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# Validity of Electrical Conductance Measurements in Evaluating the Marginal Integrity of Sealant Restorations

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**Key Words**

Electrical conductance  
Leakage  
Sealant  
Secondary caries

.....  
**Abstract**

The use of sealants and sealant restorations has increased considerably over the past 10 years, and with it increased the problem of detecting secondary caries and marginal (micro)leakage. It was the purpose of this study to investigate the validity of electrical conductance measurements (ECMs) in diagnosing marginal leakage into dentine of sealants and sealant restorations. Ninety extracted premolar teeth were divided into three groups. Initial ECMs, denoted 'baseline ECMs', were conducted in all three groups by placing the probe tip of an Electronic Caries Monitor in the occlusal fissure which was filled with a dentifrice. The ECMs were divided by the area, yielding ECM/mm<sup>2</sup> values. In group A 30 teeth were treated to receive 'nonleaking sealants'. In the 30 teeth of group B a narrow groove was cut at the occlusal surface reaching the dentine and restored by the application of a sealant without etching of the adjacent enamel to create a high probability of marginal leakage. The samples in group C received the same treatment as those in group B, but in this group the enamel was etched to reduce the probability of marginal leakage. The ECMs subsequently conducted were denoted 'sealed/restored ECMs'. Teeth in groups B and C were thermocycled 700 times (4-67°C) to provoke leakage, after which ECMs were conducted (denoted 'ECMs after thermocycling'). The teeth were immersed in fuchsin for 24 h and cut along the fissure system to validate marginal leakage. The electrical conductance decreased significantly from baseline to the sealed/restored stage in all groups ( $p < 0.05$ ). The electrical conductance per unit area increased in groups B and C after thermocycling. The electrical conductance, irrespective of area, increased significantly after thermocycling ( $p < 0.05$ ) only in group C. The sensitivities of ECMs per unit area and ECMs were 0.98 and 1.00, respectively, and the specificities were 0.77 and 0.79, respectively. The areas under the receiver operating characteristic curves of ECMs per unit area and ECMs were 0.94 and 0.96, respectively. There was no significant difference between the areas under both curves ( $p > 0.05$ ), denoting that ECMs need not necessarily be expressed relative to the area of the electrode. It was concluded that marginal leakage into dentin of sealants and sealant restorations can be accurately detected by ECM.

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Many clinical studies have demonstrated the effectiveness and the longevity of first- and second-generation fissure sealants in the prevention of caries in pits and fissures [Ripa, 1993]. A meta-analysis conducted by Llodra et al. [1993] on published data from controlled clinical studies which started between 1970 and 1978 indicated that the effectiveness of sealants to prevent the onset of caries (prevented fraction) ranged from 71 to 82%. Survival rates of 70–80% after 5–10 years of function have been reported. Those cases reported as failures were frequently associated with loss of (parts of) the sealants, a phenomenon that is likely to be preceded by marginal leakage or secondary caries. Despite the demonstrated positive effect of fissure sealing, this preventive treatment has not been introduced into routine clinical practice [Gift and Frew, 1986; Cohen et al., 1988]. The restrictive attitudes of general practitioners toward fissure sealing were explained by the unavailability of a sufficiently valid caries-predictive test to identify teeth that are in need of a sealant, the high work load associated with the treatment, the difficulties in treating freshly erupted teeth in young children, and the problems of detecting secondary caries and microleakage.

The diagnosis of secondary caries associated with sealants or sealant restorations and the assessment of marginal integrity can be troublesome, particularly if the resin material is plaque, thus obscuring the view of any progression of decay. For this reason the use of translucent sealant materials has been advocated. However, the material does not allow the dentist to clearly distinguish a fissure sealant from a sealant restoration [Deery and Pitts, 1992], and it is hence expected that neither caries nor microleakage can be detected accurately under translucent sealants. Recent reports on the performance of fissure sealants in arresting the caries process under sealed fissures indicate that this strategy can be successful [Mertz-Fairhurst et al., 1992], but will at the same time call for sophisticated diagnostic techniques to detect marginal leakage, as arrested lesions may become progressive under seemingly well-adapted sealants [Weerheijm et al., 1992].

