

## Short Communication

## Caries Research

Caries Res 2012;46:507–512

DOI: [10.1159/000339783](https://doi.org/10.1159/000339783)

Received: February 3, 2012

Accepted after revision: May 25, 2012

Published online: July 14, 2012

# Clinical Study Monitoring the pH on Tooth Surfaces in Patients with and without Erosion

A. Lussi<sup>a</sup> M. von Salis-Marincek<sup>a</sup> C. Ganss<sup>b</sup> E. Hellwig<sup>c</sup> Z. Cheaib<sup>a</sup> T. Jaeggi<sup>a</sup>

<sup>a</sup>Department of Preventive, Restorative and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; <sup>b</sup>Department of Conservative and Preventive Dentistry, Dental Clinic, Justus Liebig University, Giessen, and <sup>c</sup>Department of Operative Dentistry and Periodontology, University Clinic of Dentistry, Freiburg, Germany

## Key Words

Acid · Buffer · Clearance · Dental erosion · pH · Saliva

## Abstract

The aim of this study was to compare tooth surface pH after drinking orange juice or water in 39 patients with dental erosion and in 17 controls. The following investigations were carried out: measurement of pH values on selected tooth surfaces after ingestion of orange juice followed by ingestion of water (acid clearance), measurement of salivary flow rate and buffering capacity. Compared with the controls, patients with erosion showed significantly greater decreases in pH after drinking orange juice, and the pH stayed lower for a longer period of time ( $p < 0.05$ ). Saliva parameters showed no significant differences between the two patient groups except for a lower buffering capacity at pH 5.5 in the erosion group.

Copyright © 2012 S. Karger AG, Basel

Dental erosion is a multifactorial condition. In the majority of cases, one factor may be predominant, though other (co)factors also contribute to the condition. Both nutritional and patient-related factors lead to dissolution of tooth substance [Lussi et al., 2011]. Among other fac-

tors salivary flow rates and buffering capacity modify the erosive process. The development of dental erosion depends on the duration and intensity of acid exposure of the specific surfaces, which explains why the distribution of erosion varies within the dentition. Therefore, analysis of the pH on the various tooth surfaces is important. Results from various studies are not easily compared due to differences in measuring methods and examined samples. Bashir et al. [1995a] determined acid clearance after citric acid rinses by longitudinally measuring acid concentrations in saliva. They found an individual clearance profile in healthy volunteers. The same research group examined the retention of citric acid on selected tooth surfaces. The citric acid levels after oral exposure were higher on the labial surfaces of the upper incisors than on the lower incisors [Bashir et al., 1995b].

We hypothesized that patients with erosion have inferior acid clearance on tooth surfaces after a standardized acid attack compared to healthy individuals. Therefore, the aim of the present study was to investigate acid clearance on two selected tooth surfaces by comparing pH values of patients with erosive lesions with those of a control group. Moreover, saliva analyses were made to determine any differences between healthy individuals and patients with dental erosion.

## KARGER

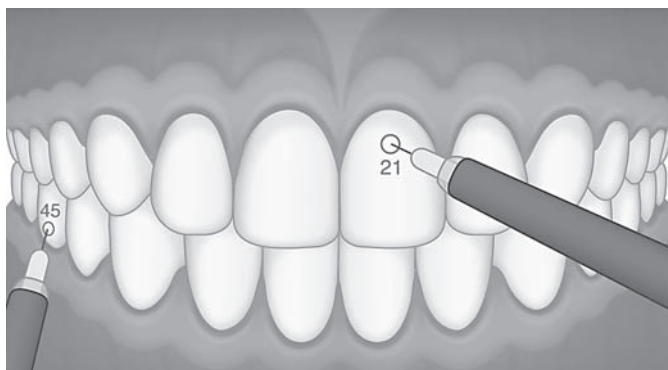
E-Mail [karger@karger.ch](mailto:karger@karger.ch)  
[www.karger.com/crc](http://www.karger.com/crc)

© 2012 S. Karger AG, Basel  
 0008–6568/12/0466–0507\$38.00/0



This is an Open Access article licensed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 License ([www.karger.com/OA-license](http://www.karger.com/OA-license)), applicable to the online version of the article only. Distribution for non-commercial purposes only.

