Brushing force of manual and sonic toothbrushes affects dental hard tissue abrasion

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Abstract: OBJECTIVES: This study aimed to determine the brushing forces applied during in vivo toothbrushing with manual and sonic toothbrushes and to analyse the effect of these brushing forces on abrasion of sound and eroded enamel and dentin in vitro. MATERIALS AND METHODS: Brushing forces of a manual and two sonic toothbrushes (low and high frequency mode) were measured in 27 adults before and after instruction of the respective brushing technique and statistically analysed by repeated measures analysis of variance (ANOVA). In the in vitro experiment, sound and eroded enamel and dentin specimens (each subgroup n = 12) were brushed in an automatic brushing machine with the respective brushing forces using a fluoridated toothpaste slurry. Abrasion was determined by profilometry and statistically analysed by one-way ANOVA. RESULTS: Average brushing force of the manual toothbrush (1.6 ± 0.3 N) was significantly higher than for the sonic toothbrushes (0.9 ± 0.2 N), which were not significantly different from each other. Brushing force prior and after instruction of the brushing technique was not significantly different. The manual toothbrush caused highest abrasion of sound and eroded dentin, but lowest on sound enamel. No significant differences were detected on eroded enamel. CONCLUSION: Brushing forces of manual and sonic toothbrushes are different and affect their abrasive capacity. CLINICAL SIGNIFICANCE: Patients with severe tooth wear and exposed and/or eroded dentin surfaces should use sonic toothbrushes to reduce abrasion, while patients without tooth wear or with erosive lesions confining only to enamel do not benefit from sonic toothbrushes with regard to abrasion.

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Brushing force of manual and sonic toothbrushes affects dental hard tissue abrasion

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Abstract

Objectives: This study aimed to determine the brushing forces applied during in vivo toothbrushing with manual and sonic toothbrushes and to analyse the effect of these brushing forces on abrasion of sound and eroded enamel and dentin in vitro.

Material and Methods: Brushing forces of a manual and two sonic toothbrushes (low and high frequency mode) were measured in 27 adults before and after instruction of the respective brushing technique and statistically analysed by repeated measures ANOVA. In the in vitro experiment, sound and eroded enamel and dentin specimens (each subgroup n=12) were brushed in an automatic brushing machine with the respective brushing forces using a fluoridated toothpaste slurry. Abrasion was determined by profilometry and statistically analysed by one-way ANOVA.

Results: Average brushing force of the manual toothbrush (1.6±0.3 N) was significantly higher than for the sonic toothbrushes (0.9±0.2 N), which were not significantly different from each other. Brushing force prior and after instruction of the brushing technique was not significantly different. The manual toothbrush caused highest abrasion of sound and eroded dentin, but lowest on sound enamel. No significant differences were detected on eroded enamel.

Conclusion: Brushing forces of manual and sonic toothbrushes are different and affect their abrasive capacity.

Clinical Significance: Patients with severe tooth wear and exposed and/or eroded dentin surfaces should use sonic toothbrushes to reduce abrasion, while patients without tooth wear or with erosive lesions confining only to enamel do not benefit from sonic toothbrushes with regard to abrasion.

Keywords

abrasion, dentin, enamel, erosion, toothbrushing force, tooth wear

Introduction

Toothbrushing abrasion is one factor in the multifactorial process of tooth wear. While toothbrushing is considered to be of minor importance for abrasion of sound enamel and dentin [1], it was shown to be a significant risk factor for the etiology of erosive lesions [2-5]. Especially on eroded enamel and dentin, toothbrushing abrasion is determined by the abrasivity [6,7] and concentration [8] of the toothpaste, but also modified by the kind of toothbrush [9,10] and the brushing force [11-13].

A large number of different electric toothbrushes (oscillating-rotating, sonic, ultrasonic) and many different brands are currently available on the market. Recent systematic reviews suggest that power toothbrushes do not demonstrate a clinically relevant damage potential to soft and hard tissues when compared with manual toothbrushes [14,15]. Among others, this observation was related to the assumption that power toothbrushes were usually applied with significantly lower brushing forces compared with manual toothbrushes. Thus, in vitro studies showed that power toothbrushes produced less dentin wear than manual toothbrushes when applied at a lower brushing force [16,17]. In contrast, oscillating-rotating, sonic and ultrasonic toothbrushes exhibited a higher abrasive potential compared with manual toothbrushes when they are applied at the same brushing force [9,10]. However, a comparison of the abrasivity of different types of toothbrushes remains difficult, not least as studies investigating the brushing forces of power toothbrushes date back several years and exhibited a high variation from 0.5 to 6 N [18-21].

No systematic evaluation of brushing forces in different sextants and sites, and of the effect of instruction on brushing technique has so far been performed. This issue is of particular interest as increasing brushing forces are assosciated with the development of wedge-shaped lesions [22] and with a higher abrasion potential on enamel and dentin [12,13]. Therefore, this study aimed 1) to determine and compare the brushing forces applied during in vivo toothbrushing with manual and sonic toothbrushes and 2) to analyse the effect of these brushing forces on abrasion of sound and eroded enamel and dentin in vitro. The null hypotheses were that (1) the brushing forces of manual and sonic toothbrushes are not significantly different and, thus, that (2) the abrasion of sound and eroded enamel or dentin is not significantly different between the toothbrushes at their specific brushing force.