The presence of secondary caries and marginal leakage of sealants has predominantly been assessed by visual inspection. Even after thorough training in diagnosis by visual inspection, still many false-positive and false-negative diagnoses can be expected to occur. It has, therefore, been recommended that sealants be replaced when only minimal evidence of leakage is observed. This strategy has the potential to lead to the removal of many well-functioning fissure sealants, so reducing cost-effectiveness.

In occlusal caries diagnosis, the value of electrical conductance measurements (ECMs) has been investigated dur-

ing the past 20 years. It was found that the electrical conductivity of matured dental enamel was low [Hoppenbrouwers et al., 1986]. Rock and Kidd [1988] found a relationship between electrical conductance measurements and enamel decalcification. Carious lesions penetrating the dentin from the base of the fissure could be detected under both in vitro and in vivo conditions by measuring the electrical conductance of the enamel [White et al., 1978; 1981; Williams et al., 1978; Flaitz et al., 1986; Verdonschot et al., 1992, 1993c; Ie and Verdonschot, 1994]. From these results, and from the low electrical conductivity of resin materials in general, it was hypothesized that ECMs of the entire sealant or sealant restoration including the margins would yield valid indications of secondary caries or marginal leakage into dentine. It was the objective of this study to evaluate the validity of ECMs in detecting marginal leakage of fissure sealants and sealant restorations under in vitro conditions using a one-measurement per surface technique. Marginal leakage in this study was defined as the existence of a connection between the outer tooth surface and the dentine at the margin of a sealant.

## Materials and Methods

### *Teeth*

The material consisted of 90 premolar teeth without visible carious lesions in the fissure. The teeth had been extracted for orthodontic reasons and were stored in a physiologic saline solution immediately after extraction. An attempt was made to balance the numbers of nonleaking and leaking sealants and sealant restorations in the entire sample. For this purpose, the teeth were randomly divided into three groups of 30 premolars each. Table 1 presents the various stages of treatment of the teeth in each group. Samples in group A were treated to receive a fissure sealant according to present-day standards. The resulting sealants were denoted 'nonleaking sealants'. Specimens in group B were treated in such a way that 'leaking sealant restorations' would result, whereas the teeth in group C would contain mainly 'nonleaking sealant restorations'. All teeth were kept moist during all stages of treatment.

### *'Nonleaking Sealant'*

To ascertain that a substantial number of negative test outcomes (samples with low electrical conductance) would be available in the analysis, 30 premolars were sealed leaving the enamel intact. The fissure was cleaned with a pumice slurry. The area around the fissure was etched for 30 s, and Estiseal sealant (Heracus Kulzer, Wehrheim, Germany) was applied and light cured during 60 s.

### *'Leaking Sealant Restoration'*

To ascertain that a substantial number of positive test outcomes (samples with high electrical conductance) would be available in the analysis, 30 premolars received sealant restorations which had a high probability of having or developing marginal leakage. The fissure was cleaned with a pumice slurry, discolorations were removed from the

**Table 1.** Sequence of treatments to which three groups of 30 premolar teeth were subjected

Stage	Group A (‘nonleaking sealant’)	Group B (‘leaking sealant restoration’)	Group C (‘nonleaking sealant restoration’)
Baseline	ECM area measurement	ECM area measurement	ECM area measurement
Sealed/restored	ECM area measurement histological validation	ECM area measurement thermocycling	ECM area measurement thermocycling
Thermocycled		ECM area measurement histological validation	ECM area measurement histological validation

fissure enamel by using a small cone-shaped diamond bur (smallest diameter 0.5 mm; largest diameter 1.0 mm), and a small groove of 3 mm depth was made at one of the marginal fossae using a diamond bur with a diameter of 1.0 mm. Care was taken to prepare this groove into dentin. The fissure enamel was etched for 30 s, and Estiseal sealant was applied and cured during 60 s. Using the diamond bur, the sealant material was removed from the groove and the adjacent enamel, and new sealant was applied without etching and subsequently cured.

