ORIGINAL ARTICLE

Diagnostic performance of the universal visual scoring system (UniViSS) on occlusal surfaces

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Abstract Aim of this investigation was to evaluate the validity and reproducibility of the universal visual scoring systems (UniViSS) on occlusal surfaces in vitro. The validity study included 65 third molars. Following to reach a UniViSS consensus diagnosis for each surface, all teeth were histologically prepared and evaluated according to the newly developed caries-extension-index (CE-index). The reproducibility study consisted of 149 molars. These teeth were examined by two dentists and four students without any calibration training. In result, the CE-index provided the exact caries depth for each UniViSS criterion, which could further be associated with a distinct preventive or treatment strategy. The mean intra-/inter-examiner weighted Kappa values amounted to 0.685/0.551 (UniViSS/severity) and 0.628/0.542 (UniViSS/discoloration). The cumulative Logit-model underlined that UniViSS/severity criteria were more frequently reproduced in comparison to the UniViSS/discoloration criteria. In conclusion, this study on the diagnostic performance of UniViSS showed encouraging results and give valuable hints for future studies.

Keywords Dental caries · Visual examination · Validity · Reproducibility · Reliability · Caries detection · Caries diagnosis

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Introduction

Bearing in mind the high frequency of non-cavitated caries lesions in industrialised nations [1] and the fact that adjunct diagnostic methods, e.g., electrical resistance measurements, fibre-optical transillumination, quantitative light-induced fluorescence and laser fluorescence measurements, do not perform as satisfactorily on such lesions as was hoped [2–6], it became evident to improve visual caries detection and diagnostic methods. Recently introduced methods—criteria by Ekstrand et al. [7, 8] and Nyvad et al. [9], the International Detection and Assessment System [ICDAS, 10] and the Lesion Activity Assessment [11]—included non-cavitated caries lesions, but classify the caries process with only a few criteria. However, due to the fact that the clinical appearance of carious lesions—especially on occlusal surfaces—is complex, a limited set of criteria seems to be of importance for the dental epidemiologist [12, 13] but is unlikely to describe the appearance of

caries lesions as precisely as possible for the clinician. Furthermore, a detailed criteria set seems to be of importance to correlate each single diagnostic score with the caries depth as prerequisite to derive a distinct treatment decision in daily practise as well as to perform a caries monitoring in longitudinal studies. Therefore, our work throughout the last years aimed at systematising the clinical appearance of (non-cavitated) caries lesions with the universal visual scoring system (UniViSS, Fig. 1) in detail [14]. As new systems should fulfill current requirements for caries detection and diagnostic methods [15], there is a need to investigate validity and reproducibility. Consequently, within the first part of this investigation UniViSS should be validated according to the newly developed quantitative caries-extension-index (CE-index), which was inaugurated to determine of the caries depth for each diagnostic score separately. The second part aimed at determining the intra- and inter-examiner reproducibility of UniViSS and focused additionally on the identification of criteria, which were associated with a lower reproducibility to get information about difficulties, which have to be balanced during future calibration trainings.

Material and methods

Validity study

Sample size A sample of 65 sound and mostly non-cavitated third molars was selected from a pool of teeth extracted for surgical or orthodontic reasons. Molars with sealants, fillings, cavitations, approximal and/or buccal/lingual caries lesions, and developmental disorders were excluded from this study. After gross debris was removed, teeth were carefully cleaned. In order to prevent bacterial growth, all teeth were stored in separate containers with physiological saline containing 0.02% sodium azide. The used material was part of a report before [14].

Determination of the UniViSS consensus diagnosis All teeth were examined visually using dental magnifying glasses (twofold), the illumination of the dental unit light and compressed air. The (visual) inspection according to UniViSS [14] was carried out under the following principles: For caries lesions detectable in the fissure pattern, the severity (first signs, established lesion, microcavity or dentine exposure) and the discoloration (white, white-brown or brown) were assessed. As the activity assessment—the third step of UniViSS—has to be understood as clinical diagnosis; the present in vitro study design did not include this. Two dentists performed the visual inspection independently (J.K., K.B.). All diagnoses were counterchecked 1 week later to form a consensus diagnosis for each surface. In case
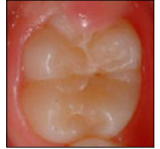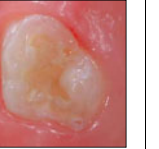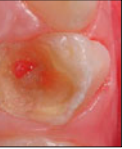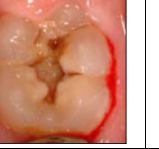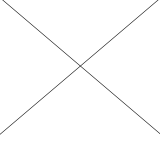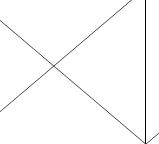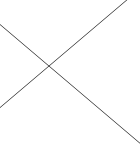
of different findings, both examiners discussed the discordant results and reached an agreement.

