
Forschung · Wissenschaft Recherche · Science

Editor-in-chief
Chefredaktor
Rédacteur en chef
Jürg Meyer, Basel

Editors
Redaktoren
Rédacteurs
Urs Belser, Genève
Peter Hotz, Bern
Heinz Lüthy, Zürich

Assistant Editor
Redaktions-Assistent
Rédacteur assistant
Tuomas Waltimo, Basel

Advisory board / Gutachtergremium / Comité de lecture

P. Baehni, Genève
F. Barbakow, Zürich
J.-P. Bernard, Genève
C.E. Besimo, Basel
M. Bickel, Zürich
S. Bouillaguet, Genève
U. Brägger, Bern
E. Budtz-Jørgensen, Genève
D. Buser, Bern
M. Cattani, Genève
B. Ciucchi, Genève
K. Dula, Bern
A. Filippi, Basel
J. Fischer, Bern
L.M. Gallo, Zürich
R. Glauser, Zürich
R. Gmür, Zürich
W. Gnoinski, Zürich
K.W. Grätz, Zürich
Ch. Hämmerle, Zürich

N. Hardt, Luzern
T. Imfeld, Zürich
K.H. Jäger, Basel
J.-P. Joho, Genève
S. Kiliaridis, Genève
I. Krejci, Genève
J.Th. Lambrecht, Basel
N.P. Lang, Bern
T. Lombardi, Genève
H.U. Luder, Zürich
A. Lussi, Bern
P. Magne, Genève
C. Marinello, Basel
G. Menghini, Zürich
R. Mericske-Stern, Bern
J.-M. Meyer, Genève
A. Mombelli, Genève
W. Mörmann, Zürich
G. Pajarola, Zürich
S. Palla, Zürich

S. Paul, Zürich
M. Perrier, Lausanne
M. Richter, Genève
S. Ruf, Bern
H.F. Sailer, Zürich
J. Samson, Genève
U.P. Saxer, Zürich
P. Schärer, Zürich
J.-P. Schatz, Genève
P. Schüpbach, Horgen
P. Stöckli, Zürich
U. Teuscher, Zürich
H. van Waes, Zürich
P. Velvart, Zürich
T. von Arx, Bern
R. Weiger, Basel
A. Wichelhaus, Basel
J. Wirz, Basel
A. Wiskott, Genève

Publisher
Herausgeber
Editeur
Schweizerische Zahnärzte-Gesellschaft SSO
Société Suisse d'Odonto-Stomatologie
CH-3000 Bern 7

Adresse der wissenschaftlichen Redaktion
Prof. Jürg Meyer
Zentrum für Zahnmedizin
Institut für Präventivzahnmedizin und Orale Mikrobiologie
Hebelstr. 3
4056 Basel

Performance of visual inspection, electrical conductance and laser fluorescence in detecting occlusal caries *in vitro*

Summary

The aim of this study was to compare visual inspection (VI) and electrical conductance (EC) and laser fluorescence (LF) measurements in detecting occlusal caries. VI was based on fissure discoloration and performed with the naked eye. EC was measured with the ECM device (Lode Diagnostic, Groningen, The Netherlands), and LF was assessed with the DIAGNOdent apparatus (KaVo, Biberach, Germany). In extracted human premolars and molars, clinically sound sites (D0-/D1-lesions), enamel caries (D2-lesions), and dentinal caries (D3-/D4-lesions) were identified using recommended cut-off values. Thereafter, the teeth were cut longitudinally and analyzed by scanning electron microscopy for verification of caries depth. Reproducibility of VI was good, that of EC and LF excellent. In identifying caries at both the enamel and dentin level, the sensitivities of VI and LF were significantly ($p < 0.05$) higher than that of EC, while EC was significantly ($p < 0.05$) more specific. The positive predictive values, however, did not exceed 43%. Improved diagnoses at the dentinal level were obtained, when EC and LF were used as an adjunct to VI and when cut-off values were raised. Thus, visual inspection relying exclusively on fissure discoloration seems to allow only proper identification of sound occlusal surfaces. In cases of discolored fissures, the appliance-based methods help to avoid false positive identification of dentinal caries. However, attainable reliabilities of diagnoses do not seem to exceed about 50% to 60%.

Schweiz Monatsschr Zahnmed 113: 852–859 (2003)

Key Words: Occlusal caries, Diagnosis, Visual inspection, Electrical conductance, Laser fluorescence

Accepted for publication: 11 April 2003

Address for correspondence:

PD Dr. H. U. Luder

Center of Dental and Oral Medicine

Institute of Oral Biology

Department of Orofacial Structures and Development

Plattenstrasse 11, CH-8028 Zurich, Switzerland

Phone +41 1 634 31 40, Fax +41 1 634 43 06

E-mail: luder@zmk.unizh.ch

ALEN KORDIC*, ADRIAN LUSSI** and
HANS-ULRICH LUDER*

* University of Zurich, Center of Dental and Oral Medicine,
Department of Orofacial Structures and Development

** University of Bern, School of Dental Medicine,
Department of Operative, Preventive, and Pediatric
Dentistry

Introduction

Several developments of the past decades have led to a new interest in the diagnosis of occlusal caries. Firstly, the proportion of fissure lesions has increased as a result of the decline in approximal caries due to prophylaxis (MENGHINI et al. 1998). Secondly, the identification of incipient occlusal lesions by clinical means has become difficult, because the wide-spread use of fluorides seems to delay cavitation (SAWLE & ANDLAW 1988). Thirdly, the classical bite-wing radiography hardly detects occlusal caries, before it has progressed well into dentin (WENZEL et al. 1990). For these reasons, appliances for measuring electrical conductance (EC) and laser fluorescence (LF) have been intro-

duced and recommended as diagnostic aids to identify both initial enamel lesions and dentinal caries requiring operative treatment.