Materials and Methods

Study design

The study was divided in two experiments: 1) Clinical assessment of brushing forces applied during toothbrushing with one manual and two sonic toothbrushes (crossover design) and 2) In vitro analysis of the effect of these brushing forces on abrasion of sound and eroded enamel and dentin.

Brushing forces were determined in 27 volunteers (5 male, 22 female, 18-55 years) before and after instruction of the respective brushing technique. Inclusion criteria were adult age and dentition with a minimum of 24 teeth. Exclusion criteria were removable dentures or orthodontic appliances, less than 24 teeth and physical disabilities with the potential to influence manual skills. Ethical approval for the study was granted by the local Ethics Committee (No 2011-0211/4). The volunteers were given oral and written information that the purpose of the study will be explained only at the end of the investigation in order to avoid bias in brushing force. All participants gave their written consent.

Mean brushing forces determined in vivo were used for the in vitro experiment, where sound and eroded enamel and dentin specimens (each subgroup n = 12) were brushed with the toothbrushes in an automatic brushing machine at the respective brushing forces. The amount of abrasion was determined by profilometry.

Toothbrushes

One manual (Candida Fresh Family X-Change, Migros, Switzerland) and two sonic toothbrushes (Sensonic Professional SR-1000 E, Waterpik; Sonic complete DLX, Oral B) were used in this crossover study. The sonic toothbrushes were used at both low and high frequency mode. Detailed information about the toothbrushes are given in Table 1.

Clinical assessment of brushing force

Brushing forces before and after the instruction of the respective brushing technique were determined with a 2-week training period in between. The sequence of toothbrushes was randomly assigned to the volunteers. The study comprised a total of 6 visits to the department for each volunteer.

In the first session, the volunteers were asked to perform their habitual brushing technique and to brush the vestibular, occlusal/incisal and lingual/palatal sites (each 20 s) sextant-wise (total: 6 min). As the first and last 5 s of each 20 s brushing interval had to be discarded due to alterations of the brushing forces by moving the toothbrush from one sextant or site to the other, the brushing time used for statistical analysis (10 s) of each sextant and site was considered to be clinically relevant. After the measurement of brushing force, volunteers received verbal information and training of the respective brushing technique. The brushing technique recommended for the manual toothbrush was the Modified Bass technique. Accordingly to the manufacturers, the sonic toothbrushes were recommended to be used with the bristles angled towards the gumline, brushhead gently moved in a slightly circular motion (Sonic complete DLX) and with the brush angled towards the gumline at a 45° angle, slow movement of the brush (Sensonic Professional SR 1000-E). The volunteers were provided with the respective toothbrush and were asked to practise the brushing technique at each toothbrushing within the 2-week training period. Two weeks after the instruction, brushing forces were measured again as described above. In both sessions, brushing was performed with a commercially available toothpaste (Elmex Sensitiv Plus, GABA International, Switzerland).

Brushing force measurement was achieved by mounting two strain gauges to the stem of the sonic toothbrushes or to a metal cantilever bridge between toothbrush holder and toothbrush head of the manual toothbrush, respectively. Flexing of the brush head was translated through a strain amplifier into different voltages, which were then monitored by a special software (PicoScope 6.0, Pico Technology, Cambridgeshire, UK, 50 measurements per s) and transfered to Microsoft Excel software. Prior to each brushing session, the set-up was calibrated for each toothbrush with standardized weights.

In vitro abrasion experiment

Cylindric enamel and dentin specimens (3 mm in diameter, in total 120 enamel and 120 dentin specimens) were obtained from the crowns or roots, respectively, of freshly extracted, non-damaged bovine incisors. The specimens were embedded in acrylic resin (Paladur, Heraeus Kulzer, Hanau, Germay), and surfaces were ground flat and polished with water-cooled carborundum discs (1200, 2400 and 4000 grit, Water Proof Silicon carbide Paper, Stuers, Erkrat, Germany). Approximately 200 µm of the outermost layer were removed as verified with a micrometer (Digimatic, Mitutoyo, Tokyo, Japan). The enamel and dentin specimens were distributed randomly to 10 groups of n = 12 specimens each. They were fixed in custom made resin appliances (Eracetal, Angst+Pfister, Zürich, Switzerland) allowing exact repositioning of the specimens in both the brushing machine and the profilometer.

Abrasion was performed in an automatic brushing machine, where the toothbrushes were applied at the respective brushing force determined in vivo (overall mean brushing force: manual: 1.6 N, sonic: 0.9 N). The toothbrushes were fixed in the holder of the brushing machine allowing alignment of the toothbrushing head parallel to the surface of the samples. The right and left sides of the specimens were covered with a stainless steel foil (0.1 mm thick) leaving a 2 mm wide area in the middle of each specimen exposed for brushing.

As the toothbrush head of the manual toothbrush was about 1.28 fold longer than the sonic toothbrushes (Table 1), the brushing time of the sonic toothbrushes was increased accordingly to ensure that the product of contact area (mm) and application time (min or s, respectively) remained constant for all brushes. Linear brushing motion was set at 100 brushing strokes/min for the manual and at 20 brushing strokes/min for the sonic toothbrushes [9,10].