Histological validation Prior to the histological preparation, a colour photograph of each surface was taken to assist the histological examination later on. After separation of the root from the coronal part, each crown was embedded in cold-polymerising methacrylate (Kallocryl, Speiko, Münster, Germany) and the teeth were catalogued. Each crown was sectioned in bucco-lingual direction into slices of 500 μm thickness with a 200-μm microtome saw (Mikrotrenn MT 1-78-03, Hofer, Switzerland) to find the maximum caries extension of the lesion. In this context, enamel lesions were defined histological as opacity and dentine caries lesions were linked with yellow and/or brown discolorations. To assess the caries extension more precisely, all slices were examined under a light microscope at 16-fold magnification (Stemi SV11 stereomicroscope, Zeiss, Oberkochen, Germany). The slice with the greatest caries extension for each specimen was identified, digitally photographed, and stored for further analyses. Following this, the caries extension was quantified.

Calculation of the CE-index For calculation of the CE-index, first a differentiation was made between histological sound slices (score 0), demineralisations in the enamel (base value=$0.x/y$) or dentine (base value=$1.x/y$) and lesions reaching the pulp (base value=2). If an enamel or dentine lesion was present, the corresponding base value has to be combined with the ratio of the caries extension (x) and the overall enamel or enamel/dentine thickness (y) as a second step. This effectively means that the caries extension needs to be measured as the distance between the outer enamel surface or the enamel–dentine junction and the deepest demineralisation point towards the pulp (x), which has to be divided by the enamel or dentine thickness (y). Therefore, the CE-index has to be understood as an index of two components: the base value and the percentage of the x/y ratio (Fig. 2). The CE-index ranges from 0.0 to 2.0.

In detail, the enamel/dentine thickness, as well as the caries extension, was measured with the ImageJ software (National Institutes of Health, USA, downloadable at http://rsb.info.nih.gov) by two blinded dentists (J.K., K.B.). All slices were reassessed 1 week later and a final decision for the caries extension was made for each specimen. In case of different findings, both examiners discussed their discordant measures to reach an agreement.

Statistical analysis The data were analysed with Excel 2003 (Microsoft Corporation, Redmond, WA, USA) and SPSS 14.0 (SPSS Inc., Chicago, IL, USA) in order to cross tabulate the findings as well as to calculate mean values (mean), standard deviations (SD), minimum value (min) and the maximum

Universal Visual Scoring System for pits and fissures (UniViSS occlusal)

Second step: Discoloration Assessment	First step: Lesion Detection & Severity Assessment					
	First visible signs of a caries lesion	Established caries lesion	Microcavity and/or localised enamel breakdown	Dentin exposure	Large cavity	Pulp exposure
	Score F	Score E	Score M	Score D	Score L	Score P
Sound surface (Score 0)	No cavitations or discolorations are detectable.					
White (Score 1)						
White-brown (Score 2)						
(Dark) Brown (Score 3)						
Greyish translucency (Score 4)						

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	Score F	Score E	Score M	Score D	Score L	Score P
Sound surface (Score 0)	No cavitations or discolorations are detectable.					
White (Score 1)	*First white spot lesions* are unobtrusive and will be detected after prolonged air drying (~5 seconds) in the deepest parts of pits and fissure.	*White spot lesions* are detectable without prolonged air drying. Air drying improves the assessment of the surface texture (smooth – rough)	Pathological enlargements are detectable with or without enamel breakdowns - visible as interruption of the surface continuity. No dentin exposure is evident. Enlargements >0.5mm (use the ball point of the CPI probe) may indicate a microcavity.	Dentin exposure is detectable.	Dentin cavity involves at least half of the tooth surface.	Pulp exposure.
White-brown (Score 2)	*White-(caramel-)brown lesions* will be detected with prolonged air drying (~5 seconds) in the deepest parts of pits and fissure. Brown areas are in most cases visible without air-drying.	*White-(caramel-)brown lesions* are detectable without prolonged air drying. Air drying improves the assessment of the surface texture, which indicates in most cases a rough lesion. The brown spot is surrounded by white demineralisations.				
(Dark) Brown (Score 3)	*Small brown spot lesions* will be detected even without air drying. This score includes hair-lined brown fissures and/or small brown superficial discolorations. (Lesion <0.5mm/CPI probe)	*Brown discoloured lesions* are always detectable without prolonged air drying. The brown discoloration is describable as wide line. (Lesion ~/>0.5mm/CPI probe)				
Greyish translucency (Score 4)	Greyish translucencies are detectable in an advanced stage only.	In the deepest part of pits and fissures is a *greyish translucency* as sign of an undermining dentin lesion detectable. Additionally, other discolorations are visible.			Greyish translucencies are only detectable on lesion without extensive cavitations.	Greyish translucencies are only detectable on lesion without extensive cavitations.