Irrespective of the availability of appliances, the identification of fissure caries in daily practice still relies largely on the classical visual inspection (VI), although its performance seems to vary. Whereas some validation studies (LUSSI 1991, 1993, VERDONSCHOT et al. 1993, IE et al. 1995, RICKETTS et al. 1995, HUYSMANS et al. 1998, ASHLEY et al. 1998, PEREIRA et al. 2001) revealed high specificity, but low sensitivity values and only moderate reproducibility, other investigations (VERDONSCHOT et al. 1992, EKSTRAND et al. 1997) indicated a moderate to good reproducibility and high sensitivity, but low specificity.

The evaluation of commercially available instruments for EC measurements, that were carried out *in vitro* (VERDONSCHOT et al. 1993, RICKETTS et al. 1995, 1996, EKSTRAND et al. 1997, HUYSMANS et al. 1998, ASHLEY et al. 1998) and *in vivo* (VERDONSCHOT et al. 1992, IE et al. 1995, LUSSI et al. 1995), revealed high sensitivity and specificity values as well as excellent reproducibility. This suggested that the technique was not only suited to reliably detect enamel and dentinal caries, but could also be used for longitudinal monitoring of lesions.

A recently introduced commercial product for LF measurements makes use of the fact that upon excitation with red laser light of 655 nm wave length, carious enamel and particularly dentin fluoresce more brightly than sound dental hard substances (HIBST 1999). First studies carried out with this method indicated a reproducibility comparable to that of EC measurement (LUSSI et al. 1999, 2001, LUSSI 2000, SHI et al. 2000, PEREIRA et al. 2001), whereas reported sensitivity values varied markedly, ranging from 0.17–0.2 (PEREIRA et al. 2001) to 0.78–0.82 (SHI et al. 2000).

Several of the previous studies evaluating EC and LF used cut-off values for the identification of enamel or dentinal caries, that were not predetermined, but chosen deliberately based on the measurements in the sample of examined teeth (HUYSMANS et al. 1998, ASHLEY et al. 1998, LUSSI et al. 1999, SHI et al. 2000). As a result, the sensitivities and specificities may not correspond to the values achievable in daily practice. It was the aim of the present investigation to compare the performance of VI, EC, and LF in one sample of extracted teeth, applying established, recommended cut-off values for the detection of caries.

Materials and Methods

Sample: Sixty-one extracted human teeth, 25 premolars and 36 molars, from 33 females and 28 males ranging from 10 to 38 years of age were used (Table I). The molars were mostly wisdom teeth which had been fully erupted and exposed to the oral environment for some time. From both types of teeth, specimens were selected to ensure that no apparent cavitation was present and all three grades of fissure discoloration described below were represented about equally (Table I). Following extraction, the teeth were immediately fixed either in 4% neutral buffered formalin or half-strength Karnovsky's fixative (pH 7.4). Thereafter, they were stored in 0.185 M Na-cacodylate buffer (pH 7.4) for variable periods of time. Prior to their examination, the specimens were transferred to Ringer lactate solution and cleaned with a toothbrush and toothpaste. Existing mineralized deposits were carefully removed from the fissure entrances using a scaler. After the sites of examination had been established, they were marked on the nearest cusps with a fine waterproof marker-pen (Figs. 1a–d).

Tab. I Sources of premolars and molars used and lesions identified.

	Premolars	Molars
Source		
Females (N)	14	19
Males (N)	11	17
Age (mean; range; years)	13.9; 10–23	24.6; 18–38
Fissure discoloration		
no discoloration (grade 0)	9	6
yellow – light brown (grade 1)	8	13
dark brown – black (grade 2)	8	17
Lesions		
Sound sites (D0)	8	5
Initial enamel caries (D1)	16	11
Deep enamel caries (D2)	1	9
Dentinal caries (D3 or D4)	0	11

Visual Inspection (VI): The specimens were evaluated in random order by four dentists. For each assessment, they were first dried thoroughly with a jet of air and then examined with the naked eye at room illumination. Marked sites were assigned a grade of fissure discoloration according to the definition of MARTHALER (1966). No discoloration (grade 0) indicated a caries-free fissure (D0) or an initial enamel lesion (D1), a yellow to light brown discoloration (grade 1) was assumed to reflect deep enamel caries (D2), and a dark brown to black discoloration was considered to correspond to dentinal caries (D3 or D4).

Electrical Conductance (EC) Measurements: Measurements were made under moist conditions with Ringer lactate solution as conducting medium, using the prototype of the ECM I device (Lode Diagnostic, Groningen, The Netherlands) at room temperature (22 °C) and with 7.2 l/min air flow. Moist teeth were held in firm contact with the reference electrode in one hand of the examiner, while the other hand was used to carry the measuring hand-piece. Each specimen was assessed twice and the average of the two measurements recorded. After an interval of 6 weeks, the examination was repeated. The recordings were assigned to degrees of caries according to the manufacturer's recommendations. Thus, conductance readings of –0.5–3.0 units, 3.1–6.0 units, and >6.0 units corresponded to D0 or D1, to D2, and to D3 or D4, respectively.

Laser Fluorescence (LF) Measurements: The DIAGNOdent device (KaVo, Biberach, Germany) equipped with probe A was used at room temperature (22 °C). The teeth were examined after drying and remoistening with an artificial saliva preparation (Glandosan®, Fresenius, Stans, Switzerland). As in the case of EC measurements, two recordings of laser fluorescence were made and averaged, and the assessment was also repeated after an interval of six weeks. Caries degrees were assigned to readings according to recommendations by LUSSI et al. (1999) for *in vitro* tests. Thus, measurements of 0–4 units, 5–10 units, and >10 units were assumed to correspond to D0 or D1, to D2, and to D3 or D4, respectively.