Sound specimens were brushed for 100 min with the manual toothbrush and for 128 min with the sonic toothbrushes at low and high frequency mode. For abrasion of eroded enamel and dentin, specimens were subjected to a cyclic erosion-abrasion experiment. In each cycle, specimens were eroded (30 s, citric acid, pH 2.6, 1.5 ml/specimen), stored in artificial saliva (composition as given by Klimek et al. [23], 15 min), brushed and again stored in artificial saliva (30 min). Brushing with the manual toothbrush was performed with 8 linear brushing strokes (each third cycle: 9 linear brushing strokes); brushing with the sonic toothbrushes at high and low frequency was performed with 2 linear brushing strokes (tenth cycle: 3; twentieth cycle: 4; thirtieth cycle: 3 linear brushing strokes). Thus mean contact time of the brushes in each cycle amounted to 5 s (manual) and 6.4 s (sonic) to compensate for the different length of the toothbrush heads.

Brushing was performed with a toothpaste slurry containing fluoridated toothpaste (Elmex, GABA International, Switzerland, RDA: 35) and water in a ratio of 1:3 (3 ml). The slurry was renewed after each 5 min brushing (sound specimens) or after each brushing cycle (eroded specimens), respectively.

Substance loss was analysed with a stylus profilometer (Perthometer S2, Mahr, Göttingen, Germany). The device was equipped with a custom-made jig for repositioning the appliances with the samples for successive measurements. Dentin specimens were measured under wet conditions. Identification marks (scratches) on the acrylic resin surface of the embedded specimen were used for exact superimposition of the profiles [24]. These scratches were covered by the metal foil during brushing. Substance loss was calculated based on the differences between pre- and post-brushing profiles with a custom-designed software (4D Client, University Zurich, Zurich, Switzerland). Five profiles were performed on each specimen via scanning from the reference surface to the treated surface. Abrasion of sound specimens was measured after 100 min or 128 min brushing, respectively. Abrasion of eroded enamel and dentin was analysed after 10, 20 and 30 cycles of the erosion-abrasion experiment. An average of these five readings (µm) was obtained and used for data analysis.

Statistical analysis

Brushing force

For each volunteer brushing force of each sextant and each site was averaged for the mean brushing force. As values might be altered by moving the toothbrush from one sextant or site to the other, the values of the first and last 5 s of the 20 s brushing interval were discarded. Based on the fact that the brushing force was measured with a frequency of 50 measurements/s, a total of 500 single values were averaged to the mean brushing force of each interval.

Statistical analysis was performed by repeated measures ANOVA and Bonferroni post-hoc tests ($p < 0.05$) to analyse differences between the toothbrushes, between the brushing forces before and after instruction of the brushing technique, and between different sited and sextants.

Due to the number of volunteers, differences in brushing forces with respect to gender and handedness were not statistically analysed.

Abrasion

Mean enamel and dentin losses of sound and eroded specimens were computed. The assumption of the normal distribution was analyzed by means of Kolmogorow-Smirnow and Shaprio-Wilks tests. One-way ANOVA followed by the Scheffé post-hoc test was used to investigate if there are differences in mean enamel or dentin loss between the different groups of toothbrushes ($p < 0.05$).

Results

Brushing force

Mean brushing forces of different sextants and sites are presented in Tables 2 (upper jaw) and 3 (lower jaw). Considering all sextants and sites, the manual toothbrush was applied with a significant higher force (mean overall: 1.6 N) compared with the sonic toothbrushes (mean overall: 0.9 N), while comparisons between high and low frequency modes of the sonic toothbrushes revealed no significant differences.

Summarizing the multiple comparisons between sextants and sites, brushing forces in the premolar/molar region (1st, 3rd, 4th and 6th sextants) were slightly lower on the vestibular site than on the occlusal and palatal/lingual sites. The incisors and canines (2^{nd} and 5^{th} sextants) were brushed with higher brushing forces at the vestibular and palatal/lingual sites than on the incisal site. Overall, brushing forces within the vestibular, occlusal or palatal/lingual sites were relatively consistent and in a narrow range.

Brushing forces before and after instruction of the respective brushing technique were not significantly different.

Substance loss

Substance loss of sound and eroded specimens is presented in figures 1 and 2.

Abrasion of sound enamel was greatest for specimens brushed with the sonic toothbrush Sensonic Professional SR-1000 E, followed by the sonic toothbrush Sonic complete DLX and the manual toothbrush. Abrasive potential of the different toothbrushes on eroded enamel was only slightly, but mostly not significantly different. The manual toothbrush (1.6 N brushing force) caused significantly higher abrasion of sound and eroded dentin than the sonic toothbrushes (0.9 N brushing force).

Discussion

This study showed that the manual toothbrush was applied with higher brushing forces than sonic toothbrushes, independently of the sextant, the site and whether the brushing technique was instructed or not. Applying these higher brushing forces resulted in an increased abrasion of sound and eroded dentin, but not of sound and eroded enamel as compared with the sonic toothbrushes. Therefore, the first null hypothesis that the brushing forces of manual and sonic toothbrushes are not significantly different was rejected. The second null hypothesis that the abrasion of sound and eroded dental hard tissue is not significantly different between the toothbrushes at their specific brushing force was accepted for eroded enamel and rejected for dentin and sound enamel.