Fig. 1 Criteria of the universal visual scoring system for pits and fissures (UniViSS occlusal)
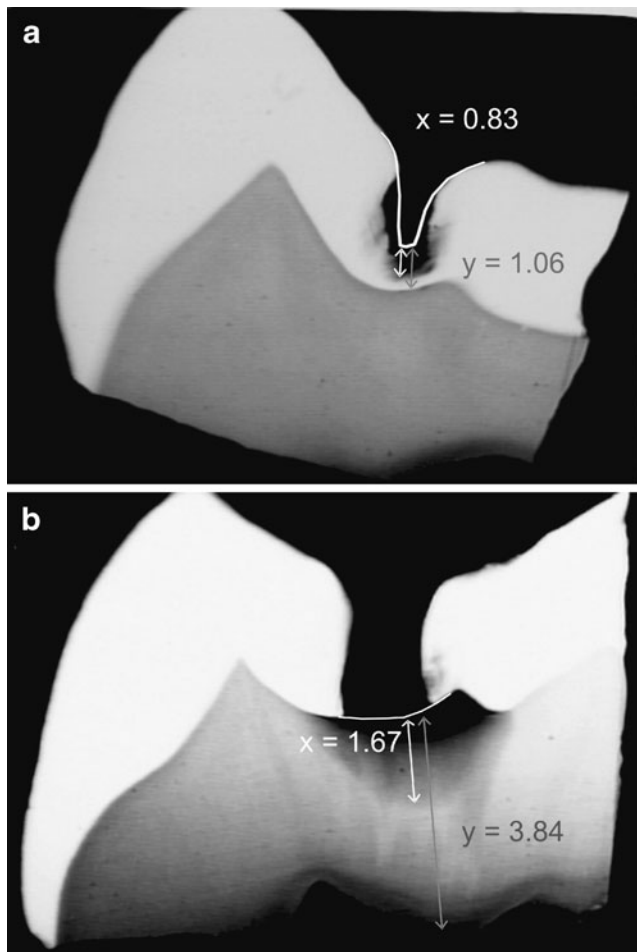
Fig. 2 Exemplified description of the caries-extension-index (CE-index). **a** Microradiography of a histological slice with enamel caries. In this case the CE-index combines the base value ($0.x/y$) with the percentage of the ratio of the caries extension in enamel ($x=0.83$) and the overall enamel thickness ($y=1.06$) and amounts to 0.78. **b** Microradiography of a histological slice with dentine caries. Below the imaginary enamel–dentine junction the zone of destruction, the zone of demineralisation and the zone of sclerotic reaction are clearly visible. In this case the CE-index combines the base value ($1.x/y$) with the percentage of the ratio of the caries extension in dentine ($x=0.50$) and the overall dentine thickness ($y=3.09$) and amounts to 1.43

values (max) of the CE-index for each UniViSS score. A CE-index of 0 is associated with sound surfaces and values between 0.01 and 1.0 are corresponding to enamel caries lesions. Dentine caries lesions will be determined by a CE-index between 1.01 and 1.99. A pulpal involvement is related to a CE-index of 2.00. The overall validity of UniViSS can be expressed by the calculation of the sensitivity (SE), the specificity (SP) and the area under the ROC curves (AUC). These results were published elsewhere [14].

Intra- and inter-examiner reproducibility study

Sample size and examiners A separate sample of 149 sound and non-cavitated third molars was selected from a pool of teeth extracted for surgical or orthodontic reasons. The inclusion criteria, specimen preparation and storage followed the same principles as mentioned above. For testing the reproducibility the inaugurator of UniViSS (D1) as well as six additional examiners took part in this study. One of these dentists had >6 years of clinical experience and practise (D2) and the other, only some months (D3). Four of the investigators were clinically low-experienced students in their fifth year of studies (S1 to S4).

Diagnostic procedure Prior to the beginning of this study all examiners were introduced to the study protocol and the use of UniViSS. The theoretical and practical training consisted of a 30-min hands-on for all examiners which included basic information about the diagnostic principles of non-tactile visual examination, the usage of the CPI probe as measuring instrument, the help of standardised illumination of each specimen with the dental operation light and the necessity of careful air drying. Extensive and detailed calibration training was not performed. The visual decision process for each occlusal surface according to UniViSS included the following evaluation steps: In case of a detectable caries process (1) the most progressed severity stage (first signs, established lesion, microcavity and dentine exposure) as well as (2) the corresponding discoloration (white, white-brown, brown and greyish) was registered for each specimen. The third (clinical) UniViSS step of an activity assessment was not part of this in vitro study protocol. All examiners were encouraged to form their surface-related diagnosis within a time interval of 30 s. Furthermore, a coloured UniViSS chart with typical examples for each score (Fig. 1) was distributed to all examiners. Each evaluation cycle was repeated after a minimum interval of 2 weeks to safeguard the blindness of each investigator between the measurement cycles. Two investigators collected a third series of measuring data (D1 and S1). Hence, all participating examiners obtained a total of 4,768 diagnoses for the occlusal fissure pattern.