Adrian Lussi  
 Department of Preventive, Restorative and Pediatric Dentistry  
 University of Bern, Freiburgstrasse 7  
 CH–3010 Bern (Switzerland)  
 Tel. +41 31 632 2570, E-Mail [adrian.lussi@zmk.unibe.ch](mailto:adrian.lussi@zmk.unibe.ch)



**Fig. 1.** Setup of the pH measurements on the plaque-free teeth 21 and 45, respectively.

## Subjects and Methods

### *Selection of Patients with Erosion and the Control Group*

A total of 56 patients were invited to participate in this study. The test group (22 females, 17 males;  $32 \pm 6.4$  years) was recruited from outpatients of the University of Bern referred by dentists or doctors for prevention and/or therapy. The study was commenced before any prevention/therapy was initiated. The control group (10 females and 7 males;  $30 \pm 10.0$  years) consisted of employees of the University of Bern who showed no dental erosion. All participants were informed about the study design and provided consent. Ethical approval was obtained from the Ethics Committee of Bern University, Switzerland (No. 012/07).

### *Study Design*

All patient measurements were performed at the same time of the day. The clinical assessment of the severity of the dental erosive lesions was made with a scoring scheme introduced by Lussi et al. [1991]. All examinations were performed by the same dentist calibrated for the assessment for erosion by the first author.

Patients were advised to abstain from eating, drinking, smoking and tooth cleaning for the last 2 h before each examination. For the surface pH measurements, two test points on the facial surfaces of tooth 21 (often attacked by erosion) and tooth 45 (close to the sublingual caruncle and measurable with the device) were selected (fig. 1), marked and measured immediately one after another. After the initial pH measurement, the subjects were asked to drink 100 ml of tap water within 1 min; the surface pH values were recorded 1, 3, 5, 7, 10, 15 and 20 min thereafter. Then, the same procedure was repeated after drinking 100 ml of orange juice (Pura, pH 3.6, Denner, Switzerland) in the same supervised manner [Shellis et al., 2011]. At the end of the experiment, 100 ml of tap water was ingested and the surface pH was measured at 1, 3 and 5 min. The mode of drinking (sipping, no swishing) was first demonstrated and then supervised by M.S. Care was taken to have both groups ingest in the same manner. Two hours later, saliva samples were collected.

Prior to clinical examinations, all patients were asked to record their dietary intake for 4 consecutive days and additional specific questions were asked [Lussi and Jaeggi, 2011].

### *Measurement of Tooth Surface pH*

Surface pH changes on the two selected plaque-free tooth surfaces of each test subject were measured by the same dentist using a Beetrode® micro-pH electrode (NMPH3, World Precision Instruments Inc., Sarasota, Fla., USA). The tip of the electrode was 0.1 mm in diameter. The electrode was calibrated with standard pH buffers before the reading and checked after the last reading [Küseler et al., 1993].

### *Determination of the Secretion Rate and Titration of Saliva (Buffering Capacity)*

The salivary flow of resting and paraffin-stimulated saliva was determined with the CRT kit (Ivoclar Vivadent, Schaan, Liechtenstein). The collected saliva samples were immediately frozen at  $-20^{\circ}\text{C}$ . Later they were thawed and titrated with 0.1 N HCl from initial pH to pH 7.0, 5.5, 4.0 and 3.0 using 4 g of saliva for each analysis [Bouchoucha et al., 1997] (Microlab®, Bonaduz, Switzerland). Buffering capacity ( $\beta$ ) was calculated as  $\beta = |\Delta C/\Delta \text{pH}|$ , where  $\Delta C$  is the amount of the acid used and  $\Delta \text{pH}$  is the change in pH caused by the addition of the titrator.