For the first time, the brushing forces of sonic and manual toothbrushes were systematically analysed for different sextants and sites and – in case of the sonic toothbrushes – for different frequencies. Generally, brushing with the manual toothbrush demonstrated significantly higher brushing forces on all sites compared with the sonic toothbrushes at both low and high frequency modes. The mean brushing force of the manual toothbrush was slightly lower than brushing forces reported earlier [21,25]. Although the purpose of the study was disclosed only at the end of the study, it can not be excluded that toothbrushing habits of the volunteers were affected by the awareness of being monitored and the fact that they were asked to perform the brushing systematically in 20 s intervals.

Toothbrushing forces in the premolar/molar region were slightly lower on vestibular than on occlusal or palatal/lingual sites. A similar trend was shown by van der Weijden et al. [26], where significantly higher brushing forces on lingual than on buccal tooth surfaces were observed. As oral sites might be more difficult to access than vestibular tooth surfaces, brushing forces might be increased unconsciously. However, brushing forces within vestibular or palatal/lingual sites were relatively constant among the different sextants, confirming that the mean brushing forces of uninstructed adults do not differ significantly between different quadrants [25].

Toothbrushing forces at baseline and two weeks after instruction of the correct brushing technique were not significantly different. Heasman et al. [21] observed that the brushing forces of oscillating-rotating but not of manual toothbrushes decreased slightly within a 6 week training period, which was attributed to the controlled pressure system of the toothbrushes, which provided feedback by a click if a certain threshold was reached. However, the sonic toothbrushes tested in the present study did not exhibit any feedback system for control of brushing force. Therefore, it is assumed that brushing force – at least at the certain level found in the present study - is not affected by the brushing technique. Moreover, it has to be taken into account that the correct brushing technique can be hardly adopted even in highly motivated patients [27,28]. Although the volunteers were asked to brush their teeth in a specific sequence with the correct brushing technique at the second visit, it is speculated that the brushing technique was not fully adopted during the 2 week training period at home.

In the in-vitro-experiment, the mean brushing forces determined in vivo were transferred to the automatic brushing machine that controls all relevant key parameters in a standardized manner [11]. In both abrasion experiments, the brushing time with the sonic toothbrushes was increased by a factor of 1.28 to account for the different length of the toothbrush heads. As electric toothbrushes are usually gently moved from one tooth to the next, the sonic toothbrushes were applied with fewer linear brushing strokes than the manual toothbrush [9,10]. However, the brushing speed was not shown to have any significant impact on enamel and dentin abrasion [11].

Abrasion of sound specimens was intentionally exaggerated to a level where enamel loss exceeds the detection limit of the profilometer (lower limit of quantification: 0.105 µm) [24]. The parameters of the erosion-abrasion experiment, especially the short duration of erosion and abrasion treatment, followed recent recommendations aiming to simulate clinical conditions as closely as possible [29]. The use of bovine enamel and dentin instead of human dental hard tissue in erosion/abrasion experiments is widely accepted, especially as relative tissue loss rather than absolute values are of interest and only slight differences between human and bovine substrates exist [29,30].

The present results confirmed previous studies showing that dentin abrasion is indeed higher for manual than for power toothbrushes [16,17]. The lower abrasivity of the sonic toothbrushes is most likely due to the lower brushing force. While it was demonstrated that dentin abrasion due to brushing with manual toothbrushes at 2.5 N and power toothbrushes at 1.5 N brushing force was not significantly different, decreasing the brushing forces of power toothbrushes to 0.9 N approximately halved dentin loss [17]. Differences in filament stiffness, bristle design and particular movement of the toothbrushes might also affect the results. The high frequency mode of the sonic toothbrushes caused higher wear than the low frequency mode, and the Sensonic Professional SR-1000 E toothbrush caused higher abrasion than the Sonic complete DLX. However, overall, these differences are suggested to be less relevant when compared to the brushing force, as it was shown that the abrasivity of various ultrasonic, sonic, oscillating-rotating and manual toothbrushes varied only slighty when the brushes were applied on the same force [9]. The higher wear of eroded dentin in specimens brushed with the manual toothbrush is also attributed to the higher brushing force as Ganss et al. [12] demonstrated that the exposed organic layer of eroded dentin is compressed with increasing brushing forces.

However, the lower abrasivity of sonic toothbrushes was not confirmed on enamel specimens. On sound enamel, both sonic toothbrushes caused greater loss than the manual toothbrush, although it has to be noticed that the susceptibility against abrasion was distinctly lower for enamel than for dentin. Abrasion of eroded enamel was not significantly different among the different toothbrush groups. These results are in accordance with a previous study [13] which found no significant impact of the brushing force on enamel abrasion when brushing forces were below 4.5 N (sound enamel) or 3.5 N (eroded enamel), respectively. Even at the same brushing force, the abrasion potential of sonic and manual toothbrushes was not significantly different [10], indicating that under the conditions of the present study the softened enamel layer is removed completely irrespective of the kind of toothbrush.

From the results of the present study it can be recommended that patients with severe tooth wear and exposed (eroded) dentin surfaces should use sonic toothbrushes to reduce abrasion, while patients without tooth wear or with erosive lesions confined only to enamel do not benefit from sonic toothbrushes with regard to abrasion.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Table 1: Characteristics of the manual and sonic toothbrushes.