Statistical analysis The data analysis was performed using SAS release 9.1 (SAS Institute Inc., Cary, NC, USA). Weighted Kappa values (wK) were calculated as measure of agreement for categorical data to determine the intra- and inter-examiner reproducibility [16] The reproducibility was assessed as low for wK below 0.40, moderate for wK between 0.41 and 0.60, good for wK between 0.61 and 0.80 and excellent for wK between 0.81 and 1.00 [17]. In addition, a cumulative Logit-model was fitted [18]. The dependence of each visual decision on the occlusal surfaces examined was modelled by a random normal effect u ($i=149$) with standard deviation Sigma. The model uses cumulative Logits to describe the transition probability from one diagnostic level to another (αj). The influence of

the examiners is assumed as equal on all levels, i.e., a common β at all stages j. There are J diagnostic levels. For all inter-examiner comparison were used the inaugurator of UniViSS as reference examiner (D1); the β values representing existing differences between the examiner D1 and each of the other investigators. The level of significance was set at $p<0.05$. If the p value was lower than 0.05, then the null hypothesis that the examiner do not differ in their scoring has to be rejected in favour of the alternative hypothesis, which states that differences exist. The following equation describes the used model:

$$\log it[P(Y_{it} \leq j|u_i)] = \alpha_j + x'_{it}\beta + z'_{it}u_i, \quad j=1,\ldots,J-1$$

The cumulative Logits were calculated as follows:

$$\log it[P(Y \leq j|x)] = \log \frac{P(Y \leq j|x)}{1-P(Y \leq j|x)}, \quad j=1,\ldots,J-1$$

Results

Validity study Table 1 summarises the results of the CE-index in relation to each of the UniViSS scores. The results showed that for sound occlusal surfaces no demineralisations were detectable. Fissures with 'First signs' of a caries process had a mean CE-index of 0.6, which indicates that most lesions were found in the enamel. With respect to the maximum value of 1.3, some exceptions occurred. The UniViSS severity score 'Established lesion' showed a heterogeneous distribution of the CE-index in relation to the UniViSS discoloration score. The following findings were observed: (1) The caries extension progresses with increased discoloration scoring. (2) The CE-indices for

'Established lesions' with white (0.4) and white-brown discolorations (0.7) indicate an enamel progression only. Contrary to this, 'Established lesions' with brown discolorations (1.2) and greyish translucencies (1.5) progressed regularly into dentine. The CE-index of 1.5 and 1.7 for 'Microcavities' and 'Dentine exposure' indicated that these lesions had histologically progressed into the middle of the dentine on average.

Reproducibility study Analyses of all inter-examiner data from the first measurement series showed that 53% (UniViSS/severity) and 61% (UniViSS/discoloration) of all measurements were repeated consistently. Viewing the results from the second measurement series, in 57% (UniViSS/severity) and 66% (UniViSS/discoloration) of all inter-examiner comparisons concordant diagnoses were made. This distinct tendency for higher accordance of the diagnoses obtained by the second measurements was confirmed by the wK values (inter-examiner data) of the first and second series. The inter-examiner wK values rose from 0.520 to 0.576 for the UniViSS/severity criteria and from 0.510 to 0.565 for the UniViSS/discoloration criteria. The intra-examiner reproducibility amounted to 0.685 (UniViSS/severity) and 0.628 (UniViSS/discoloration). The intra- and inter-examiner wK values are summarised in Table 2 for the UniViSS/severity criteria and for the UniViSS/discoloration criteria.

The results of the cumulative Logit-model are shown in Table 3. For UniViSS/severity both dentists and two out of four students did not show a significant difference to the inaugurator of the method (D1); S1 and S4 staged the severity significantly inferior. In case of UniViSS/discoloration a different observation was obtained: Only the experienced dentist (D2) reproduced their findings in concordance to the

Table 1 Quantification of the caries extension for each score of the universal visual scoring system (UniViSS) using the caries-extension-index