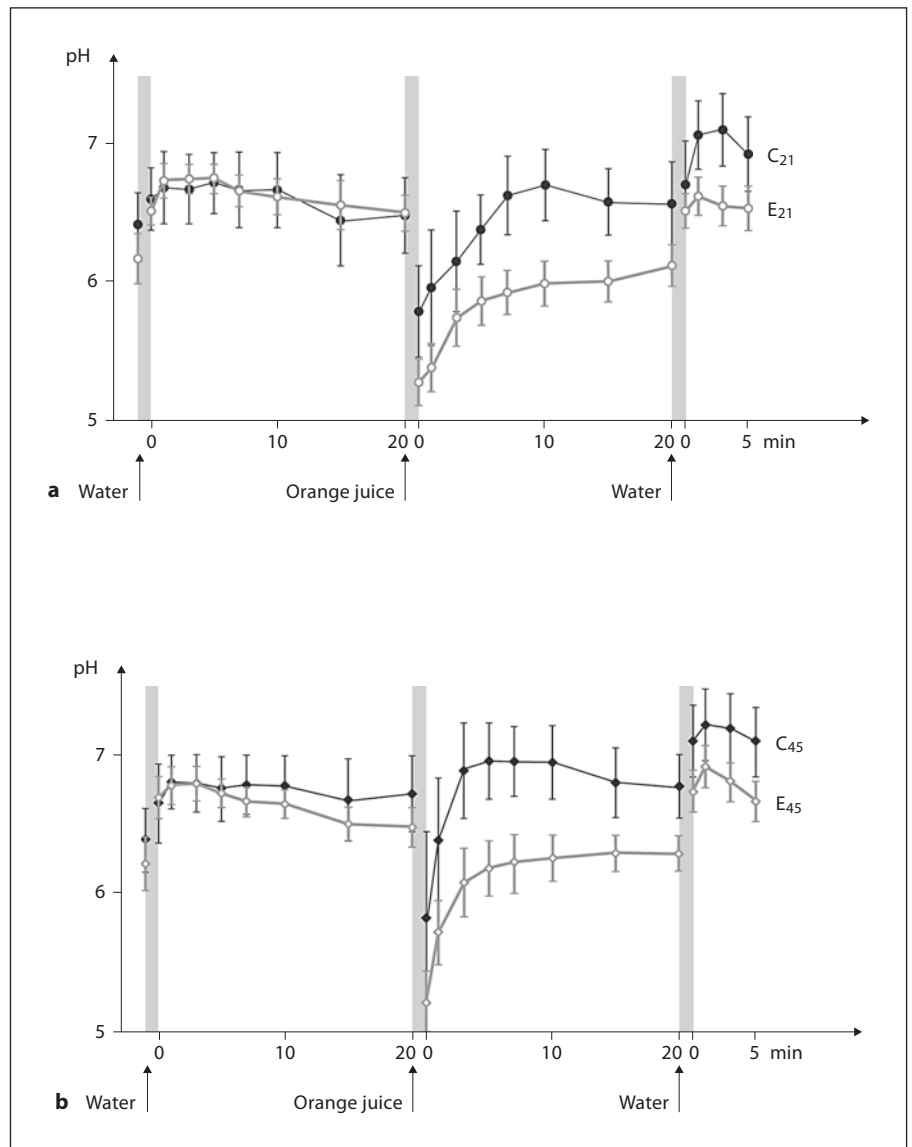
### *Statistics*

The area under the tooth surface pH curve (AUC) was calculated to quantify the pH changes on the tooth surfaces. This area was divided into three parts with  $A_{\text{H}_2\text{O}} = \text{AUC}$  during the 20 min following initial ingestion of tap water,  $A_{\text{OJ}} = \text{AUC}$  during the 20 min following ingestion of orange juice and  $A_{\text{C}} = \text{AUC}$  during the 5 min following final ingestion of drinking tap water. The three areas were compared using the ratios  $Q_1 = A_{\text{OJ}}/A_{\text{H}_2\text{O}}$  (rate of acid exposure),  $Q_2 = A_{\text{C}}/A_{\text{H}_2\text{O}/4}$  (rate of reaching the initial condition), and  $Q_3 = A_{\text{C}}/A_{\text{OJ}/4}$  (rate of pH recovery after drinking tap water). Descriptive analyses showed a normal distribution of the data. Comparison of test and control groups was performed using the t test and Bonferroni correction. The significance level was set at 0.05 for all statistical tests.

## Results

All patients in the erosion group showed dental erosion with 32 (82.1%) showing involvement of dentin on at least one facial surface. The median erosion grade on tooth 21 was 1 and on tooth 45 was 2 when using the index described elsewhere [Lussi et al., 1991]. No erosion was found in the control group.