Histological Validation: After completion of the diagnostic tests, teeth were cut axially along the occlusal markings using a band-saw (Exakt, Norderstedt, Germany). The two halves of each specimen were then dehydrated in graded series of alcohol, infiltrated in Technovit 7200 VLC (Kulzer, Wehrheim, Germany) for 2–3 weeks, and finally embedded in the same resin. Following polymerization of the blocks, their surfaces were polished with silicon carbide grinding paper followed by a polishing cloth

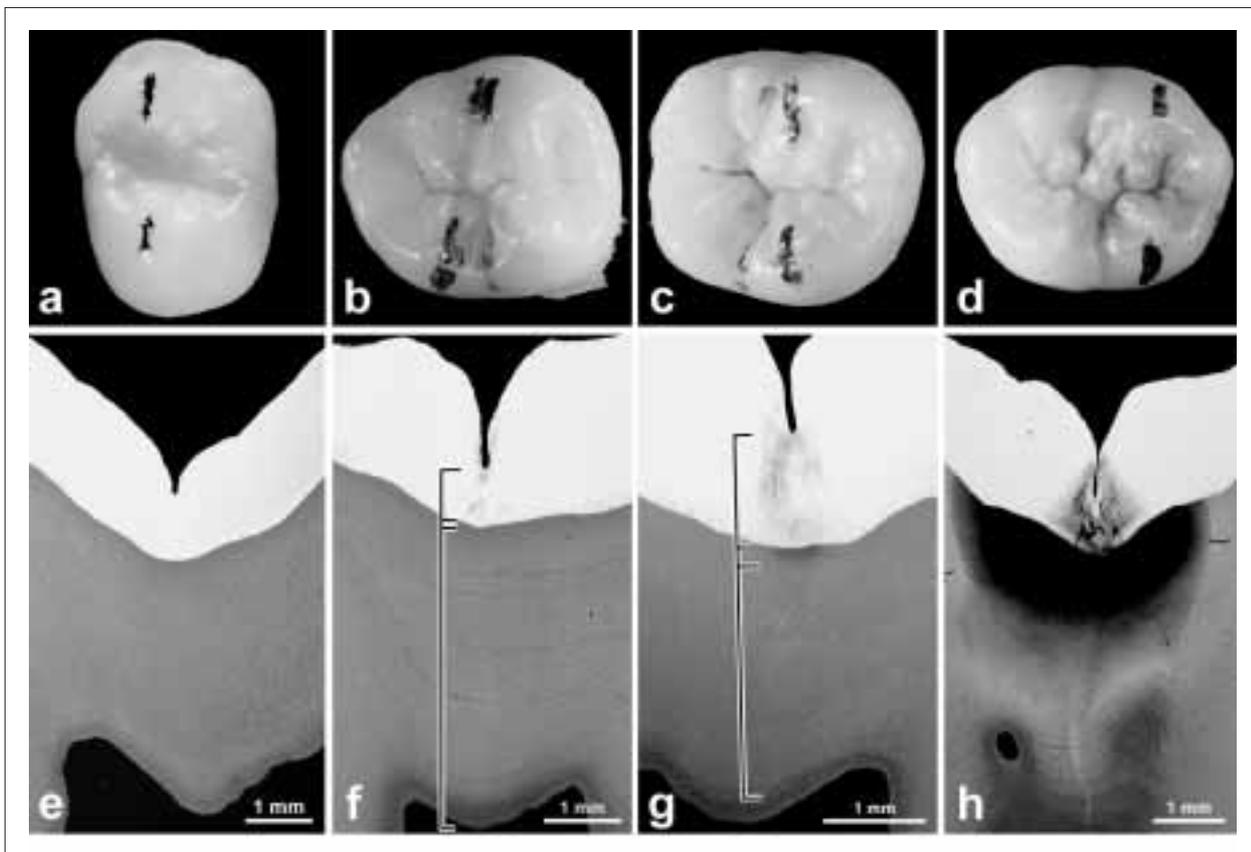


Fig. 1a–d Occlusal views of four specimens exhibiting fissure discoloration grade 1 (a), grade 2 (b, c), and grade 3 (d) at the marked sites. e–h Corresponding backscattered electron micrographs of the surfaces cut axially along the occlusal markings shown in a–d. Labels indicate enamel and dentin thickness (f, g) as well as depths of enamel caries (f) and dental caries (g) as measured from the ground of the fissures. Magnifications $\times 10$ – $\times 15$.

with diamond paste. Thereafter, blocks were coated with a 10–15 nm thick carbon layer using a MED020/EVM030 electron beam evaporator (BAL-TEC, Balzers, Liechtenstein) and examined with a Stereoscan 180 scanning electron microscope (SEM; Cambridge, Dortmund, Germany) equipped with a four quadrant silicon backscatter detector set-up to show atomic number contrast. Digital micrographs were obtained at 15–20 kV accelerating voltage, a working distance of 15–20 mm, and primary magnifications of $\times 10$ to $\times 120$, using the scanning and imaging software WinDISS (point electronic, Halle, Germany) and a personal computer connected to the SEM (Figs. 1e–h).

For the quantitative evaluation of the micrographs, the program SigmaScan Pro (Jandel Scientific, San Rafael, CA) was used. Enamel thickness, dentin thickness, and caries depth were measured along a line running from the ground of the fissure through the deepest point of an eventual carious decalcification to the limit of the pulp cavity (Figs. 1f, g). In order to standardize the data, caries depth was expressed as percentage of the enamel and dentin thickness. As a result, values of relative lesion depth were obtained, that ranged from $>0\%$ to 100% for enamel and from $>100\%$ to 200% for dental caries. These values were averaged across the two halves of each tooth. For comparison with the diagnostic outcomes, fissures lacking any decalcification were classified as sound (D0), while relative caries depths of 1–50%, 51–100%, 101–150%, and 151–200% were taken as D1-, D2-, D3-, and D4-lesions, respectively. In accor-

dance with the diagnostic abilities of VI, EC, and LF, D0- and D1-lesions were combined and considered clinically sound. Likewise, D3- and D4-lesions were pooled, because there were only very few specimens with deep dental caries.

