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Evaluation of a profilometrical method for monitoring erosive tooth wear

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The *in vivo* monitoring of erosive wear is difficult because lesions mostly progress relatively slowly and reliable reference points are difficult to obtain. To date, only a few methods for clinical monitoring of erosive loss have been described, which either require extensive equipment or do not provide sufficient sensitivity. The aim of the present study was to evaluate, using study models (epoxy resin material), a procedure that permits the reliable and accurate monitoring of erosive substance loss within acceptable observation periods. The method is the profilometric measurement of erosive tissue loss using acid-resistant markers, which represent both a reference area and a structure for the defined retracing of a given erosive lesion surface. The study model magnified values slightly (2.8%; not significant), the precision was < 4 μm, and the repeatability was good (95% limits of repeatability ranging from −4.7 to 5.2 μm). The estimated detection threshold for erosive loss is 15 μm, which appears to be adequate for monitoring. The method is indicated for special dental care in cases of severe dental erosion (e.g. eating disorders) and for clinical studies.

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Erosion is a wear process caused by repeated exposure to dietary or gastric acids, without bacterial involvement (1). The acidic attack leads to irreversible mineral substance loss, which, however, ceases if the acid impact is eliminated. The choice of therapy therefore depends on the activity status of the erosion lesion. In the case of inactivity, (restorative) therapy is only indicated if serious functional or aesthetic limitations are apparent. In the case of activity, causal or symptomatic therapeutic approaches should be carried out to render extensive restorations unnecessary. Therefore, a clinical (*in vivo*) monitoring procedure is needed to determine the activity of a given lesion, but also to demonstrate the efficacy of an implemented therapy.

A method for clinical monitoring must fulfill several requirements. Firstly it must allow the quantification of dental substance loss. As the amount of loss to be measured clinically is usually relatively small, the method must also be sensitive to avoid extended observation periods. Furthermore, it must be simple to perform and acceptable for patients; the equipment must be available in several centres and the procedure must be cost effective.

Only a few *in vivo* methods for monitoring changes of tooth morphology have been described (see AZZOPARDI *et al.*) (2). The principle of all of these methods was to compare the status of the dental hard tissue at two consecutive points of time, the difference of which was (erosive) tooth wear. A comparison of consecutive study casts using erosion or wear-indices (3, 4) allowed a macroscopic estimation of wear progression, which, however, is neither sensitive nor suitable for the quantification of erosive loss. Numerous methods are based upon superimposition techniques. Optical methods use microscopic techniques, generating consecutive images of dental casts that are superimposed either by hand (5) or in computerized systems (6), but involve significant errors. Other systems generate computerized superimposed three-dimensional (3D) digital images by profiling consecutive dental casts with a null contact profiler (7, 8) or with an optical 3D sensor (9). The accuracy and the precision of these methods are very high, but the former has been developed only for occlusal surface measurement and the latter needs expensive equipment. The use of electro-conductive replicas, and the comparison of consecutive models with an algorithm, allow only semi-quantitative analyses to be carried out (10–12). The measurement of enamel thickness with ultrasonic pulse echo is easy to perform, but shows high variation in results (13).

To date, profilometry, which is well established for *in vitro* and *in situ* studies, has not been definitely modified for clinical application. Even if several other methods are well established (14–17), profilometry is widely used *in vitro* and *in situ* for the measurement of losses greater than 2 μm (16, 18–22) and is easy to perform. This method has been thoroughly validated (16) and is therefore addressed as 'the gold standard' (17).

The principle of profilometry for monitoring erosion progression is to measure a step between an unchangeable reference area and an experimental area that is exposed to erosive impacts. An increasing step height in sequential measurements indicates a progression of substance loss (16). For monitoring procedures, the reidentification of the area of interest is essential, which is relatively easy to carry out *in vitro* or *in situ* (16). *In vivo*, however, there is lack of unchangeable and reidentifiable landmarks. The position of the gingival

margin is variable and the cemento–enamel junction may be affected by chemical or physical impacts. Existing restorations are possible areas of reference (23), but, at least for simple profilometric procedures, in the majority of cases they provide no structure for defined retracing, or may fail. In cases where no restorations are present, the preparation of cavities or the application of fillings for reference is ethically unacceptable.