Caries-Extension-Index (CE-Index) N/ **Mean** (SD) Min - Max		UniViSS (Severity)					
		Sound	First signs	Established lesion	Microcavity	Dentine exposure	Σ
	No discoloration detectable	7/ **0** (0) 0 - 0	-	-	-	-	7/ **0** (0) 0 - 0
	White spot lesion	-	6/ **0.4** (0.3) 0 - 1.0	9/ **0.4** (0.4) 0 - 1.1	-	1/ **1.9** (-) 1.9 - 1.9	16/ **0.5** (0.5) 0 - 1.9
UniViSS (Discoloration)	**White-brown lesion**	-	4/ **0.5** (0.5) 0 - 1.1	18/ **0.7** (0.5) 0 - 1.7	5/ **1.5** (0.4) 1.1 - 2.0	1/ **1.8** (-) 1.8 - 1.8	28/ **0.9** (0.6) 0 - 2.0
	Brown discoloration	-	5/ **0.9** (0.3) 0.6 - 1.3	5/ **1.2** (0.3) 1.0 - 1.7	-	1/ **1.5** (-) 1.5 - 1.5	11/ **1.1** (0.3) 0.6 - 1.7
	Greyish translucency	-	-	1/ **1.5** (-) 1.5 - 1.5	2/ **1.5** (0.4) 1.3 - 1.8	-	3/ **1.5** (0.3) 1.3 - 1.8
	Σ	7/ **0** (0) 0 - 0	15/ **0.6** (0.4) 0 - 1.3	33/ **0.7** (0.5) 0 - 1.7	7/ **1.5** (0.4) 1.1 - 2.0	3/ **1.7** (0.2) 1.5 - 1.9	65/ **0.8** (0.6) 0 - 2.0

The *bold*, *dashed line* illustrates the cut-off threshold for detecting caries lesions visually. Based on mean values >1.0 of the CE-index the cut-off threshold (*bold line*) for detecting dentine caries lesions was determined

Table 2 Weighted Kappa values for the intra- and inter-examiner reproducibility of the UniViSS/severity and UniViSS/discoloration criteria

Reproducibility (wK)	UniViSS/severity				UniViSS/discoloration			
	Intra-examiner	Inter-examiner			Intra-examiner	Inter-examiner		
		Mean	Min	Max		Mean	Min	Max
D1	0.646	0.585	0.409	0.776	0.735	0.591	0.348	0.795
D2	0.821	0.532	0.404	0.776	0.747	0.559	0.321	0.652
D3	0.680	0.578	0.419	0.704	0.595	0.577	0.396	0.721
S1	0.605	0.560	0.342	0.703	0.554	0.534	0.319	0.726
S2	0.756	0.577	0.419	0.689	0.667	0.507	0.282	0.615
S3	0.655	0.520	0.315	0.657	0.576	0.543	0.411	0.626
S4	0.634	0.506	0.315	0.689	0.522	0.486	0.282	0.678
Mean	0.685	0.551	0.315	0.776	0.628	0.542	0.282	0.795

wK weighted Kappa

inaugurator of the method (D1); the other dentist (D3) and all four students (S1-S4) registered significantly different discoloration scores in comparison to D1.

Discussion

As main result of this study it was shown that the newly developed CE-index provided quantitative information about the exact caries depth of a distinct diagnostic score. Based on these results it will be possible to assign a probable preventive or operative treatment strategy to a certain diagnostic scores (Table 1). While the traditionally used validity parameters do not provide such detailed information, the CE-index will

help to determine clearer diagnostic thresholds for intervention strategies. This aspect is of clinical importance as the indication for a restorative treatment no longer depends on the simple fact that a caries lesion penetrated the enamel–dentin junction [19].

In order to investigate the validity of UniViSS, it was possible to evaluate each diagnostic score separately with the CE-index (Table 1). 'First signs' of a caries lesion were mainly associated with an enamel caries (CE-index of 0.6); but it should be noted that in few cases with white-brown or brown discolorations the outer third of dentine was reached. Therefore, this criterion seems to be mainly associated with lesions that require a preventive treatment strategy only. 'Established lesions' showed a much greater heterogeneity:

Table 3 The cumulative Logit-model represents the comparisons between the reference examiner (D1) and each of the others for the UniViSS severity and discoloration criteria

Parameter	Estimate (Standard error)	*p* value	Lower confidence limit	Upper confidence limit
UniViSS severity criteria				
β1 (D1–D2)	−0.239 (0.17)	0.1520	−0.5668	0.0889
β2 (D1–D3)	0.075 (0.16)	0.6468	−0.2468	0.3962
β3 (D1–S1)	−0.409 (0.15)	0.0058*	−0.6984	−0.1202
β4 (D1–S2)	−0.054 (0.16)	0.7401	−0.3732	0.2657
β5 (D1–S3)	0.069 (0.16)	0.6750	−0.2553	0.3931
β6 (D1–S4)	−1.229 (0.16)	<0.0001*	−1.5527	−0.9051
UniViSS discoloration criteria				
β1 (D1–D2)	0.151 (0.16)	0.3538	−0.1698	0.4719
β2 (D1–D3)	−0.355 (0.16)	0.0310*	−0.6769	−0.0329
β3 (D1–S1)	−0.745 (0.15)	<0.0001*	−1.0339	−0.4558
β4 (D1–S2)	−1.301 (0.17)	<0.0001*	−1.6275	−0.9745
β5 (D1–S3)	−0.664 (0.16)	<0.0001*	−0.9881	−0.3406
β6 (D1–S4)	−1.764 (0.17)	<0.0001*	−2.0942	−1.4343