Statistical evaluation: In order to test the reproducibility and repeatability of the detection methods, the values of unweighted Cohen's Kappa (K) were calculated for duplicate diagnoses and Pearson's correlation coefficients for repeated EC- and LF-measurements. Values of K above 0.75 were interpreted to indicate excellent, values of 0.4–0.75 moderate to good agreement. For further analyses, the ratings of different examiners and the repeated measurements were averaged. For establishing average VI-diagnoses, mean discoloration grades of 0.5 or 1.5 were rounded up.

The determination of accuracy, sensitivity, specificity, and predictive values as well as a ROC-analysis served to estimate the performance of VI, EC, and LF. The accuracy was calculated as the proportion of correct identifications of clinically sound sites and D2- and D3/D4-lesions. Sensitivity, specificity, and predictive values were determined for the detection of caries in general and dental caries in particular. In the first case, caries-free sites and D1-lesions were regarded as sound, while D2/D3/D4-lesions were considered diseased, in the second case, the cut-off between non-diseased and diseased was assumed between D2- and D3-lesions. Differences between the three diagnostic procedures were analysed using Pearson's χ^2 -test, and when this

suggested a significant difference, pairwise using Fisher's exact test. For calculating positive and negative predictive values, the prevalence of occlusal caries in molars and upper premolars was adjusted on the basis of data obtained from an epidemiologic survey in 168 15-year-old school children living in the canton of Zurich, Switzerland (MENGHINI et al. 1998). Thus, the population prevalence of caries deeper than D1-lesions was estimated at about 20% and that of dentinal caries at about 15%.

On the same assumptions as for the calculation of sensitivities and specificities, ROC-analyses were made for the identification of caries at the enamel and dentinal level. In an attempt to evaluate the performance of EC and LF, when these were used in combination with VI, readings obtained from specimens disclosing dark fissure discoloration (grade 2) were taken to calculate sensitivity, specificity, and predictive values in detecting dentinal caries. For these analyses, both the predetermined cut-off values and higher thresholds derived from the ROC-curves were applied.

All statistical analyses were performed with the program Systat (SPSS, Chicago, IL), and the program Axum (MathSoft, Seattle, WA) served to make the graphical plots.

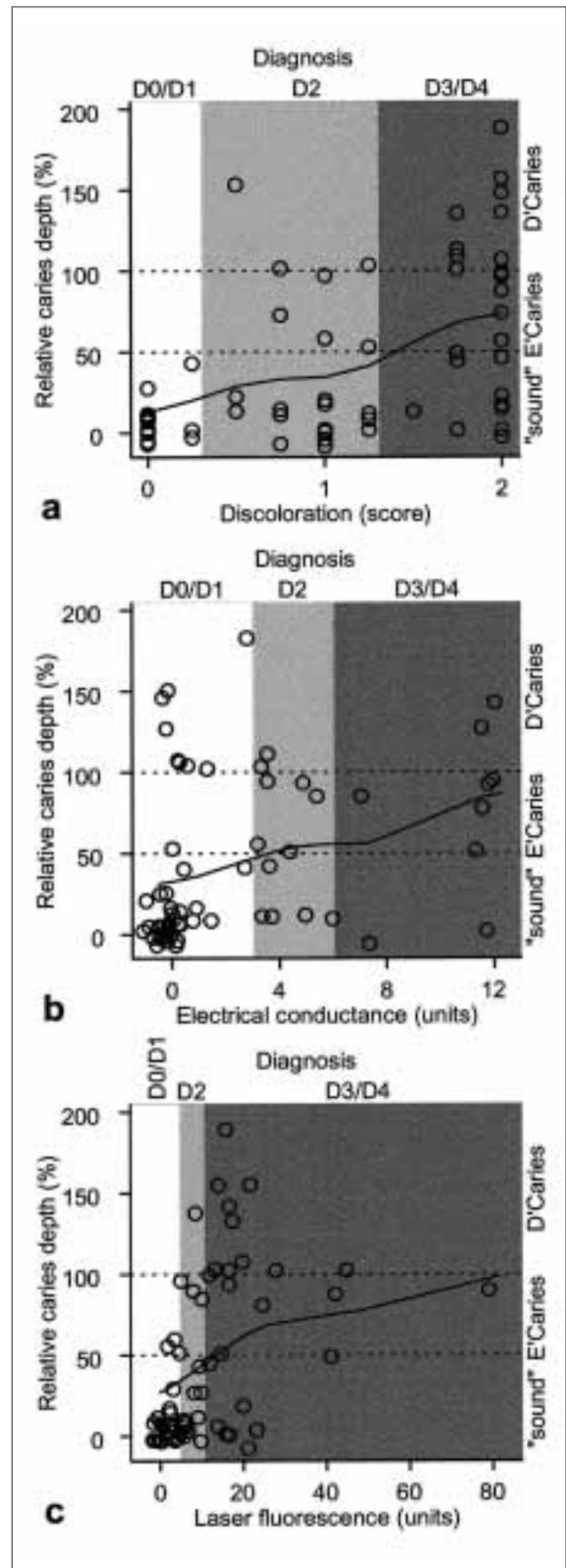
Results

The outcomes of the visual inspection varied considerably between pairs of examiners, K-values ranging from 0.6 to 0.75. In contrast, duplicate EC- and LF-measurements exhibited highly significant correlations ($p < 0.001$), and K-values for the derived diagnoses were 0.81 and 0.78, respectively.