This article presents and evaluates a profilometric method for clinical monitoring of erosive losses using acid-resistant markers, which are bonded to tooth surfaces of interest. These markers represent a reference area as well as a structure for the defined retracing of a given erosive lesion surface. By using the marker, an actual state of the dental hard tissue adjacent to the star can be obtained by measuring the step height between the marker surface (reference level) and the tooth surface. In analysing sequential study casts, the method permits monitoring and the quantification of substance loss over a defined observation period by calculating the differences between two measured step heights. An increasing step height in sequential casts is an indication of erosion progression.

Material and methods

Manufacturing and application of markers

Star-shaped markers were made of sandblasted non-precious metal (Co-Cr-Mo-alloy, Vulcano 360; Stührenberg & Wehrkamp, Osnabrück, Germany) with a thickness of 100 μm and a diameter of 1.5 mm. The markers were punched out with a special die and bonded to the tooth surface. Prior to application, markers were silanized (GC Metal Primer; GC Germany, München, Germany) for 30 s and left to dry for 5 min. Tooth surfaces were conditioned with 35% phosphoric acid (Gluma Etch 35 Gel; Heraeus Kulzer, Dormagen, Germany) for 40 s and rinsed for 40 s with water. The markers were cemented with Optibond FL (Kerr, Karlsruhe, Germany), which was light cured for 40 s. All procedures were performed according to the manufacturers' instructions. The markers were adjusted with a peak directed to the incisal/occlusal surface (Fig. 1). They were not polished in order to avoid damaging the star's peaks.

Manufacturing of models

Impressions were taken using a polyether material (Impregum Penta; 3M ESPE AG, Seefeld, Germany). To evaluate the impact of model material, two different epoxy resins were used: Blue Star (Girrbach Dental, Pforzheim, Germany) or Stycast 1266 A/B (Emerson & Cuming, ICI Belgium, Westerlo, Belgium). The manufacturers' instructions were followed. The surface of each model was inspected for contaminations or surface defects using a microscope (SMZ-1 Zoom Stereomicroscope; Nikon, Düsseldorf, Germany).

Profilometric analysis

For profilometry, a Perthometer S8P (Mahr, Göttingen, Germany) with a mechanical stylus (FRW-750; Mahr) was used. The vertical resolution of the system was 0.015 μm, and the tip of the pick-up had a radius of 10 μm. The models were mounted with plasticine on the *xy*-table of the profilometer. The star-shaped markers were positioned horizontally and in such a way that the tip of the pick-up wrote a straight line between 'tooth surface – peak of the star (point B in Fig. 2) – star surface – edge of the star (point A in Fig. 2) – tooth surface', which was controlled microscopically (magnification 10×). Five defined traces (4 mm each in length) were made and interpreted using special software (Perthometer Concept 4.0; Mahr) (Fig. 2). The software applies regression lines on a given tracing and calculates defined points on demand. On the written tracing, three regression lines were necessary to evaluate the step

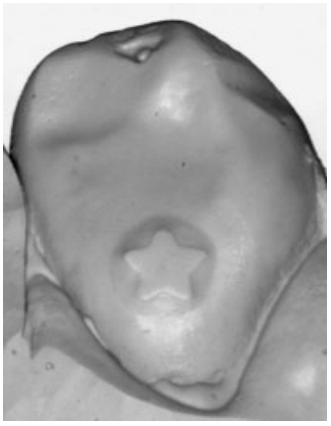

Fig. 1. The Blue Star model with a palatal star-shaped marker. The annular zone adjacent to the marker represents surface roughening after acid etching and indicates the excellent reproduction of surface microstructures.