#### ‘Nonleaking Sealant Restoration’

To further increase the number of both negative and positive test outcomes, 30 premolar teeth were restored by a ‘suboptimal’ restorative procedure. The fissure was cleaned with a pumice slurry, and a groove similar to that in the ‘nonleaking’ sample was made at one of the marginal fossae. The enamel was etched for 30 s, contrary to good clinical practice which prescribes a highly filled composite resin to restore dentinal defects, the groove was filled with Estiseal sealant and cured in two increments. The entire fissure was sealed by application of a final layer covering the fissure and the restoration. It was estimated that, due to shrinkage of the sealant resin, 30–70% of these specimens would show marginal leakage after thermocycling.

#### Electrical Conductance Measurements

An Electronic Caries Monitor (Borsboom Sensortechnology, Westeremden, The Netherlands), specially designed for the detection of dentinal carious lesions in fissures, was employed. The Electronic Caries Monitor measures the electrical conductance of enamel at the electrode. The logarithm of the unit of electrical conductance (R; kΩ) is a third-power function of ECM and has been reported by Huysmans et al. [1995]:

$$\log(R) = -0.002196 \text{ ECM}^3 + 0.042114 \text{ ECM}^2 - 0.37869 \text{ ECM} + 4.5341$$

The cusps and approximal ridges were dried with a cotton roll to prevent the electrical current from ‘escaping’ through a superficial layer of moisture. A blue-colored dentifrice (Sensodyne F; Stafford Miller Nederland, Hoofddorp, The Netherlands) was syringed onto the fissure enamel for baseline measurements. Care was taken that the toothpaste covered the entire margin of the resin when the conductance of the sealed or restored fissure was measured. The roots of a tooth

were placed in a saline solution containing the reference electrode which was connected to the Electronic Caries Monitor. The probe tip was subsequently placed in the toothpaste at a random location. The measurements (ECMs) are converted by the machine into continuous output data ranging from –1.00 (low electrical conductance) to 13.00 (high electrical conductance). According to the manufacturer of the Electronic Caries Monitor, ratings 6.00 and higher would reflect a leakage into dentin when using the probe tip as electrode area.