Although the selection of teeth intended to ensure similar frequencies of fissure discoloration in premolars and molars, the histological examination revealed that with the exception of one specimen, all premolars were caries-free or exhibited D1-lesions. In molars, however, the degrees of caries were distributed more evenly (Table I). Overall, 40 specimens were clinically sound, 10 teeth exhibited deep enamel caries, and 11 specimens disclosed dentinal caries. Hence, the prevalence of caries in the sample examined was about 34%, that of dentinal caries about 18%.

From the plots of caries depth against the diagnostic measurements (Fig. 2), it was evident that none of the regression lines predicted dentinal caries. With the predetermined cut-off values, the accuracy of VI, EC, and LF in detecting clinically sound sites was about 37%, 78%, and 53%, respectively (Table II). From the D2-lesions, about 30–40% were correctly identified by all three procedures, whereas dentinal caries was recognized most accurately by VI and LF. With respect to the detection of lesions deeper than D1, VI and LF exhibited significantly higher sensitivity, but lower specificity than EC (Table II). A similar pattern was also evident regarding the identification of dentinal caries,

► **Fig. 2** Scattergrams and non-parametric regression lines of relative caries depth as a function of fissure discoloration (a), electrical conductance (b), and laser fluorescence (c). Ranges of diagnostic measurements corresponding to clinically sound sites, enamel caries, and dentinal caries are labeled D0/D1, D2, and D3/D4, respectively; ranges of relative caries depth corresponding to the respective true diagnoses are marked as "sound", E'Caries, and D'Caries, respectively. Note that due to averaging across examiners, fissure discoloration grades (a) could assume non-integer values.



Tab. II Accuracy and diagnostic performance of visual inspection (VI) as well as electrical conductance (EC) and laser fluorescence (LF) measurements in identifying caries (cut-off at D2) and dentinal caries (cut-off at D3). Significant ($p \leq 0.05$) differences are marked by bars.

	VI	EC	LF
Accuracy			
Clinically sound sites	37.5% — 77.5% — 52.5%		
D2-lesions	40.0%	40.0%	30.0%
D3-/D4-lesions	81.8%	36.4% — 90.9%	
Performance (caries)			
Sensitivity	100.0% — 66.7% — 95.2%		
Specificity	37.5% — 77.5% — 52.5%		
PPV ^a	28.6%	42.6%	33.4%
NPV ^a	100.0%	90.3%	97.8%
ROC-area	0.764	0.785	0.811
Performance (dentinal caries)			
Sensitivity	81.8%	36.4% — 90.9%	
Specificity	68.0% — 90.0%		76.0%
PPV ^b	31.1%	39.1%	40.1%
NPV ^b	95.5%	88.9%	97.9%
ROC-area	0.745	0.727	0.727

^a Adjusted to an estimated prevalence of 20%

^b Adjusted to an estimated prevalence of 15%

although significant differences were found only between EC and LF with respect to sensitivity and between VI and EC with respect to specificity (Table II).

Positive predictive values for the presence of enamel and dentinal caries ranged from about 29% to 43% and from about 31% to 40%, respectively (Table II). Thus, compared to predictions by chance alone (which would yield hit rates corresponding to prevalence values) diagnoses of caries were improved by about 9–25%. In contrast, predictions of the absence of caries (NPV) varied between about 89% and 100% (Table II).

The ROC-areas characterizing the three diagnostic procedures in detecting either caries deeper than D1-lesions or dentinal caries were similar (Table II). The respective ROC-curves also disclosed only slight differences regarding the identification of enamel caries (Fig. 3a). With respect to the identification of dentinal caries (Fig. 3b), however, the performance of the procedures differed. In the high sensitivity/low specificity range, VI and LF performed somewhat better than EC. In the low sensitivity/high specificity range, where the ROC-curve characterizing the performance of VI is theoretical, because this method did not offer any cut-off points beyond discoloration grade 2, EC yielded higher specificities than LF. The inferior performance of LF was mainly due to a marked drop in sensitivity without a proportionate gain in specificity above the threshold of 10 LF-units. As a result, the corresponding positive predictive values revealed a maximum of about 0.35 at 10 LF-units and decreased at higher cut-off values (Fig. 3d). In contrast, the positive predictive values produced by EC increased almost continuously and attained levels around 0.45 for the prediction of caries at the dentinal level (Fig. 3c).

When EC was used as an adjunct to VI for the identification of dentinal caries, the high sensitivity attained with VI alone dropped to about 36%, i.e. the value produced by EC alone. Conversely, the specificity increased to 96% at a cut-off value of 8 units, yielding positive and negative predictive values of about 62% and 90%, respectively. With the complementary use of LF,

optimal performance was achieved at a threshold of 10 units with a sensitivity of about 82%, a specificity of 84%, and positive and negative predictive values of about 47% and 96%, respectively.

Discussion

Although the teeth used for validation were chosen to obtain an even distribution of all grades of fissure discoloration, only 11 out of the 61 specimens exhibited dentinal caries. This rather low frequency renders estimates of diagnostic performance susceptible to confounding effects of e.g. staining, deposits, or irregular enamel structure in the fissures and may account for part of the discrepancies between the present and previous findings. On the other hand, the caries prevalence found in our experimental teeth was about two to three times higher than that observed in randomly selected individuals of a comparable age (STEINER M. personal communication). Therefore, the prevalence of caries was adjusted for obtaining clinically relevant estimates of positive and negative predictive values.

The technique of VI applied in this study has been introduced by MARTHALER (1966). Although it has been refined in various ways since then, the method has been and still is widely used in numerous epidemiologic surveys (MENGHINI et al. 1998). However, it has never been validated histologically so far.

