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A graphic tool to help consumers determine when to replace a toothbrush: a cohort study

Michèle Muller-Bolla[1,2], Alexandra Repetto[1] and Ana Miriam Velly[3–5]

[1]*Department of Dental Public Health, Unité de Formation et de Recherche (UFR) Odontology, Nice Sophia Antipolis University (UNS), Centre Hospitalo-Universitaire de Nice, Nice, France;* [2]*Laboratory URB2i-EA 4462, Department of Biomaterials, University of Paris Descartes, Paris, France;* [3]*Department of Diagnostic and Biological Sciences, School of Dentistry, University of Minnesota, Minneapolis, MN, USA;* [4]*Centre of Clinical Epidemiology and Community Studies, Faculty of Dentistry, McGill University, Montreal, QC, Canada;* [5]*Department of Dentistry, Jewish General Hospital, Montreal, QC, Canada.*

Objectives: The aim of this study was to create and validate a drawing to help adults establish when to replace a manual toothbrush. **Methods:** This cohort study had two phases. Phase I (3 months, 50 subjects) aimed to create a drawing of average wear in a toothbrush based on a wear index (WI) of 68% for the tested toothbrush. This was validated in Phase II (3 months, 30 participants). Pictures of worn brushing surfaces were generated using an image acquisition system. Images in each study phase were superimposed to provide a single reference outline to indicate when a toothbrush should be replaced. Residual plaque index values for identical brushing protocols were recorded using new and worn toothbrushes in Phase I and compared using Student's paired *t*-test. Student's *t*-test was used to compare duration of tooth-brushing and WI values in both phases. **Results:** After brushing according to a uniform protocol, the residual plaque index at baseline was significantly lower than that at the last use of the toothbrush ($P < 0.01$). The drawings generated in Phases I and II were similar in terms of WI ($P = 0.33$) and period of use ($P = 0.12$). **Conclusions:** This simple drawing may help adults establish when they should replace a toothbrush.

Key words: *Toothbrush, wear, cohort study*

Advice on how long a toothbrush should be kept and used varies. Most national dental associations recommend replacing a toothbrush after about 3 months; some recommend slightly longer or shorter periods (*Table 1*). Guidelines in France recommend that toothbrushes be replaced every 3 months if they are used for 3 min three times per day[1]. When this recommendation was made, toothbrushes may have been of different quality and had harder bristles than they do today and as a result may not have worn out so fast[2]. Today's toothbrushes have softer bristles that damage the periodontium less without reducing their efficacy in removing plaque. However, recommendations on the length of time for which a toothbrush should be used have not changed.

The design of toothbrushes has changed: the disposition of tufts and hence the shape of the area brushed is different and bristle lengths on the same toothbrush may vary[3]. Differences in wear characteristics, bristle layout and length affect the efficiency of plaque removal[4]. Every toothbrush has its own duration of usefulness and this is affected by the user's habits, frequency of tooth-brushing, duration of each brushing session and the pressure exerted[5]. This makes it difficult to give a standard recommendation on how often a toothbrush should be replaced.

In addition, the wear index (WI) of the toothbrush affects the quantity of plaque removed in a given duration of brushing: the efficacy of a toothbrush with a WI of 68% in removing plaque was significantly lower than that of a new toothbrush[6].

This cohort study sought to validate the use of a simple drawing illustrating the WI to encourage toothbrush users to replace their toothbrushes when necessary.

METHODS

This prospective cohort study was conducted in two phases. The aim of Phase I was to determine the wear after use of a tested toothbrush (Soft Elmex®; Gaba Laboratoire, Paris, France).

The aim of Phase II was to validate the wear drawing generated in Phase I among other users. Both phases were of 3 months' duration. The study received ethical

Table 1 Duration of toothbrush use recommended by national dental associations

Country or region	National dental association	Recommended duration of use, months
Africa		
South Africa	South African Dental Association	3.5
Americas		
Latin America	Hispanic Dental Association	3
Canada	Canadian Dental Association	3
USA	American Dental Association*	3–4*
	California Dental Association	A few months or until toothbrush appears worn
	National Institutes of Health*	3*
	Oregon Dental Association	3–4
Asia		
India	Dental India	3–4
Iran	Iranian Dental Association	3–4
Malaysia	Malaysian Dental Association	3
Singapore	Singapore Dental Association	3–4
Germany	German Dental Association	3
Belgium	Société de Médecine Dentaire	No
France	Union Française pour la Santé Bucco-Dentaire	3
Ireland	Irish Dental Association	3–4
UK	British Dental Association	3–4
Oceania		
Australia	Australian Dental Association	2–5
New Zealand	New Zealand Dental Association	3

*Based on expert opinion without using evidence-based dentistry. Sixteen of the 18 associations do not indicate the method to be used.

approval from the regional ethical committee (Espace Ethique Côte d'Azur, France).