Name	**Type**	**Manufacturer**	**Frequency**	**Length of brushing head**
Candida Fresh Family X-Change	manual	Migros, Switzerland		13.4 mm
Sonic complete DLX	sonic	Oral B, Procter&Gamble, Switzerland	High: 260 HZ (31.200 strokes/min, clean mode) Low: 240 Hz (28.800 strokes/min, soft mode)	10.6 mm
Sensonic Professional SR-1000 E	sonic	Waterpik, Water Pik, Switzerland	High: 250 HZ (30.000 strokes/min) Low: 200 HZ (24.000 strokes/min)	10.5 mm

Both sonic toothbrushes do not have a feedback system for controlled pressure.

Table 2: Mean (± standard deviation) brushing forces (N) in the upper jaw before and after the instruction of the respective brushing technique.

		Prior instruction of brushing technique					**After instruction of brushing technique**				
		Sensonic Professional SR-1000 E		Sonic Complete DLX		manual	Sensonic Professional SR-1000 E		Sonic Complete DLX		manual
Sextant	Site	low	high	low	high		low	high	low	high	
1	vestibular	$0.90^{b,A,\beta}$ (0.63)	$0.63^{a,A,\alpha}$ (0.48)	$0.70^{ab,A,\alpha}$ (0.60)	$0.81^{ab,A,\alpha\beta}$ (0.85)	$1.04^{ab,A,\alpha}$ (0.87)	$0.81^{b,A,\alpha\beta}$ (0.59)	$0.52^{a,A,\alpha}$ (0.42)	$0.62^{ab,A,\alpha}$ (0.48)	$0.65^{ab,A,\alpha\beta}$ (0.54)	$1.06^{ab,A,\alpha}$ (0.86)
	occlusal	$1.38^{ab,B,\beta}$ (0.54)	$1.12^{a,B,\beta}$ (0.55)	$1.13^{a,B,\beta}$ (0.52)	$1.26^{a,B,\beta}$ (0.63)	$1.91^{b,B,\beta}$ (0.97)	$1.23^{ab,B,\beta}$ (0.63)	$1.02^{a,B,\beta}$ (0.63)	$0.89^{a,B,\beta}$ (0.43)	$1.00^{a,B,\beta}$ (0.53)	$1.95^{b,B,\beta}$ (1.29)
	palatal	$1.01^{a,B,\alpha}$ (0.43)	$0.93^{a,B,\alpha\beta}$ (0.48)	$1.06^{a,B,\alpha\beta}$ (0.43)	$1.14^{a,AB,\beta}$ (0.44)	$1.83^{b,B,\beta}$ (0.96)	$1.08^{a,B,\beta}$ (0.62)	$1.07^{a,B,\alpha\beta}$ (0.65)	$0.92^{a,B,\beta}$ (0.46)	$0.98^{a,B,\beta}$ (0.53)	$1.74^{b,B,\alpha}$ (1.05)
2	vestibular	$1.01^{b,B,\beta}$ (0.45)	$0.78^{a,B,\alpha}$ (0.43)	$0.78^{ab,B,\alpha}$ (0.44)	$0.96^{ab,B,\beta}$ (0.50)	$1.89^{c,B,\beta}$ (1.13)	$0.93^{a,B,\beta}$ (0.41)	$0.74^{a,B,\beta}$ (0.48)	$0.72^{a,B,\alpha}$ (0.40)	$0.75^{a,B,\beta}$ (0.34)	$1.64^{b,B,\beta}$ (0.92)
	incisal	$0.44^{ab,A,\alpha}$ (0.32)	$0.44^{ab,A,\alpha}$ (0.33)	$0.45^{a,A,\alpha}$ (0.37)	$0.69^{bc,A,\alpha}$ (0.58)	$0.96^{c,A,\alpha}$ (0.67)	$0.55^{ab,A,\alpha}$ (0.40)	$0.39^{a,A,\alpha}$ (0.42)	$0.43^{a,A,\alpha}$ (0.30)	$0.45^{a,A,\alpha}$ (0.34)	$1.02^{b,A,\alpha}$ (0.81)
	palatal	$1.07^{ab,B,\alpha\beta}$ (0.52)	$0.79^{a,B,\alpha}$ (0.33)	$0.87^{a,B,\alpha}$ (0.54)	$0.88^{a,B,\alpha}$ (0.43)	$1.49^{b,B,\alpha}$ (0.77)	$0.97^{b,B,\alpha}$ (0.45)	$0.93^{ab,B,\alpha}$ (0.63)	$0.70^{a,B,\alpha}$ (0.38)	$0.71^{a,B,\alpha}$ (0.37)	$1.54^{b,B,\alpha}$ (1.05)
3	vestibular	$0.69^{a,A,\alpha}$ (0.57)	$0.58^{a,A,\alpha}$ (0.52)	$0.60^{a,A,\alpha}$ (0.65)	$0.69^{a,A,\alpha}$ (0.61)	$1.43^{b,A,\alpha}$ (0.97)	$0.66^{ab,A,\alpha}$ (0.47)	$0.56^{ab,A,\alpha\beta}$ (0.52)	$0.53^{a,A,\alpha}$ (0.48)	$0.45^{a,A,\alpha}$ (0.44)	$1.19^{b,A,\alpha}$ (0.93)
	occlusal	$1.25^{ab,B,\beta}$	$1.01^{a,B,\beta}$	$1.07^{a,B,\beta}$	$1.17^{a,B,\beta}$	$1.88^{b,AB,\beta}$	$1.19^{ab,B,\beta}$	$0.97^{a,B,\beta}$	$0.90^{a,B,\beta}$	$0.97^{a,B,\beta}$	$1.86^{b,B,\beta}$

In each row, significant differences between the toothbrushes before or after the instruction of the brushing technique, respectively, were marked with different small letters.