In order to simulate the clinical circumstances of LF measurements, the saliva substitute Glandosan[®] was used as a fluid interface between the probe tip and the experimental teeth. Glandosan[®] has been reported to be acidic and to cause considerable decalcification of enamel after a storage period of two weeks (KIELBASSA et al. 2002). If significant decalcification had occurred during LF measurements as well, the lesion depth would have been overestimated systematically. However, no indication for such an effect could be detected, apparently because the application periods of the saliva substitute were too short.

In comparison to the findings of a majority of previous studies (LUSSI 1991, 1993, 2000, VERDONSCHOT et al. 1993, IE et al. 1995, RICKETTS et al. 1995, HUYSMANS et al. 1998, PEREIRA et al. 2001), VI exhibited a better reproducibility and sensitivity, but a lower specificity. This discrepancy seems to be related to the way caries is graded visually. When the examiners (LUSSI 1991, 1993, 2000, VERDONSCHOT et al. 1993, IE et al. 1995, RICKETTS et al. 1995, HUYSMANS et al. 1998, PEREIRA et al. 2001) were asked to identify the degree of caries on the basis of their own, mostly not further specified criteria and experience, reproducibility and sensitivity were low, while specificity was high. Conversely, reproducibility was good and sensitivity higher than specificity, when the examiners, as in our study, had to indicate only the degree of fissure discoloration (VERDONSCHOT et al. 1992, EKSTRAND et al. 1997). Therefore, when VI based on fissure discoloration is used as the sole technique, it is associated with a risk of false positive diagnoses and, hence, unnecessary treatments of about 70%.

In accordance with the findings from previous studies (VERDONSCHOT et al. 1992, IE et al. 1995, LUSSI et al. 1995, RICKETTS et al. 1995, EKSTRAND et al. 1997, LUSSI et al. 1999, LUSSI 2000), both EC and LF exhibited good to excellent repeatability, which renders them suitable for longitudinal monitoring. At the predetermined cut-off values used in our evaluation, EC was generally more specific, but less sensitive than LF. In fact, the sensitivities obtained with EC are among the lowest and vice versa the specificity values among the highest observed so far. It would

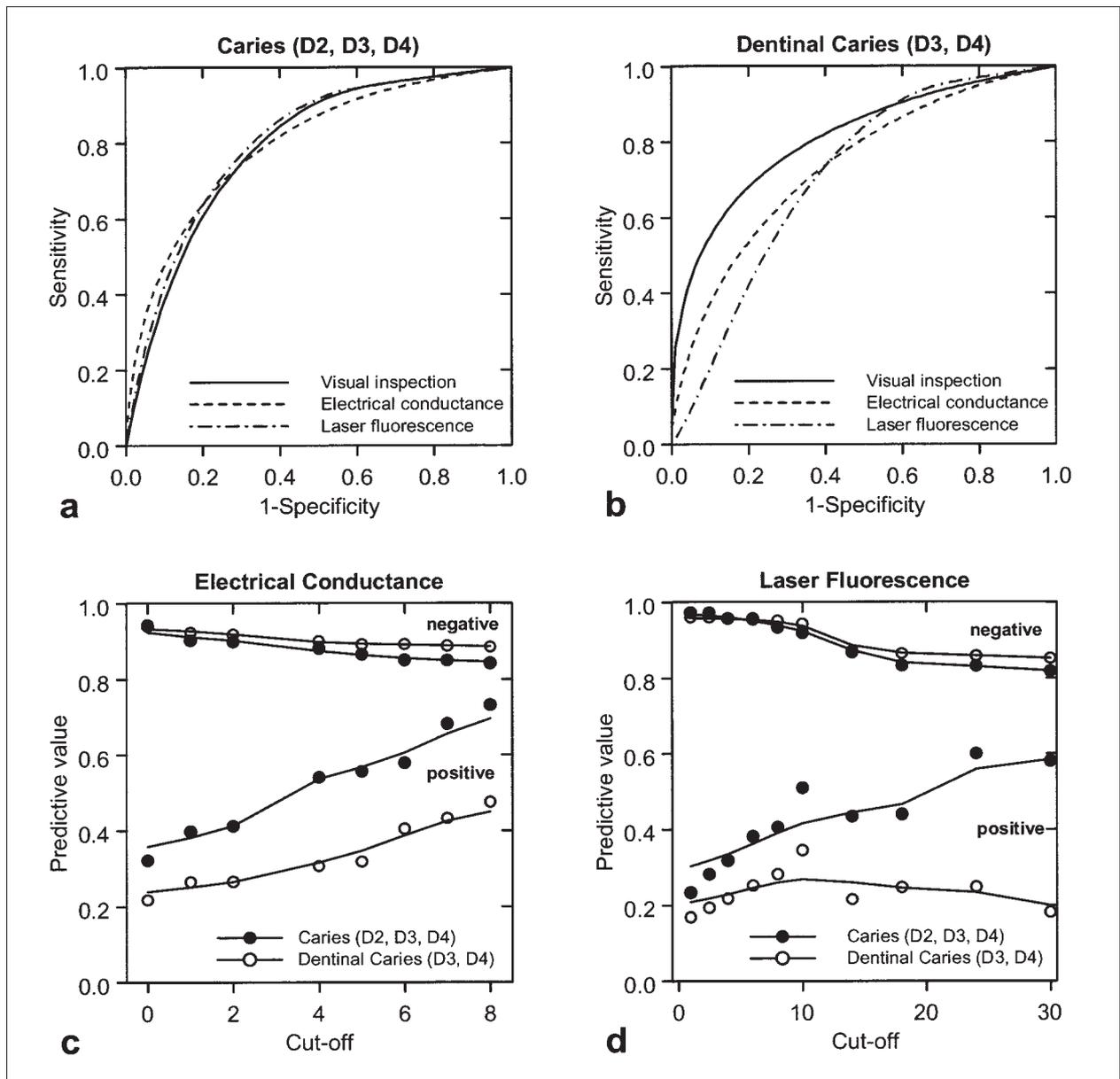


Fig. 3 Parametric ROC-curves regarding the identification of caries (a) and dentinal caries (b) with the three diagnostic methods and corresponding positive and negative predictive values regarding the identification of caries (c) and dentinal caries (d) with EC and LF measurements, plotted as a function of the cut-off values.

appear, therefore, that recommendations for the usage of the ECM are well adjusted to a situation of low caries prevalence, where specificity is more important than sensitivity.