Study population

Participants were patients at the dental hospital in Nice, France. Eligibility for participation required candidates to be aged > 18 years and to complete and sign an informed consent form. Phase I involved 50 participants. Phase II included 30 different participants. Subjects who had fewer than 25 intact teeth, cervical caries, a restoration or a crown on a scorable tooth (teeth 12, 31, 16, 26, 36 and 46), were currently undergoing orthodontic treatment, were using a removable prosthesis or had advanced periodontal disease were excluded.

Phase I

Clinical assessment

At baseline, all 50 participants were interviewed about their usual brushing habits by one examiner (AR). A Soft Elmex® toothbrush (*Figure 1*) was distributed to each participant to be used according to that person's usual brushing habits. Subsequently, the duration and

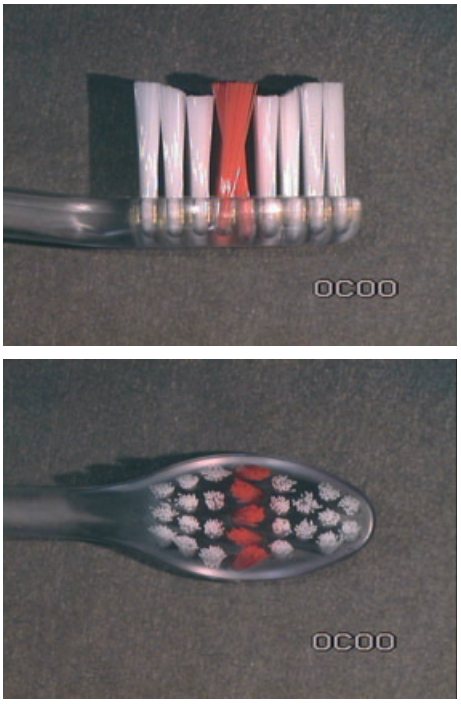

Figure 1. Soft Elmex® toothbrush (Gaba Laboratoire, Paris, France) recommended for use by persons with a healthy periodontium.

the quality of tooth-brushing with this Soft Elmex® toothbrush were assessed by the examiner. Plaque, disclosed with an erythrosine dye (Reveal©; Henry Schein, Paris, France), was scored pre- and post-brushing using the Turesky *et al.* modification of the Quigley–Hein plaque index (TQHPI)[7]. The buccal surfaces of teeth 12, 31, 46 and 26 were scored for plaque, as were the lingual-palatal surfaces of teeth 36 and 16. Scoring was always performed by the same examiner (AR), who had 3 years' experience in dentistry and had been trained and calibrated by a professor in the Department of Dental Public Health, Nice Sophia Antipolis University, in order to ensure that examinations and clinical scoring were consistent. After 1 week of training, intra-examiner consistency was assessed using a process in which 15 patients were examined and then re-examined after 30 min. The kappa value for repeat scoring was 0.80.

Participants were requested to return to the dental clinic when they considered their toothbrush to be too worn out to brush properly. At the latest, this visit was to be made 3 months after receipt of the toothbrush. After this follow-up period (≤ 3 months), the residual plaque index was measured again after a tooth-brushing session of the same duration as that at baseline.

Toothbrush assessment

The condition of the returned toothbrushes was assessed. Wear of the bristles was recorded using a

Sony® camera (Sony CCD-IRIS; Sony Corp., Tokyo, Japan) fitted with a 50-mm lens. Photographs were processed using the Visilog 5.2® image analysis program (Noesis Vision, Saint Laurent, QC, Canada). The camera was maintained at a fixed height above the toothbrush for all photographs. The brush was supported in a plaster cast including a ruler. The ruler was graduated in tenths of a millimetre to allow the measurement of new brush (A_0) and worn brush (A_f) areas. These measurements allowed the WI $[(A_f - A_0) \times 100/A_0]$ of each toothbrush to be calculated[8]. Thus, photographic images of the total brushing area were captured for a new toothbrush and for the 50 worn brushes. The outline brushing area of each brush was traced starting with the external bristles, using the computer mouse and the software CATIA Version 5 (Dassault Systèmes, Vélizy-Villacoublay, France).