Within each column, significant differences in brushing force at the different sites of each sextant were marked by different capital letters. Within each site, significant differences between the 1^{st} to 3^{rd} sextant were marked by different greek letters.

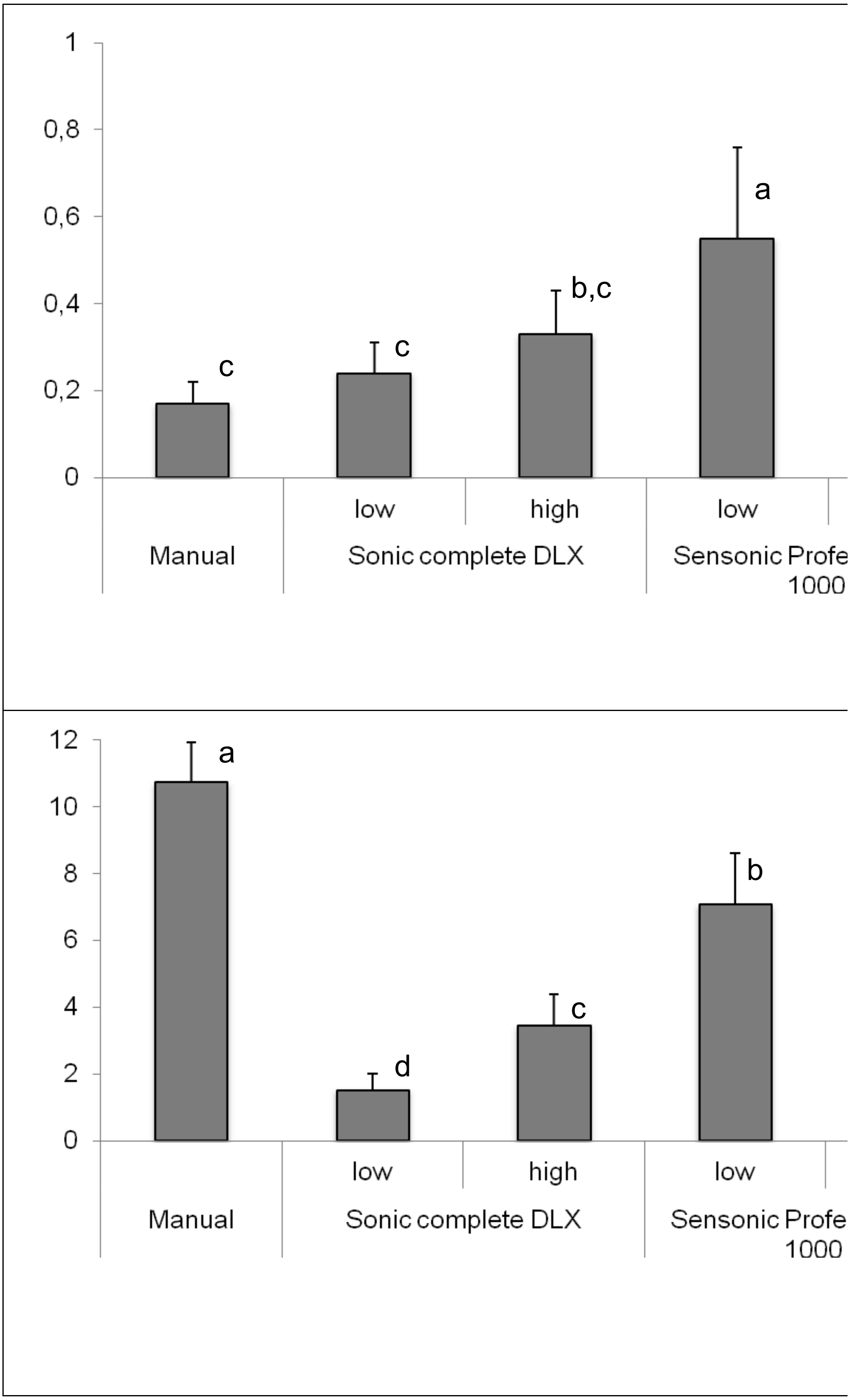
Within one toothbrush, differences between brushing forces before and after instruction of the brushing technique were not significant independently of the site and sextant.

Table 3: Mean (± standard deviation) brushing forces (N) in the lower jaw before and after the instruction of the respective brushing technique.