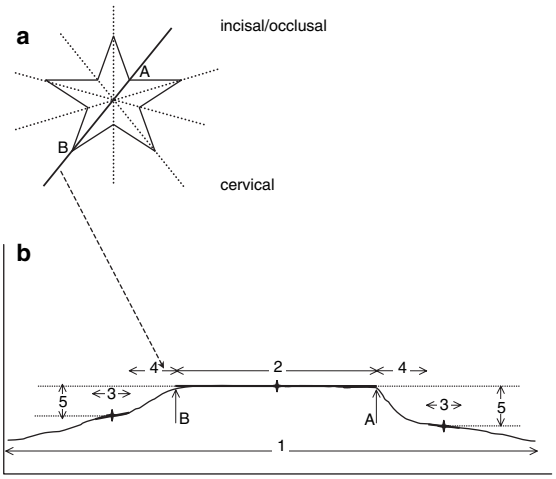

Fig. 2. (a) A star-shaped marker allowing for five defined tracings. Each tracing gives two values for step height (10 values per marker). The solid line indicates the interpreted tracing at the bottom (B); dotted lines represent the other four possible tracings. (b) Interpretation of a given tracing: 1, length of the entire tracing (4.0 mm); 2, regression line constructed on the marker surface from peak (B) to edge (A); 3, regression lines constructed on the tooth surface (300 μm in length); 4, distance between the peak/edge and the regression line on the tooth surface (400 μm in x-direction); and 5, vertical distance of the mid-points of regression lines defined as step height 'star surface–tooth surface'.

height between the marker and the tooth surface. The first was generated between the peak and the edge on the marker surface. This regression line was adjusted parallel to the *x*-axis of the coordinate system of the software. Two further regression lines were applied on the tooth surface adjacent to both sides of the marker. For this purpose, two points were defined, one with a distance of 400 μm in the *x*-direction from each end-point of the marker's regression line and one further with a distance of 700 μm, and the software applied the regression lines accordingly. The mid-points of all three regression lines were calculated. The vertical distances (μm) between the mid-points of the regression lines on the marker surface and the tooth surface were defined as the step height 'marker surface – tooth surface'. The substance loss of a tooth was defined as the mean of the 10 values for step height that could be calculated for one star. The mean step height of each model represented an actual state of dental hard tissue adjacent to the star. In sequential models, the difference in mean step height was defined as the erosive loss.

Factors evaluated

The factors precision, repeatability, accuracy, linear trend and measuring range were investigated. As there is sometimes uncertainty about the terms used to describe the properties of a measurement, the following definitions are given:

- *Precision* is the standard deviation of a series of replicate determinations of the same quantity (repeated interpretation of one given tracing, repeated analysis of one tooth or one model).
- The *Repeatability* refers to the capacity of a measuring procedure to produce the same result on each occasion in a series of procedures conducted under identical conditions (analysis of multiple study models obtained from the same situation).
- *Accuracy* is defined as the degree to which a measurement (step height as obtained from the study casts) or an estimate based on measurements represents the true value of the attribute that is being measured (step height as obtained from the respective original tooth) (24).

Evaluation of precision, repeatability, and accuracy

Two extracted teeth, one ground flat and one with the natural surface preserved, represented master models. The natural tooth surface was ground flat using P800 silicon carbide abrasive paper (Leco, St Joseph, MO, USA), and polished with P1200 and P4000 (nominal grain diameter 5 μm; Leco). As described above, markers were applied to the flat as well as to the natural tooth surface. For the evaluation procedure, the natural and the ground tooth, as well as epoxy resin models from different impressions of the teeth, were measured repeatedly.

The precision of the method was analyzed by the fivefold interpretation of the five given traces of one marker, and further by the fivefold measurement of one model.

For analysing the repeatability, the mean step height was measured repeatedly on five different models obtained from the same situation. For each measuring procedure, the tooth or the respective study model was removed from and repositioned into the profilometer system.

To analyze the accuracy, repeated impressions (Impregum Penta) and study models (Blue Star or Stycast) were made. Both the master model and the corresponding Blue Star or Stycast models were measured fivefold. The mean values of the corresponding measurements were compared.

As the use of the star-shaped markers for monitoring erosive loss has already been introduced into the routine treatment of our patients, a pool of study models exists. For each patient, two impressions and two study models (Blue Star) were available. Impressions are subject to further influences *in vivo*, such as pellicle and saliva, and for this reason 10 pairs of models were randomly selected from this pool of study models to evaluate the repeatability of the method from models obtained under *in vivo* conditions.