#### Area Measurement

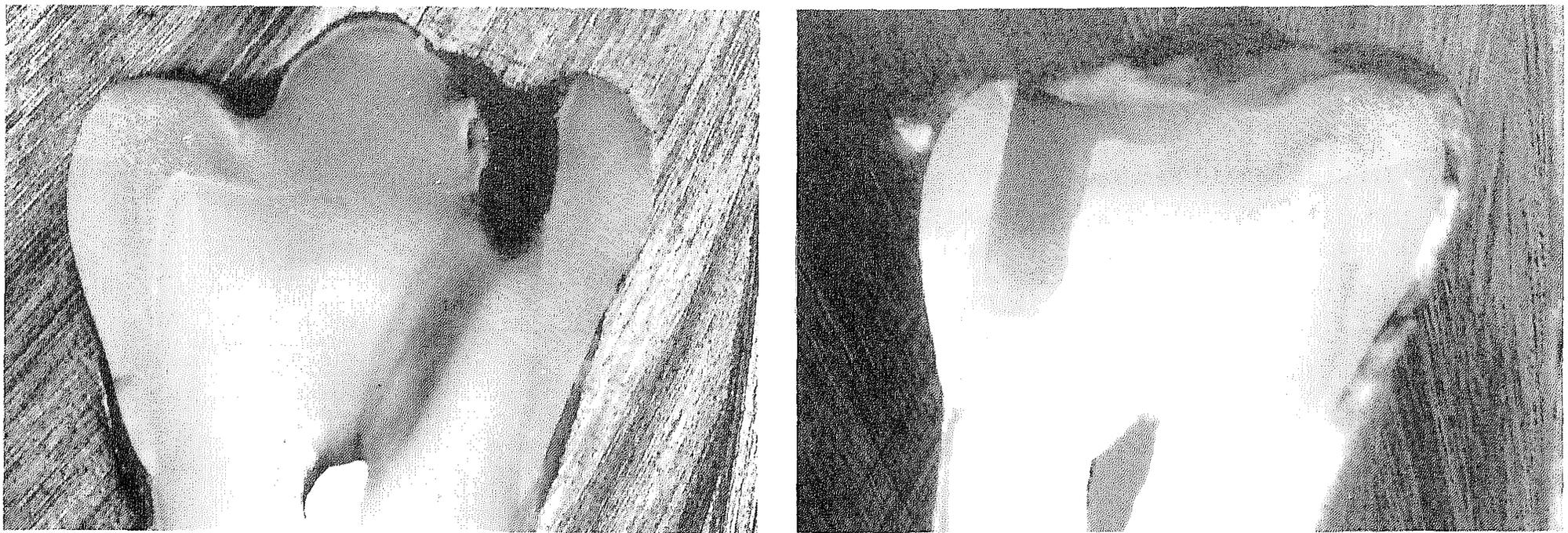
It was hypothesized that the measurements of the electrical conductance would be dependent on the area of the electrode, i.e., the area of the toothpaste. To measure the area of the toothpaste, color slides were made from the occlusal surfaces together with a metric reference. The optical contrast between enamel and toothpaste was enhanced by the addition of a few drops of blue ink to the toothpaste. The color slides were digitized using a CCD camera and an imaging board (Matrox, Dorval, Que., Canada). The area of one pixel was calculated and multiplied by the number of pixels on the blue-colored dentifrice, according to the method described by Verdonschot et al. [1990].

#### Thermocycling and Histological Validation

Fissure sealants and sealant restorations were thermocycled between relatively extreme temperatures (700 cycles of 3 min at 4°C and of 3 min at 67°C) to provoke microleakage. The coronal parts of the teeth were placed in basic fuchsin for 24 h, after which the teeth were embedded in polymethylmethacrylate. Two sections with a thickness of 0.8–1.0 mm were cut through and along the fissure system. The section showing the deepest penetration of fuchsin at the margin toward the dentin was used for validation. The sections were rated by two observers separately, using the following rating scale: 0 = no penetration of dye into dentine, denoting no marginal leakage into dentin, and 1 = any penetration of dye into dentine, denoting marginal leakage into dentin. Joint decisions by the two observers were made in those cases in which the observers disagreed on the histology ratings.

#### Data Treatment

Differences between the ECMs per unit area and between ECMs irrespective of area obtained after the stages ‘baseline’, ‘sealed/restored’, and ‘thermocycled’ were tested using a paired t test at  $\alpha = 0.05$ . Sensitivities and specificities of ECM per unit area and ECM were calculated with a cutoff at ECM rating 6.50 (just beyond the center of



**Fig. 1.** Stained sections used for validation. **a** Dye penetrated into dentine. **b** No leakage of dye into dentine.