In comparison with previous *in vitro* investigations of LF (LUSSI et al. 1999, SHI et al. 2000), which in the absence of pertinent experience relied on cut-off values derived from the examined teeth, our evaluation yielded somewhat higher sensitivities and slightly lower specificities. Using the same predetermined cut-off values as in our study, PEREIRA et al. (2001) obtained considerably higher specificities and markedly lower sensitivities. These authors argued that their deviating findings could possibly be attributed to sampling as well as non-random variability of the DIAGNOdent instruments. Our results do not support

such an assumption, although a reason for the discrepancy between our and the close to perfect ROC-curves of SHI et al. (2000) was not readily apparent either.

As indicated by the predictive values, the performance of both EC and LF alone was unsatisfactory, the risks of false positive diagnoses amounting to about 60%. An improvement in reliability was achieved, when these techniques were applied as an adjunct to VI in teeth displaying fissures with a dark discoloration, and when cut-off values were raised. In the case of EC, this produced a more or less continuous increase of positive predictive values to about 60% at the level of dentinal caries. For unknown reasons, the reliability of diagnoses from LF, however, increased only up to a cut-off value of about 10.

These findings suggest that in permanent teeth of adolescents and young adults, VI is suitable to safely rule out the presence of caries, when fissures are not discolored. When higher than the recommended cut-off values are applied, the supplementary use of EC and LF appears to improve the insufficient performance of VI in identifying dentinal caries. Still, attainable reliabilities of diagnoses do not seem to exceed about 50% to 60%.

Acknowledgments

The authors cordially thank Mrs. Andrea Werlen for her careful laboratory work and preparation of the scanning electron micrographs. Heartfelt thanks are due to Drs. Giorgio Menghini and Marcel Steiner (Clinic of Preventive Dentistry, Periodontology, and Cariology, Center of Dental and Oral Medicine, University of Zurich) for their collaboration in determining the reproducibility of the visual inspection and for providing epidemiologic data on the prevalence of occlusal caries. Last but not least we are grateful to Prof. Theo Gasser and Dr. Burkhardt Seifert (Institute of Social and Preventive Medicine, University of Zurich) for their advice on statistical analyses.

Zusammenfassung

Das Ziel dieser Studie war, Diagnosen von Fissurenkaries, die mit visueller Inspektion (VI), Messungen der elektrischen Leitfähigkeit (EC) und Laserfluoreszenz-Messungen (LF) gestellt wurden, zu vergleichen. Bei der VI wurde mit blossen Auge der Grad der Fissurenverfärbung beurteilt. Die elektrische Leitfähigkeit wurde mit dem ECM Gerät (Lode Diagnostic, Groningen, Niederlande) gemessen, und zur Bestimmung der Laserfluoreszenz diente der DIAGNodont Apparat (KaVo, Biberach, Deutschland). Unter Anwendung etablierter Beurteilungskriterien wurden an extrahierten menschlichen Prämolaren und Molaren klinisch gesunde Stellen (D0-/D1-Läsionen), Schmelzkaries (D2-Läsionen) und Dentinkaries (D3-/D4-Läsionen) identifiziert. Danach wurden die Zähne axial entzwei geschnitten und für die Untersuchung im REM präpariert. Die Reproduzierbarkeit der VI war gut, die von EC und LF hervorragend. Bei der Identifikation von Schmelz- und Dentinkaries war die Sensitivität der VI und von LF signifikant ($p < 0,05$) höher als die von EC, während EC signifikant ($p < 0,05$) spezifischere Diagnosen ergab. Die positiven Voraussagewerte überstiegen jedoch den Wert von 43% nicht. Zuverlässigere Diagnosen von Dentinkaries ergaben sich, wenn EC und LF als Ergänzung zur VI verwendet oder die diagnostisch massgebenden Schwellenwerte erhöht wurden. Die Ergebnisse zeigen, dass mit einer visuellen Beurteilung der Fissurenverfärbung nur gesunde Okklusalfächen zuverlässig identifiziert werden können. In Fällen von verfärbten Fissuren tragen die Messgeräte zwar dazu bei, falsch positive Identifikationen von Dentinkaries zu vermeiden, die damit erreichte Zuverlässigkeit der Diagnosen scheint aber 50% bis 60% nicht zu übersteigen.