Simulated monitoring procedure

An *in vitro* experiment was undertaken to simulate the clinical situation during chronic erosive loss. From our tooth bank, 14 caries-free teeth were selected (4 molars, 4 premolars, 2 canines, 2 lateral incisors, and 2 central incisors). The teeth were cleaned with pumice and with fluoride-free paste, after which they were stored in saturated thymol solution until use. The teeth were fixed into special trays fitting into a phantom head (Frasaco Phantomkopf; Sachs & Co., Tettnang, Germany), simulating a natural dentition of the upper jaw, and then kept in 100% humidity. Application of the markers and impression procedures were performed in the phantom head. One marker was applied to the natural buccal (left side) or palatal (right side) aspects, as previously described. For erosive demineralization, the trays were removed from the phantom head and immersed in 0.05 M citric acid, pH 2.3, at room temperature under gentle agitation. Erosion times were 20, 60 and 120 min. The teeth were thoroughly rinsed with tap water after each erosive attack. Before erosive demineralization (baseline), and after each erosion time, the trays were repositioned into the phantom head and an impression was made. Study models were made from Blue Star. Each tooth was separated in order to facilitate the adjustment into the profilometer system. The mean step height of each model represented an actual state of the dental hard tissue around the star. Comparing the sequential models and calculating the differences of step heights allowed the quantification of erosive substance loss. An increasing step height indicates a progression of substance loss.

Statistics

Statistical procedures were performed with SPSS 10.0 statistics software for Windows. For all data no significant differences from normal distribution were found (Kolmogorov–Smirnov test).

For the repeatability of paired study models (model 1 and model 2) obtained from the patients' model pool, a regression analysis was performed. The mean value of model 1 was used as the independent variable, and the mean value of model 2 was used as the dependent variable. Further 95% limits of repeatability of paired values were analyzed (25).

For comparison of the values obtained from the natural flat tooth and the Blue Star or Stycast model (accuracy), the *t*-test for paired samples was used.

Single random errors were evaluated as error in analysis of a given tracing, error in positioning of the model in the profilometer, impression error, and error during casting. The total error of the procedure is represented by the multiple analysis of different Blue Star models and was additionally calculated as the square root of the sum of the squares of the errors in the single steps.

Table 1

Mean step height values (in μm) of a series of different repeated measurements (M1–M5)

	M1	M2	M3	M4	M5	Mean of M1–M5	SD of M1–M5
1 Fivefold interpretation of given tracings of one star	279.4	278.7	279.7	279.0	278.7	279.1	0.4
2 Ground flat tooth ('true value')	147.9	148.7	148.4	149.4	148.9	148.7	2.2
3 Blue Star model of the ground flat tooth one model, five measurements	144.0	143.7	143.6	144.2	143.6	143.8	2.9
4 Blue Star model of the ground flat tooth – five models	146.8	144.3	143.3	145.6	142.4	144.5	3.9
5 Stycast model of the ground flat tooth – five models	155.1	157.7	160.5	166.2	161.2	160.1	11.1
6 Blue Star model of the curved natural tooth – one model, five measurements	280.8	291.0	290.2	290.7	289.5	288.5	3.9

Each measurement (M1–M5) included 10 values.
SD, standard deviation.

For comparison of erosive losses after different erosion times in the simulated monitoring procedure, the *t*-test for paired samples was used. In addition, the quadratic or linear trend was tested with an analysis of variance with repeated measures with Fisher's *F*-test for trend components.

For all statistical procedures, the level of significance was set at 0.05.

Results

Precision, repeatability, and accuracy

The results of repeated measurements are displayed in Table 1. For analysis of precision, the fivefold interpretation of one given tracing had a standard deviation (SD) of 0.4 μm (row 1). The fivefold analysis of the flat natural tooth revealed a SD of 2.2 μm (row 2). A curved natural tooth surface revealed a slightly higher SD of 3.9 μm (row 6). The values of fivefold measurement of one Blue Star model from one impression showed a similar SD (2.9 μm, row 3).

The measurement and the analysis of the Blue Star models from five different impressions showed an SD of 3.9 μm (row 4), which reflected the repeatability. The repeatability of the Stycast models was obviously poorer (SD of 11.1 μm, row 5).

Accuracy was analyzed by comparing the natural flat tooth with the corresponding Blue Star or Stycast model. Compared with the flat natural tooth (mean step height of 148.7 μm, row 2), the Blue Star models from five different impressions gave a somewhat lower step height of 144.5 μm (row 4) with a mean difference of 4.2 μm (2.8%; not significant). Stycast models led to significantly increased step height (row 5) compared with the natural flat tooth (mean difference 11.4 μm, 7.7%; $P \leq 0.001$).