**Table 2.** Areas of electrodes, mean ECM per unit area (ECM/mm<sup>2</sup>), and standard deviations (SD)

Treatment stage	Group A			Group B			Group C		
	electrode area, mm <sup>2</sup>	mean ECM/mm <sup>2</sup>	SD	electrode area, mm <sup>2</sup>	mean ECM/mm <sup>2</sup>	SD	electrode area, mm <sup>2</sup>	mean ECM/mm <sup>2</sup>	SD
Baseline	7.33	0.99	0.41	6.99	1.02	0.44	8.52	1.01	0.48
Sealed/restored	10.05	0.54	0.21	10.36	0.84	0.41	7.70	0.54	0.12
Thermocycled				9.90	1.02	0.21	8.95	1.24	0.25

\*Paired t test:  $p < 0.05$ .

the scale) and using histology ratings as validating criterion. Sensitivity in this respect reflects the number of true-positive test outcomes (ECM values  $> 6.50$ ) relative to the total number of cases in which histological observation showed leakage into dentine, whereas specificity is the number of true-negative outcomes (ECM values  $< 6.50$ ) relative to the total number of cases in which histological observation showed no leakage into dentine. Receiver operating characteristic (ROC) analysis, also using histological ratings as validating criterion, was performed to evaluate sensitivity as a function of specificity. ROC analysis performed on the output data of the Electronic Caries Monitor is permitted, as these ratings are on an ordinal level and possess a monotonic relationship with the likelihood ratio [Verdonschot et al., 1993a, b], i.e., the ratings obtained from the Electronic Caries Monitor represent interpretations of electrical conductance measurements. The area under a ROC curve reflects the performance of the diagnostic test. The area under the ROC curve of ECM per unit area was compared to the area under the ROC curve of ECM by a Z-score test for correlated data [Hanley and McNeil, 1983].

## Results

After histological validation, 59 samples showed marginal leakage into dentine (fig. 1a), whereas in 31 cases (30 in group A and 1 in group B) no signs of dye penetration into dentin were observed (fig. 1b). Table 2 shows the ECMs per unit area obtained at baseline, after sealing or restoration, and after thermocycling. The ECMs per unit area decreased statistically significantly from baseline to the sealed/restored stage in all groups ( $p < 0.05$ ). The ECMs per unit area of the restored specimens (groups B and C) increased significantly after thermocycling ( $p < 0.05$ ).

When comparing the ECMs irrespective of area (table 3), the ECMs of the specimens in groups A and C decreased from baseline to the sealed/restored stage ( $p < 0.05$ ), whereas the conductance of the teeth in group B increased statistically significantly. No statistically significant difference was found among the ECMs from the restored and thermocycled specimens in group B, whereas the

**Table 3.** Mean ECM and standard deviations (SD) of ECM

Treatment stage	Group A		Group B		Group C	
	mean ECM	SD	mean ECM	SD	mean ECM	SD
Baseline	6.88	2.30	7.07	3.05	8.43	3.62
Sealed/restored	5.24	1.83	8.36	3.67	4.06	0.69
Thermocycled			9.77	1.56	10.83	1.16

\*Paired t test:  $p < 0.05$ .

ECMs in group C increased significantly from the restored to the thermocycled stage ( $p < 0.05$ ).

The sensitivities of ECMs per unit area and ECMs were 0.98 and 1.00, respectively, indicating an almost perfect to perfect ability of the diagnostic test to correctly identify truly leaking sealant restorations (table 4). The moderate specificities (0.77 and 0.79) indicate that still some false-positive test results were obtained. The areas under the ROC curves of ECMs per unit area and ECMs (fig. 2) were both very high and approached the maximum value of 1.00. There was no significant difference between the areas under both curves ( $p > 0.05$ ), denoting that ECMs need not necessarily be expressed relative to the area of the electrode to be used as an accurate diagnostic tool.