		Prior instruction of brushing technique					**After instruction of brushing technique**				
		Sensonic Professional SR-1000 E		Sonic Complete DLX		manual	Sensonic Professional SR-1000 E		Sonic Complete DLX		manual
Sextant	Site	low	high	low	high		low	high	low	high	
4	vestibular	0.81 $^{ab,A,\alpha}$ (0.53)	0.68 $^{a,A,\alpha}$ (0.56)	0.74 $^{ab,A,\alpha}$ (0.53)	0.68 $^{ab,A,\alpha}$ (0.58)	1.27 $^{b,A,\alpha\beta}$ (0.95)	0.66 $^{ab,A,\alpha}$ (0.42)	0.57 $^{a,A,\alpha}$ (0.51)	0.63 $^{a,A,\alpha}$ (0.44)	0.60 $^{a,A,\alpha}$ (0.50)	1.30 $^{b,A,\alpha}$ (0.86)
	occlusal	1.19 $^{a,B,\beta}$ (0.48)	1.01 $^{a,B,\beta}$ (0.52)	1.01 $^{a,B,\beta}$ (0.57)	1.13 $^{a,B,\beta}$ (0.55)	1.86 $^{b,A,\beta}$ (0.92)	0.99 $^{a,B,\beta}$ (0.51)	0.92 $^{a,AB,\beta}$ (0.68)	0.89 $^{a,B,\beta}$ (0.40)	0.96 $^{a,B,\beta}$ (0.44)	1.69 $^{b,A,\beta}$ (0.98)
	lingual	0.99 $^{a,AB,\alpha}$ (0.40)	0.94 $^{a,AB,\alpha}$ (0.47)	1.16 $^{ab,B,\alpha}$ (0.62)	1.24 $^{a,B,\alpha}$ (0.68)	1.77 $^{b,A,\alpha}$ (0.85)	0.93 $^{a,AB,\alpha}$ (0.45)	1.02 $^{a,B,\alpha}$ (0.63)	0.99 $^{a,B,\alpha}$ (0.43)	1.09 $^{ab,B,\beta}$ (0.47)	1.73 $^{b,A,\alpha}$ (0.99)
5	vestibular	0.82 $^{a,AB,\alpha}$ (0.44)	0.74 $^{a,B,\alpha}$ (0.53)	0.74 $^{a,A,\alpha}$ (0.44)	0.70 $^{a,A,\alpha}$ (0.36)	1.68 $^{b,A,\beta}$ (0.80)	0.73 $^{a,A,\alpha}$ (0.34)	0.65 $^{a,A,\alpha}$ (0.45)	0.64 $^{a,A,\alpha}$ (0.31)	0.66 $^{a,A,\alpha}$ (0.35)	1.46 $^{b,A,\alpha}$ (0.76)
	incisal	0.56 $^{a,A,\alpha}$ (0.39)	0.49 $^{a,A,\alpha}$ (0.35)	0.61 $^{a,A,\alpha}$ (0.41)	0.68 $^{a,A,\alpha}$ (0.45)	1.24 $^{b,A,\alpha}$ (0.74)	0.56 $^{a,A,\alpha}$ (0.40)	0.53 $^{a,A,\alpha}$ (0.51)	0.51 $^{a,A,\alpha}$ (0.30)	0.59 $^{a,A,\alpha}$ (0.33)	1.16 $^{b,A,\alpha}$ (0.72)
	lingual	1.07 $^{ab,B,\alpha}$ (0.45)	0.96 $^{a,B,\alpha}$ (0.50)	0.97 $^{a,B,\alpha}$ (0.54)	1.01 $^{ab,B,\alpha}$ (0.46)	1.61 $^{b,A,\alpha}$ (0.86)	1.06 $^{ab,B,\alpha}$ (0.50)	1.02 $^{a,B,\alpha}$ (0.55)	0.89 $^{a,B,\alpha}$ (0.45)	0.92 $^{a,B,\alpha\beta}$ (0.41)	1.60 $^{b,A,\alpha}$ (0.90)
6	vestibular	0.77 $^{a,A,\alpha}$ (0.52)	0.60 $^{a,A,\alpha}$ (0.49)	0.73 $^{a,A,\alpha}$ (0.56)	0.68 $^{a,A,\alpha}$ (0.50)	1.06 $^{a,A,\alpha}$ (0.82)	0.69 $^{ab,A,\alpha}$ (0.48)	0.66 $^{ab,A,\alpha}$ (0.75)	0.62 $^{ab,A,\alpha}$ (0.39)	0.54 $^{a,A,\alpha}$ (0.38)	1.13 $^{b,A,\alpha}$ (0.84)
	occlusal	1.03 $^{a,AB,\beta}$ (0.50)	0.88 $^{a,B,\beta}$ (0.51)	1.03 $^{a,B,\beta}$ (0.62)	1.11 $^{a,B,\beta}$ (0.61)	1.93 $^{b,B,\beta}$ (1.15)	0.95 $^{a,A,\beta}$ (0.61)	0.89 $^{a,A,\beta}$ (0.58)	0.89 $^{a,B,\beta}$ (0.40)	0.90 $^{a,B,\beta}$ (0.38)	1.86 $^{b,A,\beta}$ (1.17)
	lingual	1.05 $^{a,B,\alpha}$ (0.44)	1.05 $^{a,B,\alpha}$ (0.52)	1.04 $^{a,B,\alpha}$ (0.52)	1.08 $^{a,B,\alpha}$ (0.52)	1.85 $^{b,B,\alpha}$ (1.11)	0.92 $^{a,A,\alpha}$ (0.46)	1.03 $^{ab,A,\alpha}$ (0.57)	0.89 $^{a,B,\alpha}$ (0.41)	0.91 $^{a,B,\alpha}$ (0.34)	1.55 $^{b,A,\alpha}$ (0.89)
mean		**0.92 (0.19)**	**0.81 (0.20)**	**0.89 (0.19)**	**0.92 (0.23)**	**1.58 (0.32)**	**0.83 (0.17)**	**0.81 (0.18)**	**0.77 (0.17)**	**0.80 (0.20)**	**1.50 (0.26)**