The calculation of random errors was performed in a stepwise manner (Table 1, rows 1–4). The error caused by the interpretation procedure of one tracing is shown by its SD of 0.4 μm (row 1). The error in the fivefold analysis of the flat tooth (2.2 μm, row 2) is composed of the error of the interpretation of the tracing and the error caused by the adjusting of the model in the profilometer. The error of the impression procedure and of the model casting is additionally contained in the fivefold analysis of one model (2.9 μm, row 3). The error of the whole procedure can be read off the SD of the analysis of five different models obtained from the same situation (3.9 μm, row 4). This corresponds quite well with the calculation of total error (square root of the sum of the squares of the errors in the single steps; 3.7 μm).

Table 2

Mean step height (μm; calculated from the 10 values of one star) of 10 paired Blue Star models obtained from our pool of patient casts (mean ± standard deviation: 0.3 ± 2.5)

Patient	Model 1 (mean value)	Model 2 (mean value)	Model 1– Model 2
1	286.3	281.3	5.0
2	162.6	161.9	0.7
3	263.8	266.6	−2.8
4	172.9	175.2	−2.3
5	117.0	115.9	1.1
6	216.8	219.8	−3.0
7	83.8	84.4	−0.6
8	125.7	125.4	0.4
9	230.8	227.4	3.5
10	194.3	193.8	0.6

The analysis of the paired models from the pool of patient models revealed a mean difference of 0.3 ± 2.5 μm (maximum 5.0 μm). The values are displayed in Table 2. The 95% limits of repeatability ranged from −4.7 to 5.2 (Fig. 3). The regression analysis showed a slope of 1.01 ± 0.01 (95% confidence interval: 0.98–1.04) and an intercept of −1.08 ± 2.71 (95% confidence interval: −7.33 to 5.16), the regression coefficient (r^2) was 0.99 ($P = 0.001$).

Simulated monitoring procedure

Thirteen teeth were analyzed (one tooth was excluded because remnants of the impression material were detected on the model surface during the measuring procedure). The mean erosive loss was 10.3 ± 6.5, 17.6 ± 6.1, and 29.4 ± 15.0 μm after 20, 60, and 120 min erosion time, respectively ($P = 0.001$ for all differences). The analysis of variance with repeated

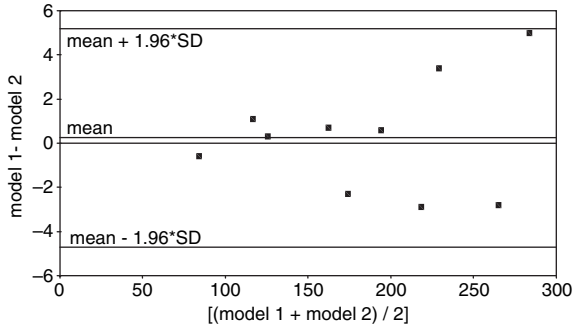

Fig. 3. Bland-Altman plot of the values obtained from the 10 paired models of our pool of patient casts (data are displayed in Table 2). The outer horizontal lines mark the 95% limit of repeatability.

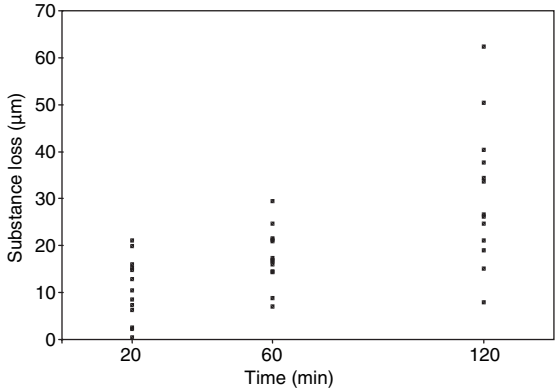

Fig. 4. Erosive loss after 20, 60, and 120 min immersion time in 0.05 M citric acid, as determined under simulated clinical conditions.

measures (*F*-test) showed a significant linear trend ($P = 0.001$) and a non-significant quadratic trend (Fig. 4).