The mean ( $\pm$  SD) baseline surface pH on tooth 21 was  $6.16 \pm 0.57$  for the erosion and  $6.42 \pm 0.46$  for the control group ( $p > 0.05$ ), and on tooth 45,  $6.24 \pm 0.54$  for the erosion and  $6.38 \pm 0.47$  for the control group ( $p > 0.05$ ). Immediately after drinking orange juice, the pH values on tooth 21 dropped to  $5.28 \pm 0.52$  for the erosion and  $5.78 \pm 0.63$  for the control group and on tooth 45 to  $5.24 \pm 0.65$  for the erosion and  $5.83 \pm 1.12$  for the control group. The pH values of the erosion group showed significantly lower values than those of



**Fig. 2.** Mean pH changes (95% confidence interval) on tooth surfaces before ingestion of tap water, following ingestion of tap water (20 min), following ingestion of orange juice (subsequent 20 min) and after drinking tap water (5 min). **a** E<sub>21</sub> = Facial surfaces of tooth 21 (patients with erosion); C<sub>21</sub> = facial surfaces of tooth 21 (controls). **b** E<sub>45</sub> = Facial surfaces of tooth 45 (patients with erosion); C<sub>45</sub> = facial surfaces of tooth 45 (controls).

the controls at each measuring point following ingestion of orange juice and after clearance with water ( $p < 0.05$ ). The pH recovering was significantly lower on tooth 21 (E<sub>21</sub>) than on tooth 45 (E<sub>45</sub>) for up to 15 min following orange juice ingestion. For the controls, significantly lower values were found 3 and 5 min after orange juice ingestion on tooth 21 (C<sub>21</sub>) compared to tooth 45 (C<sub>45</sub>). Immediately after the second ingestion of tap water as well as after 1 and 3 min, the pH values on tooth 21 (E<sub>21</sub>) were significantly lower than those on tooth 45 (E<sub>45</sub>) ( $p < 0.05$ ; fig. 2).

The mean acid exposure (Q<sub>1</sub>) on both tooth surfaces was significantly higher (quotient is lower) for the erosion

group than for the controls. Furthermore, the mean rate of reaching the initial condition (Q<sub>2</sub>) was significantly lower for the patients with erosions compared to the controls ( $p < 0.05$ ). The mean rate of pH recovery after the final ingestion of tap water (Q<sub>3</sub>) showed no significant differences (table 1).

Salivary analyses showed no significant differences in flow rates of both resting and stimulated saliva between the erosion and control groups. The buffering capacity of stimulated saliva (pH 5.5) in the erosion group was significantly lower than that in the control group ( $p = 0.02$ ; table 2).

**Table 1.** Q<sub>1</sub>, Q<sub>2</sub> and Q<sub>3</sub> (mean ± SD) on facial surfaces of teeth 21 and 45 for both the erosion and control groups, and significance levels between these groups

	Erosion group		Control group		p	
	21	45	21	45	21	45
Q <sub>1</sub>	0.90 ± 0.07	0.93 ± 0.07	0.98 ± 0.07	1.01 ± 0.08	<0.001	0.001
Q <sub>2</sub>	1.05 ± 0.14	1.08 ± 0.14	1.14 ± 0.05	1.14 ± 0.06	<0.001	0.033
Q <sub>3</sub>	1.17 ± 0.15	1.16 ± 0.14	1.16 ± 0.06	1.13 ± 0.06	NS	NS

**Table 2.** Saliva parameters of the erosion and control groups, and the significance levels between these groups

	Erosion group	Control group	p
Flow rate, ml/min			
Unstimulated	0.9 ± 0.4	1.3 ± 0.9	NS
Stimulated	2.3 ± 1.3	2.4 ± 0.8	NS
Buffering capacity, mmol/(l × pH)			
pH 7.0, unstimulated	3.5 ± 1.8	3.3 ± 1.1	NS
pH 7.0, stimulated	3.2 ± 1.0	3.5 ± 2.7	NS
pH 5.5, unstimulated	3.9 ± 1.4	4.0 ± 1.6	NS
pH 5.5, stimulated	4.1 ± 1.3	4.9 ± 1.2	0.02
pH 4.0, unstimulated	4.3 ± 1.5	4.4 ± 2.1	NS
pH 4.0, stimulated	3.7 ± 0.85	4.3 ± 1.1	NS
pH 3.0, unstimulated	4.6 ± 1.6	4.5 ± 2.2	NS
pH 3.0, stimulated	3.7 ± 0.7	4.1 ± 1.1	NS

## Discussion

The aim of this study was to obtain more insight into factors critical to the genesis of dental erosion and to increase the understanding of the parameters contributing to differences between healthy individuals and patients with dental erosion. Care was taken to follow recently published recommendations as to the design of in situ erosion models [Wiegand and Attin, 2011; Young and Tenuta, 2011]. The drinking mode chosen was consistent with everyday habits and did not pose the risk of damaging the volunteer's teeth.