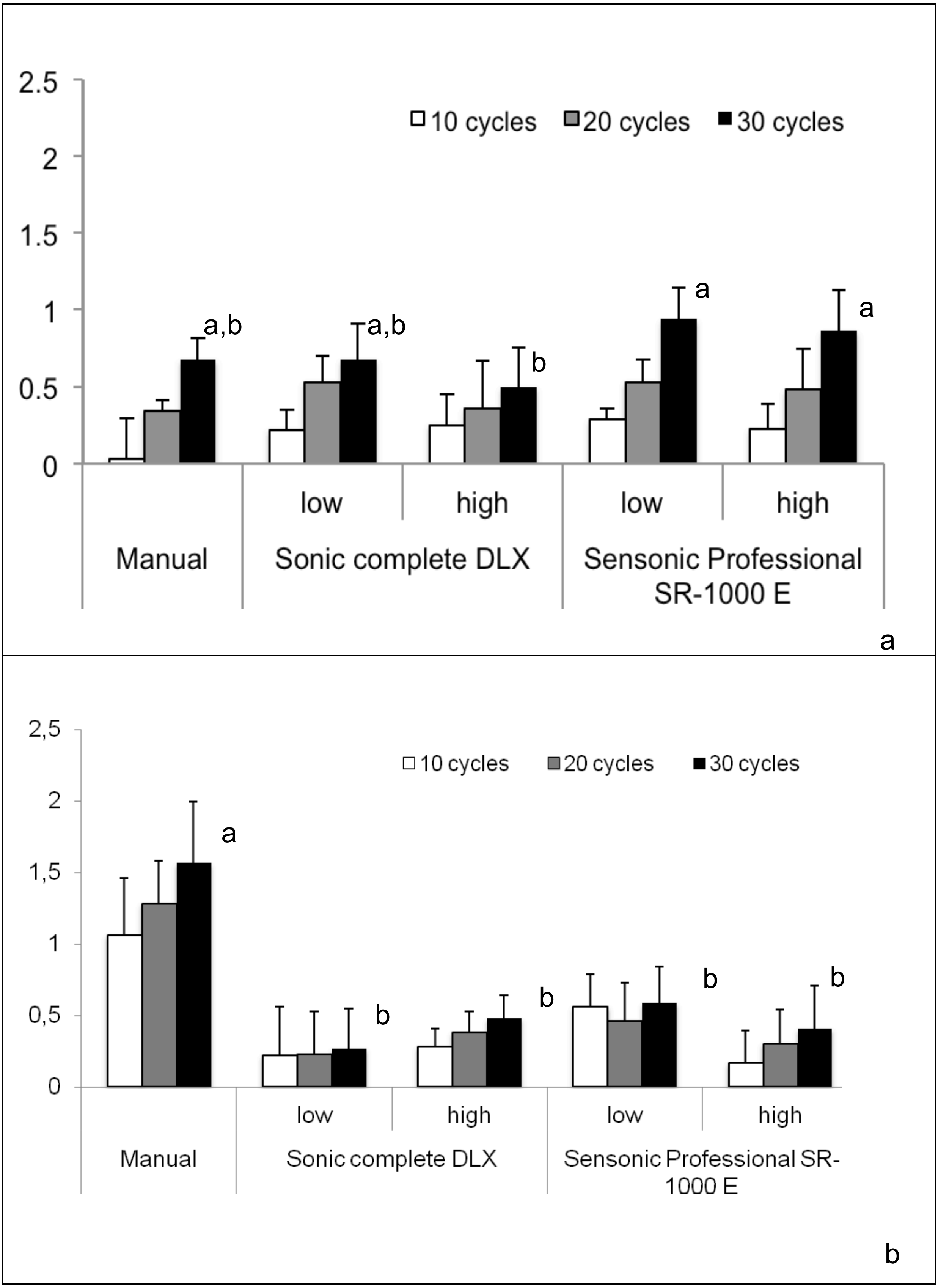
In each row, significant differences between the toothbrushes before or after the instruction of the brushing technique, respectively, were marked with different small letters.
Within each column, significant differences in brushing force at the different sites of each sextant were marked by different capital letters. Within each site, significant differences between the 4th to 6th sextant were marked by different greek letters.
Within one toothbrush, differences between brushing forces before and after instruction of the brushing technique were not significant independently of the site and sextant.

Figure 1: Enamel (a) and dentin (b) loss (mean ± standard deviation,
specimens after brushing with the different toothbrushes.



Significant differences are marked by different letters.

Figure 2: Enamel (a) and dentin (b) loss (mean ± standard deviation, µm) of eroded specimens after 10, 20 and 30 cycles of the erosion-abrasion experiment.



Significant differences after 30 cycles are marked by different letters.