Discussion

The application of markers serving as a reference and taking impressions for analysis was first described in a publication by BARTLETT *et al.* (26). The inherent problem of this method was that in a significant number of impressions the reference points on the tooth surface could not be reidentified with sufficient precision. The correlation for repeated measurements was good, but the limits of agreement for a single site were in the region of $\pm$ 25 μm, making the clinical use of the procedure questionable. Furthermore, analysing impressions instead of casts might improve the accuracy of the procedure, but requires sufficient long-term dimensional stability of the impression material. Even if only a small change appears to occur within a couple of weeks (26), limited information are available concerning the stability for 6 months or more.

The method presented here seeks to eliminate the above-mentioned shortcomings. The principle of the procedure is to use markers that represent the reference area, but which also provide a structure for the reidentification of the traced tooth area. This was obtained by using star-shaped markers, which allow the exact repositioning of a trace by running through the edge and the peak of the star independently of changes in tooth morphology. To avoid problems from long-term storage of the impressions, models were made. Prerequisites of such model materials are resistance to mechanical wear, which allows unlimited repetitive measurements to be carried out, and reproduction and visualization of surface details. Therefore, only epoxy resin materials were considered.

The present study sought a thorough evaluation procedure with a series of *in vitro* experiments and the analysis of study models obtained from our pool of patient models.

The precision reflects random errors of the measuring procedure itself. It can be attributed to errors from the interpretation procedure, which is very small with an SD of 0.4 μm, and to errors from repositioning in the profilometer system, ranging between 2.2 and 2.9 μm. It must, however, be assumed that the precision decreases somewhat with increasing curvature of the tooth surface, which is reflected in the higher SD of 3.9 μm. This is, to a lesser extent, caused by the interpretation of the tracing than by the repositioning procedure. Even if the adjustment of the stylus running through the edge and tip of the star-shaped marker is relatively easy, even small deviations could produce significant errors in cases of severely or even irregularly arched tooth surfaces. Markers should therefore preferably be applied to relative plane areas.

The repeatability was surprisingly high, when the number of sources of error is considered. The multiple impression and casting procedure (when Blue Star was used) increased the standard deviation only up to 4 μm. Compared with the *in vitro* procedure, the measurement of the paired models from the patients' pool showed a considerably lower SD of 2.5 μm (95% limit of repeatability from -4.7 to 5.2 μm), which can be attributed to the better performance of the impression procedure in the presence of saliva and pellicle as well as to the smoother appearance of the tooth surface (see below).

The error of the whole procedure with SDs of 3.9 μm (analyzed) or 3.7 μm (calculated as the square root of the sum of the squares of the errors in the single steps) appears small when compared with other methods. The accuracy and the precision of the method presented here are comparable with those of the method of CHADWICK *et al.* (27), who found an accuracy of 4.4 μm with a computer-controlled electrical probe measuring electro-conductive replicas, and to the method of PINTADO *et al.* (8) with an accuracy of 7 μm and a precision of 5 μm. These results were obtained from ideal validation conditions using geometric structures. However, if applied on tooth structures the measurement error could increase markedly (14.4 μm) (10). The results of the present study were even somewhat better than those from the method of MEHL *et al.* (9), who found an accuracy of 10 μm when analysing occlusal wear using the non-contacting laser-profilometry.

The accuracy was good for the Blue Star model. The material diminished the mean step height slightly, but in an acceptable dimension (2.8%), whereas Stycast enlarged it significantly (7.7%). This could partly have been anticipated, as the latter material has a linear shrinkage of 1–2% (manufacturers' specification). The higher SD obtained from Stycast models, however, was unexpected and is probably caused by its vitreous properties, which may have hampered the adjustment of the models under the microscope. The enlargement and, in particular, the high SD rendered the material unsuitable for further evaluation. The epoxy resin Blue Star appeared particularly applicable, because its linear shrinkage is about 0.05% (manufacturers' specification), the reproduction and the visualization of surface details is excellent (Fig. 1), and the material is resistant to mechanical wear. As a result of the blue color, the adjustment of the models in the profilometer system is much easier than when a reflecting vitreous material is used.

In all, the measuring range of the proposed method can be estimated as 15–250 μm (the latter is the maximal deflection of the pick-up of the profilometer and depends on the system used).