*p values <0.05 are indicating a significant difference between the tested investigators, which means that the tested comparison revealed an inferior reproducibility

Established white-spot lesions were mainly associated with caries extending into the enamel and possibly needing preventive care. In contrast to this, 'Established lesions' with white-brown or brown discoloration showed a more heterogeneous distribution. While the mean CE-index of 0.7 and 1.2 indicated a caries process extending into the enamel or the dentine beneath the enamel–dentine junction, the maximum values of 1.7 for both scores showed that variations could be possible. These exceptions underline the known clinical problem of the difficulty to assess the caries extension on non-cavitated occlusal lesion by visual means correctly. Consequently, occlusal 'Established lesions' need clinically a diagnostic 'safety net' under inclusion of additional diagnostic methods, e.g., bitewing radiographs and/or laser fluorescence measurements, to detect caries lesions that have progressed far into dentine and need restorative treatment [20–23].

'Microcavities' and 'Dentine cavities' on occlusal surfaces were always associated with dentine caries regardless of the state of discoloration (Table 1) and should be therefore restored. Based on our results the potential of the quantitative CE-index was shown. Therefore, this index could help to advance the analysis and interpretation of validation data in future diagnostic studies.

When further comparing the established validity parameters (SE, SP and AUC) of UniViSS on occlusal caries lesions [14] with results from other recently published visual caries detection and diagnostic methods [7–11] the registered validity parameters for UniViSS were found to be in the same order of magnitude. When generalizing previously made suggestions that the sum of SE and SP should be at least ~160% before a diagnostic method could be considered as a legitimate candidate for practical use [24, 25], then the potential of UniViSS was illustrated. For both, the overall caries detection level (SE 100.0%, SP 58.3%) as well as for the dentine caries detection level (SE 62.5%, SP 97.6%), the sum of ~160% was reached [14]. Furthermore, the documented AUC for the caries detection level (0.84) and for the dentine caries detection level (0.81) are high and correspond to other studies on meticulous visual inspection methods [26–34].

Besides evaluation of diagnostic accuracy, caries activity assessment gained more attention throughout the last years. With respect to the definition of 'caries activity', which designates such lesions as active which are showing an ongoing mineral loss due to the metabolic activity of the biofilm [35], the need for longitudinal clinical trials is obvious. For this basic reason, we deliberately excluded an activity assessment from this in vitro study even though it is part of UniViSS [14]. Nevertheless, Braga et al. [11] published a first attempt to quantify caries activity in vitro. The authors included the parameters 'ICDAS score', 'plaque stagnation area' and 'surface texture' into their

lesion activity assessment system. While plaque stagnation areas and roughness can be justified aetiologically, there is currently no unanimous consensus as to when a plaque stagnation area, plaque presence and/or surface roughness should be rated as such. Further, it has also be taken into account that during the investigation the operator is constantly aware of the visual diagnosis and hence biased when it comes to the decision about activity [1]. All of these uncertainties will be completed by the fact that there are no quantitative reference standards published so far to determine the caries activity itself [36] as well as the validity of the criteria 'plaque stagnation area' and 'roughness'. Therefore, more research to improve the caries activity assessment under inclusion of objective and quantifiable diagnostic criteria is needed. Within the second part of this investigation the reproducibility of UniViSS was comprehensively analysed. According to the wK results the all-over reproducibility can be assessed as good to moderate (Table 2). While good wK values were obtained mostly for the intra-examiner reproducibility, the inter-examiner reproducibility proved to be on a moderate level. Nevertheless, for several inter-examiner comparisons good wK values were found, too (Table 2). The registered wK values show almost the same order of magnitude as the Kappa values that were obtained for the visual criteria by Ekstrand et al. [7, 8] on occlusal surfaces [7, 30, 31, 33, 34].

With respect to the almost identical criteria sequences of ICDAS II and UniViSS/severity comparisons of the reproducibility data between both systems are feasible. The wK values for the intra- and inter-examiner reproducibility for ICDAS II amounted to 0.62 to 0.83 [28] and 0.88 to 0.90 [1] and indicate more favourable results than those for UniViSS from the present study. Since this can be explained by a more extensive calibration training in both ICDAS studies [1, 28], which was explicitly not part of the present study design, it can be assumed that an extensive calibration training should improve the reproducibility for UniViSS substantially.