Résumé

L'objectif de cette étude était de diagnostiquer des caries occlusales en comparant les méthodes suivantes: inspection visuelle (IV), mesures par conductibilité électrique (CE) et mesures par fluorescence laser (FL). IV pratiquée à l'œil nu se basait sur le changement de couleur des fissures. CE était mesurée avec l'équipement ECM (Lode Diagnostic, Groningue, Pays-Bas). La détermination par FL s'était faite au moyen de l'appareil DIA-

GNOdent (KaVo, Biberach, Allemagne). A partir de prémolaires et molaires humaines extraites, des zones saines (lésions D0/D1), des caries dans l'émail (lésions D2) et des caries dentinaires (lésions D3/D4) ont été identifiées sur la base de critères établis. Par la suite, les dents ont été axialement sectionnées en 2 parties et préparées pour l'observation au MEB. La reproductibilité pour IV était bonne, tandis que celles concernant CE et FL étaient remarquables. Pour l'identification des caries au niveau de l'émail et de la dentine, les sensibilités de IV et par FL étaient significativement plus élevées que celle par CE ($p < 0,5$), alors que CE produisait de façon significative ($p < 0,5$) des diagnostics plus spécifiques. Cependant les valeurs de prédiction ne dépassèrent pas 43%. Des diagnostics plus fiables de caries dentinaires ont été obtenus quand les mesures par CE et FL ont été utilisées en tant qu'aide complémentaire à IV ou quand les valeurs de seuil diagnostique ont été sensiblement augmentées. Les résultats montrent que par inspection visuelle des changements de couleur des fissures, seules les surfaces occlusales saines peuvent être fiablement identifiées. Bien que dans les cas de changement de couleur des fissures, l'apport d'appareils de mesure contribue à éviter de fausses identifications positives de caries dentinaires, la fiabilité diagnostique obtenue ne semble pas dépasser 50% à 60%.

References

- ASHLEY P F, BLINKHORN A S, DAVIES R M: Occlusal caries diagnosis: an in vitro histological validation of the electronic caries monitor (ECM) and other methods. *J Dent* 26: 83–88 (1998)
- EKSTRAND K R, RICKETTS D N J, KIDD E A M: Reproducibility and accuracy of three methods for assessment of demineralization depth on the occlusal surface: An in vitro examination. *Caries Res* 31: 224–231 (1997)
- HIBST R: Optische Messmethoden zur Kariesdiagnose. *ZWR* 108: 50–55 (1999)
- HUYSMANS M-C D N J M, LONGBOTTOM C H, PITTS N B: Electrical methods in occlusal caries diagnosis: An in vitro comparison with visual inspection and bite-wing radiography. *Caries Res* 32: 324–329 (1998)
- IE Y L, VERDONSCHOT E H, SCHAEKEN M J M, VAN'T HOF M A: Electrical conductance of fissure enamel in recently erupted molar teeth as related to caries status. *Caries Res* 29: 94–99 (1995)
- KIELBASSA A M, SHOHADAI S P, SCHULTE-MÖNTING J: Effect of saliva substitutes on mineral content of demineralized and sound dental enamel. *Support Care Cancer* 9: 40–47 (2002)
- LUSSI A: Validity of diagnostic and treatment decisions of fissure caries. *Caries Res* 25: 296–303 (1991)
- LUSSI A: Comparison of different methods for the diagnosis of fissure caries without cavitation. *Caries Res* 27: 409–416 (1993)
- LUSSI A: Laserinduzierte Fluoreszenz zur Erkennung der Okklusalkaries. Erste In-vivo-Resultate. *Acta Med Dent Helv* 5: 15–19 (2000)
- LUSSI A, FIRESTONE A, SCHOENBERG V, HOTZ P, STICH H: In vivo diagnosis of fissure caries using a new electrical resistance monitor. *Caries Res* 29: 81–87 (1995)
- LUSSI A, IMWINKELRIED S, PITTS N B, LONGBOTTOM C, REICH E: Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. *Caries Res* 33: 261–266 (1999)
- LUSSI A, MEGERT B, LONGBOTTOM C, REICH E, FRANCESCUT P: Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. *Eur J Oral Sci* 109: 14–19 (2001)

- MARTHALER T M: A standardized system of recording dental conditions. *Helv Odont Acta* 10: 1–18 (1966)
- MENGHINI G D, STEINER M, MARHALER T M: Zahngesundheit und weitere orale Befunde bei Schülern in 16 Landgemeinden des Kantons Zürich 1996. *Acta Med Dent Helv* 3: 87–92 (1998)
- PEREIRA A C, VERDONSCHOT E H, HUYSMANS M C D N J M: Caries detection methods: Can they aid decision making for invasive sealant treatment? *Caries Res* 35: 83–89 (2001)
- RICKETTS D N J, KIDD E A M, LIEPINS P J, WILSON R F: Histological validation of electrical resistance measurements in the diagnosis of occlusal caries. *Caries Res* 30: 148–155 (1996)
- RICKETTS D N J, KIDD E A M, WILSON R F: A re-evaluation of electrical resistance measurements for the diagnosis of occlusal caries. *Br Dent J* 178: 11–17 (1995)
- SAWLE R F, ANDLAW R J: Has occlusal caries become more difficult to diagnose? A study comparing clinically undetected lesions in molar teeth of 14–16-year old children in 1974 and 1982. *Br Dent J* 164: 209–211 (1988)
- SHI X-Q, WELANDER U, ANGMAR-MÄNSSON B: Occlusal caries detection with KaVo DIAGNOdent and radiography: An in vitro comparison. *Caries Res* 34: 151–158 (2000)
- VERDONSCHOT E H, BRONKHORST E M, BURGERSDIJK R C W, KÖNIG K G, SCHAEKEN M J M, TRUIN G J: Performance of some diagnostic systems in examinations for small occlusal carious lesions. *Caries Res* 26: 59–64 (1992)
- VERDONSCHOT E H, WENZEL A, TRUIN G J, KÖNIG K G: Performance of electrical resistance measurements adjunct to visual inspection in the early diagnosis of occlusal caries. *J Dent* 21: 332–337 (1993)
- WENZEL A, FEJERSKOV O, KIDD E, JOYSTON-BECHAL S, GROENEVELD A: Depth of occlusal caries assessed clinically, by conventional film radiographs, and by digitized, processed radiographs. *Caries Res* 24: 327–333 (1990)