## Discussion

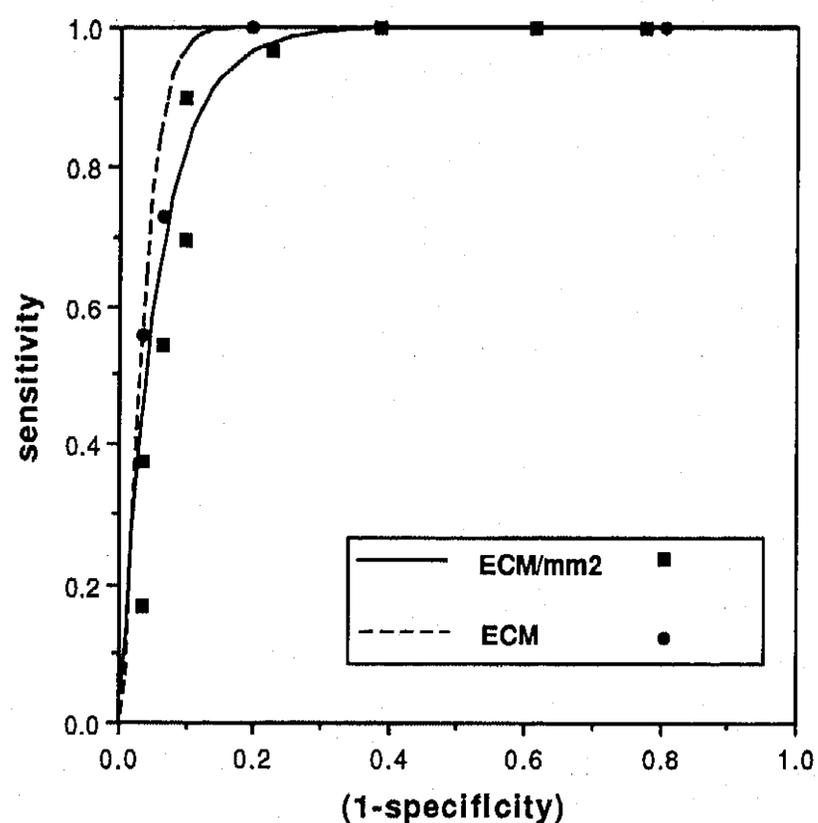
The objective of this study was to investigate the feasibility of detecting marginal leakage into dentine around sealants and sealant restorations. For this purpose, the generally accepted guidelines for the preparation and application of sealant restorations were not adopted, but instead were modified such that marginal leakage would likely occur in group B and would eventually occur in group C. It should be stressed that in the present study no attempt was made to evaluate the quality of a sealant resin, nor that of sealants or sealant restorations.

Area measurements were performed to express the electrical conductance, as it was found by Hoppenbrouwers et al. [1986] that the resistivity of human enamel was dependent on the area of the electrode. The areas measured at baseline in this study, however, were not the true electrode areas, but were preferred because the area of the converging cusps adjacent to the fissure could not conveniently be determined. Since the areas at baseline will be underestimated, the values of ECM/mm<sup>2</sup> shown in table 2 will hence be overestimations. This makes the value of the ECMs per unit area obtained at baseline difficult to interpret. The areas of the

**Table 4.** Sensitivities and specificities of ECMs and results of ROC analysis

Diagnostic method	Cutoff	Sensitivity	Specificity	Area under the ROC curve
ECM/mm <sup>2</sup>	0.70	0.98	0.77	0.94
ECM	6.50	1.00	0.79	0.96

\*Z-score test:  $p > 0.05$ .



**Fig. 2.** ROC graphs expressing the performance of ECM per unit area (ECM/mm<sup>2</sup>) and ECM in detecting marginal leakage.

sealed/restored specimens could be measured more accurately because the base of the fissure was filled up by the sealing procedure to form a 'platform'. The mean electrical conductances of the nonleaking sealed (group A) and the nonleaking restored (group C) occlusal surfaces were both 0.54 ECM/mm<sup>2</sup> before thermocycling. The fall in electrical

conductance from baseline to 0.54 ECM/mm<sup>2</sup> in these groups is in part caused by the underestimated electrode area and in part by the addition of a layer of resin material with a high electrical resistivity. The value of 0.84 ECM/mm<sup>2</sup> in group B, obtained after sealing but before thermocycling, can be explained by the presence of marginal leakage in a number of restorations at that stage.