To our knowledge, this was the first study that used a cumulative Logit-model to assess the reproducibility of a caries diagnostic method. In case of our investigation the developed cumulative Logit-model served to evaluate measurements in comparison to the decisions of the inaugurator of UniViSS (D1). As shown in Table 3, statistically non-significant differences were found for the majority of comparisons for UniViSS/severity. In contrast, the results for the UniViSS/discoloration criteria showed a more heterogeneous pattern (Table 3). Here, only one dentist (D2) was able to obtain similar decisions, which can be explained by longer clinical experience. These findings indicate that clinically and scientifically inexperienced dentists have a higher need for training especially for the

assessment of the UniViSS/discoloration criteria. The main keys for successful calibration training seem to impart theoretical knowledge, to discuss visual decisions on dental photographs and extracted teeth and to perform a clinical training. In case of clinically inexperienced dentists, the training should be intensified and, perhaps, repeated to eliminate possible subjective errors. Under these circumstances it can be hypothesised that the registered reproducibility values could be substantially improved when extensive calibration training is performed.

In conclusion of the present study, the overall validity and reproducibility of UniViSS has to be assessed as encouraging. Based on our findings we could further state that the detailed approach to categorise (non-)cavitated caries lesions with UniViSS provides additional information especially on 'Established lesions' for the clinician. With respect to the UniViSS/discoloration score and the CE-index, it was shown that each discoloration score on 'Established lesions' was associated with a different caries depth which would further result in different preventive/ treatment strategies. As such detailed and clinically important information are not part of recently published visual caries detection and diagnostic systems [7–11], this aspect has to be understood as the unique feature of UniViSS. Nevertheless, further investigations are needed to validate UniViSS with a larger sample size before final treatment recommendations could be drawn. With respect to the results of the reproducibility study, it has to be concluded to adapt the calibration training to the clinical experience of the dentist(s). As the UniViSS/discoloration score seems to be more difficult to reproduce, more emphasis should be paid on this finding in the future. The used cumulative Logit-model enabled statistical comparisons between all examiners and enhanced the informative value of the reproducibility study. Therefore, such models could be used more frequently to investigate intra- and inter-examiner reproducibility in future.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Kühnisch J, Berger S, Goddon I, Senkel H, Pitts N, Heinrich-Weltzien R (2008) Occlusal caries detection in permanent molars according to WHO basic methods, ICDAS II and laser fluorescence measurements. Community Dent Oral Epidemiol 36:475–484
2. Heinrich-Weltzien R, Kühnisch J, Oehme T, Ziehe A, Stösser L, Garcia-Godoy F (2003) Comparison of different DIAGNOdent cut-off limits for in vivo detection of occlusal caries. Oper Dent 28:672–680
3. Heinrich-Weltzien R, Kühnisch J, Ifland S, Tranæus S, Angmar-Månsson B, Stösser L (2005) Detection of initial caries lesions on smooth surfaces by quantitative light-induced fluorescence (QLF) and visual examination—an in vivo comparison. Eur J Oral Sci 113:494–498
4. Kühnisch J, Ziehe A, Brandstädt A, Heinrich-Weltzien R (2004) An in vitro study of the reliability of DIAGNOdent® measurements. J Oral Rehabil 31:895–899
5. Kühnisch J, Heinrich-Weltzien R, Tabatabaie M, Stösser L, Huysmans MCDNJM (2006) An in vitro comparison between two methods of electrical resistance measurements for occlusal caries detection. Caries Res 40:104–111
6. Kühnisch J, Ifland S, Tranæus S, Hickel R, Stößer L, Heinrich-Weltzien R (2007) In vivo detection of initial caries lesions on occlusal surfaces by visual inspection and quantitative light-induced fluorescence. Acta Odontol Scand 65:183–188
7. Ekstrand KR, Ricketts DNJ, Kidd EAM (1997) Reproducibility and accuracy of three methods for assessment of demineralization depth of the occlusal surface: an in vitro examination. Caries Res 31:224–231
8. Ekstrand KR, Ricketts DNJ, Kidd EAM, Qvist V, Schou S (1998) Detection, diagnosis, monitoring and logical treatment of occlusal caries in relation to lesion activity and severity: an in vivo examination with histological validation. Caries Res 32:247–254
9. Nyvad B, Machiulskiene V, Baelum V (1999) Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 33:252–260
10. Pitts NB, Stamm JW (2004) International Consensus Workshop on caries clinical trials (ICW-CCT)—final consensus statements: agreeing where the evidence leads. J Dent Res 83(Spec Iss C):125–128
11. Braga MM, Mendes FM, Martignon S, Ricketts DN, Ekstrand KR (2009) In vitro comparison of Nyvad's system and ICDAS-II with Lesion Activity Assessment for evaluation of severity and activity of occlusal caries lesions in primary teeth. Caries Res 43:405–412
12. Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, Pitts NB (2007) The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries. Community Dent Oral Epidemiol 35:170–178
13. Topping GVA, Pitts NB (2009) Clinical visual caries detection. Monogr Oral Sci 21:15–41
14. Kühnisch J, Goddon I, Berger S, Senkel H, Bücher K, Oehme T, Hickel R, Heinrich-Weltzien R (2009) Development, methodology and potential of the new Universal Visual Scoring System (UniViSS) for caries detection and diagnosis. Int J Environ Res Public Health 6:2500–2509
15. Pitts NB (2004) Modern concepts of caries measurements. J Dent Res 83(Spec Iss C):C43–C47
16. Cohen J (1968) Weighted kappa: nominal scale agreement with provision for scaled disagreement or partial credit. Psychological Bulletin 70:213–220
17. Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. Biometrics 33:159–174
18. Agresti A (2002) Categorical data analysis. John Wiley & Sons, Inc., Hoboken, New Jersey
19. Kidd EAM (2004) How 'clean' must a cavity before restoration? Caries Res 38:305–313
20. Weerheijm KL, Groen HJ, Bast AJ, Kieft JA, Eijkman MA, van Amerongen WE (1992) Clinically undetected occlusal dentine caries: a radiographic comparison. Caries Res 26:305–309
21. Poorterman JHG, Weerheijm KL, Groen HJ, Kalsbeek H (2000) Clinical and radiographic judgement of occlusal caries in adolescents. Eur J Oral Sci 108:93–98
22. Wenzel A (2004) Bitewing and digital bitewing radiography for detection of caries lesions. J Dent Res 83(Spec Iss C):C72–C75
23. Lussi A, Hibst R, Paulus R (2004) DIAGNOdent: an optical method for caries detection. J Dent Res 83(Spec Iss C):C80–C83
24. Kingmann A (1990) Statistical issues in risk models for caries. In: Bader JD (ed) Risk assessment in dentistry. University of North Carolina, Chapel Hill