To the best of the authors' knowledge, this is one of the first studies of its kind involving not only healthy individuals but also patients with erosive lesions that all consumed an acidic beverage in a standardized and supervised manner, thus excluding possible behavioral factors. This is in contrast to other studies in which the individual method of drinking was not standardized [Moazzez et al., 2000; Johansson et al., 2002, 2004].

The present study clearly shows that the pH drop on tooth surfaces was lower in the erosion than in the control group. After the second water ingestion, the final pH was measured for up to 5 min, which proved to be enough to reach the initial value. Furthermore, the measured pH values were different from those obtained after the first water intake. This might be due to a different response of the saliva, which was exposed to various stimulants (water/acid) before the second water ingestion. Saliva normally requires 1–2 h for recuperating the initial pH condition after eating or drinking [Navazech, 1993]. Millward et al. [1997] monitored the pH changes on the palatal surfaces of teeth 16 and 21 in healthy subjects after drinking 100 ml of a 1% citric acid solution. Compared to the present findings, their results showed a similar pattern for acid clearance when the same drinking method (by glass) was used. The more pronounced pH drop may be due to the lower pH of 1% citric acid (native pH 2.3) compared to the orange juice used in the present study (pH 3.6). A further reason may be the possibly higher retention rates of acid because of their measuring devices (vacuum-formed splints) compared to the freely clearable electrode tips placed on the tooth surface as in the present investigation. Furthermore, acid will be readily neutralized in the layer adjacent to it [Lussi et al., 2011]. This will then lead to faster neutralization in comparison with an artificial surface without any buffer capacity like a splint. Another reason could be the immediate measuring after acid exposure with the splint model compared to the present study which used a latency of a few seconds with the present device until the electrode tip was positioned on the measuring point.

Patients with erosions showed significantly faster pH recovery after ingestion of orange juice on tooth 45 than on tooth 21 (fig. 2). This may be explained by the close vicinity of the parotid salivary gland to tooth 45. Interestingly and of clinical importance, this difference was

only significant for the first 5 min in the control group. No differences in pH were found among three measuring sites in the upper jaw (11 palatally; 11, 16 buccally) of 18 individuals without erosion when the same method (Beetrode) was used [Johansson et al., 2004]. However, the drinking method (e.g., holding, sipping, gulping) strongly affected the levels of tooth surface pH [Johansson et al., 2004]. Moazzez et al. [2000] compared the pH changes on tooth surfaces of 11 patients with erosion (age range 10–16 years) with those of 10 controls. They showed that the oral pH at four tooth surfaces differed between subjects of these two groups after drinking an acidic beverage. The authors concluded that these findings might be related to the observed differences in drinking habits. In the present study, the way of drinking was standardized and may therefore be an expression of inherent differences between the groups.

In another study, saliva samples were collected before a rinse with 2% citric acid and at 1, 2, 5, 10 and 15 min after the rinse. Then, their saturation was analyzed with respect to hydroxyapatite. On average, the saliva was undersaturated at 1 and 2 min after rinsing but had returned to supersaturation levels after 5 min. The individual differences were large [Bashir and Lagerlöf, 1996]. In our study, the calculation of the degree of saturation as described earlier [Lussi et al., 2012] showed undersaturation with respect to hydroxyapatite at the first measurement after intake of orange juice. These differences could be due to weaker acid exposure in this study as the acidity of orange juice is less than that of the citric acid used in the other study. Furthermore, the present pH measurements were carried out in direct contact with the enamel surfaces and not in saliva. Obviously, pH recovery on tooth surfaces is fast.

These pH measurements on tooth surfaces indicated that, compared to the controls, patients with erosion had a significantly greater decrease in pH after acid ex-

posure (Q1), while the ability to reach initial conditions without additional measures (Q2) was also significantly lower. One can speculate as to the differences between the two groups. However, besides the buffering capacity to pH 5.5 of stimulated saliva, no significant differences in saliva parameters were found, and the secretion rates of saliva were similar for both groups. Nevertheless, the difference in titratable acidity or buffering capacity could play a role in the genesis of dental erosion, as suggested by other investigators [Piangprach et al., 2009]. Holbrook et al. [2009] showed the significant impact on dental erosion of dietary factors, low salivary buffer rates and acid reflux disease. The fact that ratio Q3 showed no significant differences between the erosion and control groups suggests an equal potential for pH recovery after drinking water in the two groups. This is not surprising as this process is dependent on physical and anatomical parameters.