The drawings of the 51 brushing surfaces were then stacked in order by referring to the ruler. From this superimposition, five smoothed outlines were drawn in different colours (*Figure 2*). A pink outline corresponded to the outline of the new toothbrush. In the superimposed drawings of the brushing areas of the worn toothbrushes, the smallest area was indicated by a blue outline and the largest by a green outline. The average brushing area of a used brush was indicated by a purple outline. The turquoise outline in the last drawing represented the 68% increase in brushing area compared with the brushing area of the new toothbrush (*Figures 2 and 3*).

To assess the reproducibility of the tracing procedure, the operator measured the brushing area 10 times for each of five randomly selected toothbrushes.

Phase II

As the aim of Phase II was to validate the drawings obtained in Phase I, 30 new subjects were invited to participate in this phase of the study. These new participants were each given a new Soft Elmex® toothbrush and were invited to return to the dental clinic with the toothbrush when they considered the toothbrush to be worn out or, at the latest, 3 months after receiving the toothbrush.

Drawings of the brushing area of each toothbrush returned were made using the same methods as in Phase I. To evaluate whether the drawing of the brushing area in Phase II corresponded with the drawing obtained in Phase I, the second drawing (turquoise dotted outline) was superimposed on the first drawing (turquoise continuous outline) obtained in Phase I (*Figure 4*).

Statistical analyses

The plaque index, the duration of use of each toothbrush and the WI were assessed for distribution normality to choose the appropriate method of analysis. To evaluate plaque removal by worn toothbrushes in Phase I, the residual plaque index values at baseline and at the last use of the toothbrush (with equal brushing times) were compared using Student's paired *t*-test.

To test differences between outcomes in Phases I and II, the duration of use of toothbrushes and the WI in both studies were compared using the *t*-test. Statistical analyses were undertaken using SPSS Version 18 (SPSS, Inc., Chicago, IL, USA). The significance level was set at $P \leq 0.05$.

RESULTS

Phase I

Thirty-two women and 18 men [mean ± standard deviation (SD) age: 38.0 ± 15.1 years; range: 18–77 years] participated in Phase I. At baseline, most of these subjects reported using a manual toothbrush (n = 43, 86.0%); a few used an electric toothbrush (n = 6, 12.0%); one used both a manual and an electric toothbrush (n = 1, 2.0%). These participants reported that their brushing frequency varied from one to three times per day (mean ± SD: 2.1 ± 0.4 times/day).

At baseline, the mean ± SD duration of brushing recorded in all subjects was 118.6 ± 54.0 s (range: 52–258 s). All 50 participants returned the Soft Elmex® toothbrush within 3 months when they considered the toothbrush was no longer usable. The mean ± SD duration of use was 38.6 ± 13.5 days (range: 15–65 days).

The superimposed drawings of the brushing areas of the 50 used toothbrushes are presented in *Figure 2*. The baseline brushing area was 178.83 mm^2, whereas the mean ± SD final brushing area was 337.5 ± 61.0 mm^2 (range: 243.0–480.6 mm^2). Fifteen (30.0%) participants returned their used toothbrushes with a WI of < 68%. The mean ± SD WI for all 50 toothbrushes was 88.7 ± 34.1% (range: 6–169%).

For brushing sessions of the same duration, the residual plaque index at baseline was statistically significantly different from that at the last tooth brushing independently of dental location (*Table 2*).

Phase II

The drawing of toothbrush wear was validated among 30 new subjects. The superimposition of drawings of the areas brushed by worn toothbrushes to determine the average area brushed by a used brush with a WI of 68% (turquoise outline) is presented in *Figure 3*. The mean ± SD WI in Phase II was 81.4 ± 28.1% (range: 36–147%) and did not differ significantly from that registered in Phase I (P = 0.33). Ten subjects (33.3%)