25. Hausen H (1997) Caries prediction—state of the art. Community Dent Oral Epidemiol 25:87–96
26. Braga MM, Oliveira LB, Bonini GA, Bönecker M, Mendes FM (2009) Feasibility of the International Caries Detection and Assessment System (ICDAS-II) in epidemiological surveys and comparability with standard World Health Organization criteria. Caries Res 43:245–249
27. Diniz MB, Rodrigues JA, Hug I, Cordeiro Rde C, Lussi A (2009) Reproducibility and accuracy of the ICDAS-II for occlusal caries detection. Community Dent Oral Epidemiol 37:399–404
28. Jablonski-Momeni A, Stachniss V, Ricketts DNJ, Heinzel-Gutenbrunner M, Pieper K (2008) Reproducibility and accuracy of the ICDAS-II for detection of occlusal caries in vitro. Caries Res 42:79–87
29. Rodrigues JA, Hug I, Diniz MB, Lussi A (2008) Performance of fluorescence methods, radiographic examination and ICDAS II on occlusal surfaces in vitro. Caries Res 42:297–304
30. Burin C, Burin C, Loguercio AD, Grande RH, Reis A (2005) Occlusal caries detection: a comparison of a laser fluorescence system and conventional methods. Pediatr Dent 27:307–312
31. Reis A, Zach VL Jr, de Lima AC, de Lima Navarro MF, Grande RH (2004) Occlusal caries detection: a comparison of DIAGNOdent and two conventional diagnostic methods. J Clin Dent 15:76–82
32. Cortes DF, Ekstrand KR, Elias-Boneta AR, Ellwood RP (2000) An in vitro comparison of the ability of fibre-optic transillumination, visual inspection and radiographs to detect occlusal caries and evaluate lesion depth. Caries Res 34:443–447
33. Cortes DF, Ellwood RP, Ekstrand KR (2003) An in vivo comparison of a combined FOTI/Visual examination of occlusal caries with other diagnostic methods and the effect of stain on their diagnostic performace. Caries Res 37:8–16
34. Ando M, Eggertsson H, Isaacs R, Analoui M, Stookey GK (2000) Comparative studies of several methods for the early detection of fissure lesions. In: Stookey GK (ed) Early detection of dental caries II: Proceedings of the 4th Annual Indiana Conference. Indiana University, Indianapolis, pp 279–299
35. Nyvad B, Fejerskov O, Baelum V. Visual-tactile caries diagnosis. In: Fejerskov O, Kidd EAM (eds) Dental Caries. The disease and its clinical management. 2nd edn Blackwell Munksgaard, Oxford, pp 50–68
36. Nyvad B, Machiulskiene V, Baelum V (2003) Construct and predictive validity of clinical caries diagnostic criteria assessing lesion activity. J Dent Res 82:117–122