The present study indicates that patients with manifest erosive lesions have a greater risk for increased tooth substance loss by erosive tooth wear than healthy individuals because of lower pH levels on tooth surfaces and lower clearance capacity. Drinking of water was an effective measure to increase the tooth surface pH to levels close to the initial levels.

### Acknowledgments

This study was supported by the Department of Preventive, Restorative and Pediatric Dentistry, University of Bern, Switzerland.

### Disclosure Statement

There is no conflict of interest for any of the authors that might introduce bias or affect their judgment.

### References

- Bashir E, Ekberg O, Lagerlöf F: Salivary clearance of citric acid after an oral rinse. *J Dent* 1995a;23:209–212.
- Bashir E, Gustavsson A, Lagerlöf F: Site specificity of citric acid retention after an oral rinse. *Caries Res* 1995b;29:467–469.
- Bashir E, Lagerlöf F: Effect of citric acid clearance on the saturation with respect to hydroxyapatite in saliva. *Caries Res* 1996;30:213–217.
- Bouchoucha M, Callais F, Renard P, Ekindjian OG, Cugnenc PH, Barbier JP: Relationship between acid neutralization capacity of saliva and gastro-oesophageal reflux. *Arch Physiol Biochem* 1997;105:19–26.
- Holbrook WP, Furuholm J, Gudmundsson K, Theodors A, Meurman JH: Gastric reflux is a significant causative factor of tooth erosion. *J Dent Res* 2009;88:422–426.
- Johansson AK, Lingström P, Birkhed D: Comparison of factors potentially related to the occurrence of dental erosion in high- and low-erosion groups. *Eur J Oral Sci* 2002;110:204–211.
- Johansson AK, Lingström P, Imfeld T, Birkhed D: Influence of drinking method on tooth-surface pH in relation to dental erosion. *Eur J Oral Sci* 2004;112:484–489.

- Küseler A, Baelum V, Fejerskov O, Heidmann J: Accuracy and precision in vitro of Beetrode<sup>®</sup> microelectrodes used for intraoral pH measurements. *Caries Res* 1993;27:183–190.
- Lussi A, Jaeggi T: Etiology and risk assessment; in Lussi A, Jaeggi T (eds): *Dental Erosion: Diagnosis, Risk Assessment, Prevention, Treatment*. Surrey, Quintessence, 2011, pp 37–53.
- Lussi A, Megert B, Shellis RP, Wang X: Analysis of the erosive effect of different dietary substances and medications. *Br J Nutr* 2012;107:252–262.
- Lussi A, Schaffner M, Hotz P, Suter P: Dental erosion in a population of Swiss adults. *Community Dent Oral Epidemiol* 1991;19:286–290.
- Lussi A, Schlueter N, Rakhmatullina E, Ganss C: Dental erosion – an overview with emphasis on chemical and histopathological aspects. *Caries Res* 2011;45:2–12.
- Millward A, Shaw L, Harrington E, Smith AJ: Continuous monitoring of salivary flow rate and pH at the surface of the dentition following consumption of acidic beverages. *Caries Res* 1997;31:44–49.
- Moazzez R, Smith BG, Bartlett DW: Oral pH and drinking habit during ingestion of a carbonated drink in a group of adolescents with dental erosion. *J Dent* 2000;28:395–397.
- Navazesh M: Methods for collecting saliva. *Ann NY Acad Sci* 1993;694:72–77.
- Piangprach T, Hengtrakool C, Kukiattrakoon B, Kedjarune-Leggat U: The effect of salivary factors on dental erosion in various age groups and tooth surfaces. *J Am Dent Assoc* 2009;140:1137–1143.
- Shellis RP, Ganss C, Ren Y, Zero DT, Lussi A: Methodology and models in erosion research: discussion and conclusions. *Caries Res* 2011;45(suppl 1):69–77.
- Wiegand A, Attin T: Design of erosion/abrasion studies – insights and rational concepts. *Caries Res* 2011;45(suppl 1):53–59.
- Young A, Tenuta LMA: Initial erosion models. *Caries Res* 2011;45(suppl 1):33–42.