The simulated monitoring procedure revealed increasing mineral loss with time. It has been demonstrated, at least for polished enamel surfaces, that the progression of erosive mineral loss is linear (16), which could also be assumed for the simulated monitoring experiment. Within the limitations of the respective procedure, mineral loss indeed revealed a significant linear, but no quadratic, trend. Mean values for substance loss were 0.5 μm min^{-1} after the first erosion time and 0.25 μm min^{-1} in the following, which is in good agreement with results published previously (0.4 μm min^{-1}) (20). Mineral loss, however, varied considerably between different teeth; this was also found in other experimental studies (10,20) and corresponds to the clinical finding that exposure to acids significantly contributes, but does not entirely explain, the occurrence of erosion (28). However, simulated clinical conditions only partly reflect the true *in vivo* situation, where eroded surfaces are also prone to abrasive impacts and are therefore much smoother. The tooth surfaces eroded *in vitro* macroscopically appeared markedly rough and, as observed under the microscope, exhibited an irregular erosion pattern. Furthermore, as a result of the absence of saliva and pellicle coating, the withdrawal of the impression spoon was difficult, which may have caused some small deformations and slight tear-offs from the impression material. This was definitely the case in one tooth, which had to be excluded from the experiment. Both factors might also have contributed to the scatter observed in the simulated monitoring experiment.

For evaluating the potential of a method for clinical monitoring of erosive wear, a relationship with clinical treatment needs must be made. In this regard, a lucid definition was given by Smith & Knight (4): 'The distinction between acceptable and pathological tooth wear at a given age is based on the prediction of whether the tooth will survive the rate of wear'. A clinically relevant threshold for pathological wear, however, is difficult to establish. Approximate annual physiological wear rates have been estimated as 10–30 μm on occlusal surfaces (8,29) and 8 μm in palatal surfaces (26). In subjects with erosive tissue loss, much higher rates of tissue loss can occur. Progression rates in patients with exposed dentine and an assumed history of intrinsic or extrinsic acid exposure of 5–10 yr (i.e. in cases of eating disorders) would denote a tissue loss of $\approx$75–150 μm within 6 months if an enamel thickness of 1500 μm is assumed (30). This corresponds well with values ranging from 17.6 to 108.2 μm within 6 months, obtained from a group of bulimics (26). A measuring range from 15 to 250 μm, as presented here, would therefore fit well into clinical requirements.

A robust method is acceptable for patients, is as time- and cost-effective as possible, is easy to perform and useful in most clinical situations. Our patients accepted the 'twinkle-like' appearance of the markers very well and also felt comfortable shortly after application. The cementing and impression procedure is easy, but the casting and analysis of models is somewhat laborious and time-consuming. Analysing one marker takes about 30 min, which is caused by the need for thorough positioning of the model in the profilometer system. This time-period corresponds approximately to Bartlett's method (26). Even if more elaborate equipment could save time for analysis, the profilometer system used here is relatively cheap and also available in many institutions. Compared with other procedures, the method presented here appears robust, but nevertheless is too costly (especially in terms of time) for a broad indication. We see an area of application in patients who need special care (e.g. bulimics), but in particular for clinical studies, the more so, as it facilitates multicentre approaches.

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References

1. Zipkin J, McClure F. Salivary citrate and dental erosion. *J Dent Res* 1949; **28**: 613–626.
2. Azzopardi A, Bartlett DW, Watson TF, Smith GN. A literature review of the techniques to measure tooth wear and erosion. *Eur J Prosthodont Restor Dent* 2000; **8**: 93–97.
3. Eccles JD. Dental erosion of nonindustrial origin. A clinical survey and classification. *J Prosthet Dent* 1979; **42**: 649–653.
4. Smith BG, Knight JK. An index for measuring the wear of teeth. *Br Dent J* 1984; **156**: 435–438.
5. Sorvari R, Kiviranta I. A semiquantitative method of recording experimental tooth erosion and estimation of occlusal wear in the rat. *Arch Oral Biol* 1988; **33**: 217–220.
6. Mistry M, Grenby TH. Erosion by soft drinks of rat molar teeth assessed by digital image analysis. *Caries Res* 1993; **27**: 21–25.
7. Pesun IJ, Olson AK, Hodges JS, Anderson GC. In vivo evaluation of the surface of posterior resin composite restorations: a pilot study. *J Prosthet Dent* 2000; **84**: 353–359.

