has the potential

to differentiate surface alterations on the basis of occlusal roughness and chipping of the ceramic. The disadvantages of a more detailed rating scale may include major variation in ratings with inadequate reproducibility.[6,27] Although the ACE rating scale contained two more criteria, both evaluation systems resulted in comparable correlations in this study (Table 3). Therefore, it seems possible to achieve a more specific evaluation of all-ceramic surfaces using the ACE rating scale, with concurrent adequate repeatability.

Statistical analysis identified these correlation rates as significant, but high absolute concordance is lacking. Nevertheless, most of the discrepancy was recorded between the "excellent" and "slightly rough surface" subratings for all assessment modes and for both evaluation systems (Tables 4 and 5). For example, 26 restoration units were rated one subrating worse by SEM for a slightly rough surface, and 3 restorations with the dental stone replica were downgraded for both evaluation systems. Therefore, the assessment of all-ceramic surfaces with SEM seems to be more sensitive to surface alterations compared with dental stone replicas, as expected (see Figs 1b and 1c), although both ratings were within the "satisfactory" category.

Dental stone replicas achieved the highest correlation with SEM for both evaluation systems (CDA: $r = 0.6$, ACE: $r = 0.61$), possibly because both examination methods are based on indirect observation of replicas made by dental impressions.

The single-step impression technique was used for the stone replicas. In vivo studies confirmed single-stage techniques as a favorable three-dimensional reproduction of teeth and finishing lining compared to two-stage impressions.[28,29] Therefore, a sufficient accuracy of the stone replicas can be assumed. In recall appointments, stone replicas are beneficial to analyze surface texture and detect ceramic chippings. Furthermore, they can be used for three-dimensional scanning and quantitative measuring of ceramic wear.[30,31] Replica-based assessment is not affected by time or the limitations of direct intraoral examination, such as a compromised field of view, distance to the restoration, or salivation. The dental stone replica–SEM correlations generated were consistent with the clinical examination–SEM correlations (Table 3), possibly emphasizing the benefit of replicas in confirming the clinical evaluation.[6,12]

Since the lowest correlation was recorded between photographs and the gold standard (ACE: $r = 0.50$), the use of photography as a diagnostic method to improve clinical assessment of all-ceramic surfaces is highly questionable. It is difficult to standardize intraoral photography from all views without compromising quality; wet and therefore reflective ceramic surfaces are especially problematic for evaluation of restorations in the mandible. Nevertheless, photographic documentation for illustration of clinical findings is valuable.[32]

Qualitative fractography is commonly combined with SEM to understand the failure process in brittle restorative materials.[15,33,34] Hence, ceramic surface analysis with SEM was considered the gold standard in this study. To date, only a few publications have dealt with SEM for constant monitoring of all-ceramic surface alterations in clinical studies.[5,35]

The major concern of the SEM analysis was to view the ceramic surface texture most precisely. In the two-step putty-wash technique, the primary impression was filled with the light-body silicone and seated with low pressure. This approach generated a continuous film of the light-body silicone with high accuracy of veneering details.

Limitations of the replica technique for SEM analysis include inadequate impressions or imperfections resulting from inadequate epoxy pouring[36]—artifacts that may hinder sound assessment of ceramic surface alterations. In this study, ceramic surface alteration was more frequently assessed as a slightly rough surface by SEM than by dental stone replica (Tables 4 and 5). Therefore, indirect observations with SEM replicas will be most critical in the case of surface alterations. Chipping of the veneering ceramic can originate from a rough occlusal area; detection and quantification are therefore meaningful for prospective clinical studies.[18] Although time-consuming and costly, SEM of epoxy replicas may serve as a diagnostic tool for qualitative surface evaluation in clinical studies.[5] The high absolute concordance between ratings of the clinical examination and SEM by both evaluation systems (CDA: 69.5%, ACE: 67.6%) underlines the applicability and benefit of SEM analysis.

The development of a standardized protocol including the systematic use of dental stone replicas and SEM and consistent use of a detailed rating scale would greatly aid ceramic surface analysis in fixed prosthodontics, leading to an improvement in comparability of clinical studies and use in meta-analyses.

Conclusion

The current study demonstrated that a multistage rating scale based on enhancement of CDA criteria is a reliable instrument for precise assessment of all-ceramic surface alterations. The use of dental stone replicas and SEM images to evaluate all-ceramic surface alterations in clinical settings should therefore evolve from a supplemental documentation to a standard procedure.

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