In investigating whether ECMs can be applied as routine diagnostic procedures in general practice, feasibility and convenience of the procedure are of utmost importance. Because the determination of the area of the electrode is a very complicated aspect of the diagnostic procedure, the value of ECMs in detecting marginal leakage was also assessed irrespective of the area. In general, the data presented in table 3 show the same trend as those in table 2. A decrease in electrical conductivity from baseline to the sealed/restored stage can be observed in groups A and C. This decrease was also observed when expressing the electrical conductance per unit area. However, an increase from 7.07 to 8.36 ECM/mm<sup>2</sup> was observed in group B, whereas a decrease from 1.02 to 0.84 ECM/mm<sup>2</sup> is reported in table 2. These apparently contradictory results were caused by the generally very large area of toothpaste (10.36 mm<sup>2</sup>) applied during the ECMs in the sealed/restored stage in group B. This also explains the different outcomes of the statistical tests applied to the ECMs per unit area and the ECMs irrespective of area in group B. This illustrates that ECMs irrespective of area should be interpreted with caution.

Marginal leakage in this study was defined in terms of dye penetration into dentine. The criterion of dentinal involvement was selected because enamel is known to have a very low electrical conductance. Adopting leakage into enamel as evaluation criterion would undoubtedly have caused more false-negative test outcomes, thus reducing the sensitivity of ECMs. It is, therefore, unlikely that ECMs could be used to accurately detect marginal leakage restricted to enamel. However, when a pathway exists between the electrode and the electrolyte-containing dentine through which ions can readily pass, electrical current and conductance can be measured reliably. The results from this study indicate that nonleaking sealants were associated with a value of about 0.54 ECM/mm<sup>2</sup> and with an ECM of about 5.24. Since all restorations in group C and 29 out of 30 restorations in group B presented marginal leakage upon histological validation, leaking sealant restorations were associated with 1.02 and 1.24 ECM/mm<sup>2</sup> and ECMs of 9.77 and 10.83, respectively. Apparently, the location of the cutoff that would result in the best differentiation between leaking and nonleaking restorations is in the intervals 0.54–1.02 ECM/mm<sup>2</sup> and 5.24–9.77 ECM, respectively. The cut-

off values chosen in this study to calculate sensitivity and specificity of ECMs and ECMs per unit area were both within these intervals. However, if a cutoff value of 6.50 ECM would have been applied to diagnose 'leakage into dentine' at unsealed and unrestored occlusal surfaces (baseline) in groups A–C, a majority of the diagnostic tests would have been positive, as all averaged ECMs were beyond the cutoff (table 3). Although these test results were not validated, it seems very unlikely that all 90 occlusal surfaces would contain leakages (porosities, caries) into dentine at that stage. Assuming that the unrestored surfaces in group B did not contain leakages and knowing that all thermocycled restorations in group C presented leakage into dentine, an appropriate cutoff value would lie between ECMs 7.07 and 10.83. This cutoff may, however, vary with the type of tooth and size of restoration measured. Future investigations should clarify the impact of these variables on the assessment of marginal integrity of sealants and sealant restorations. In such studies the role of thermocycling in relation to the restoration procedure and the restoration material requires reconsideration, as all but one thermocycled sealant restorations presented leakage upon validation. The application of less extreme temperatures could possibly reduce the number of leaking sealant restorations and may balance the number of nonleaking specimens.

An area of 0.96 under the ROC curve for ECMs indicates that these measurements are almost as perfect in diagnosing marginal leakage into dentine around sealants and sealant restorations as the validating technique. This finding offers attractive opportunities for clinical studies in which the marginal integrity of sealants and composite resin restorations is under study in relation to the detection of dentinal caries. If ECMs are used as validation method, teeth would no longer have to be extracted for validation purposes, hence facilitating the design of a clinical study. However, before ECMs can be adopted as a validating technique, a clinical study equivalent to this *in vitro* study should be envisaged to assert that ECMs can be applied reliably and accurately in patients as well.

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