8. Pintado MR, Anderson GC, Delong R, Douglas WH. Variation in tooth wear in young adults over a two-year period. *J Prosthet Dent* 1997; **77**: 313–320.
9. Mehl A, Gloger W, Kunzelmann KH, Hickel R. A new optical 3-D device for the detection of wear. *J Dent Res* 1997; **76**: 1799–1807.
10. Chadwick RG, Mitchell HL. Conduct of an algorithm in quantifying simulated palatal surface tooth erosion. *J Oral Rehabil* 2001; **28**: 450–456.
11. Chadwick RG, Mitchell HL, Ward S. Evaluation of the accuracy and reproducibility of a replication technique for the manufacture of electroconductive replicas for use in quantitative clinical dental wear studies. *J Oral Rehab* 2002; **29**: 540–545.
12. Chadwick RG, Mitchell HL, Ward S. A novel approach to evaluating the reproducibility of a replication technique for the manufacture of electroconductive replicas for use in quantitative clinical dental wear studies. *J Oral Rehab* 2004; **31**: 335–339.
13. Huysmans MC, Thijssen JM. Ultrasonic measurement of enamel thickness: a tool for monitoring dental erosion? *J Dent* 2000; **28**: 187–191.
14. Barbour ME, Parker DM, Allen GC, Jandt KD. Human enamel dissolution in citric acid as a function of pH in the range 2.30 <=pH <=6.30 – a nanoindentation study. *Eur J Oral Sci* 2003; **111**: 258–262.
15. De Josselin De Jong E, Van Der Linden AHIM, Borsboom PCF, Ten Bosch JJ. Determination of mineral changes in human dental enamel by longitudinal microradiography and scanning optical monitoring and their correlation with chemical analysis. *Caries Res* 1988; **22**: 153–159.
16. Ganss C, Lussi A, Klimek J. Comparison of calcium/phosphorus analysis, longitudinal microradiography and profilometry for the quantitative assessment of erosive demineralisation. *Caries Res* 2005; **39**: 178–184.
17. Hall AF, Sadler JP, Strang R, De Josselin DJ, Foye RH, Creanor SL. Application of transverse microradiography for measurement of mineral loss by acid erosion. *Adv Dent Res* 1997; **11**: 420–425.
18. Attin T, Zirkel C, Hellwig E. Brushing abrasion of eroded dentin after application of sodium fluoride solutions. *Caries Res* 1998; **32**: 344–350.
19. Davis WB, Winter PJ. Measurement in vitro of enamel abrasion by dentifrice. *J Dent Res* 1976; **55**: 970–975.
20. Ganss C, Klimek J, Schwarz N. A comparative profilometric in vitro study of the susceptibility of polished and natural human enamel and dentine surfaces to erosive demineralisation. *Arch Oral Biol* 2000; **45**: 897–902.
21. Ganss C, Klimek J, Schäffer U, Spall T. Effectiveness of two fluoridation measures on erosion progression in human enamel and dentine in vitro. *Caries Res* 2001; **35**: 325–330.
22. West NX, Maxwell A, Hughes JA, Parker DM, Newcombe RG, Addy M. A method to measure clinical erosion: the effect of orange juice consumption on erosion of enamel. *J Dent* 1998; **26**: 329–335.
23. Grenby TH. Methods of assessing erosion and erosive potential. *Eur J Oral Sci* 1996; **104**: 207–214.
24. Last JM. *A dictionary of epidemiology*, 4th edn. New York: Oxford University Press, 2001.
25. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**: 307–310.
26. Bartlett DW, Blunt L, Smith BG. Measurement of tooth wear in patients with palatal erosion. *Br Dent J* 1997; **182**: 179–184.
27. Chadwick RG, Mitchell HL, Cameron I, Hunter B, Tulley M. Development of a novel system for assessing tooth and restoration wear. *J Dent* 1997; **25**: 41–47.
28. Lussi A, Schaffner M. Progression of and risk factors for dental erosion and wedge-shaped defects over a 6-year period. *Caries Res* 2000; **34**: 182–187.
29. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. Quantitative in vivo wear of human enamel. *J Dent Res* 1989; **68**: 1752–1754.
30. Grine FE. Enamel thickness of deciduous and permanent molars in modern Homo sapiens. *Am J Phys Anthropol* 2005; **126**: 14–31.