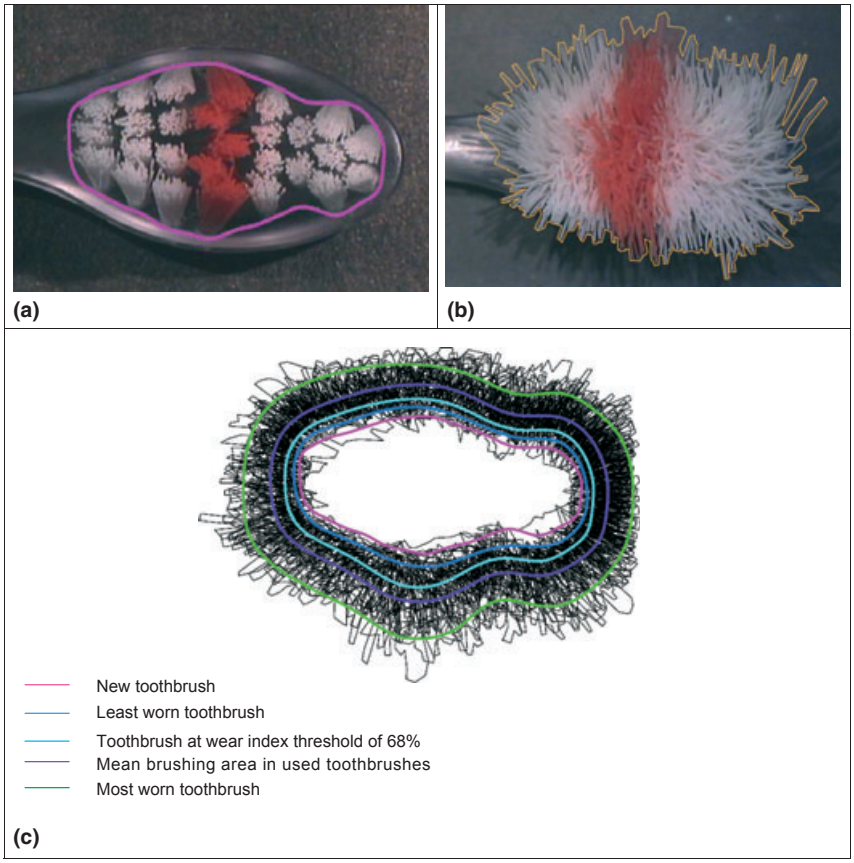

Figure 2. (a) New and (b) most worn Soft Elmex® toothbrushes. (c) Outlines of brushing areas correspond to those in the 50 toothbrushes tested in Phase I.

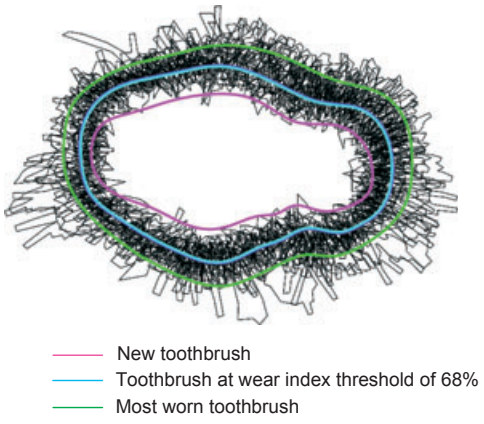

Figure 3. Outlines of brushing areas in the Soft Elmex® toothbrush correspond to those in the 30 toothbrushes tested in Phase II.

returned their used toothbrushes with a WI of < 68%. The mean ± SD period of toothbrush use was 34.2 ± 7.9 days (range: 15–45 days) and did not differ significantly from the period observed in Phase I ($P = 0.12$). We compared the turquoise outlines obtained in Phases I and II (*Figure 4*).

Figure 5 shows a new simple tool that can be used to assess the quality of a toothbrush. The red outline shows the limits of an inefficient toothbrush that should be discarded and the green outline shows the limits of a new toothbrush.

DISCUSSION

A simple drawing corresponding to the brushing area of a particular type of toothbrush can be used to help the consumer assess the quality of a toothbrush and, if necessary, to decide to replace it.

It is generally recommended that toothbrushes should be replaced before the first signs of wear appear on the bristles[5]. However, it is difficult for the user to assess the spreading and bending of toothbrush bristles, although these are considered to represent the main indicators of wear and to demonstrate that the toothbrush should be replaced[9]. This simple tool might help in this. It is based on the outline of a worn toothbrush that corresponds to an increase in the WI value of 68%. Depending on the initial toothbrush design, it may be easier to evaluate toothbrush wear using this method than by judging the spread and flexibility of bristles.

This method is more objective than adherence to the recommendations of numerous dental associations to replace a toothbrush after 3 months. This advice is not based on any evidence because there is little clinical support for this recommendation for currently available

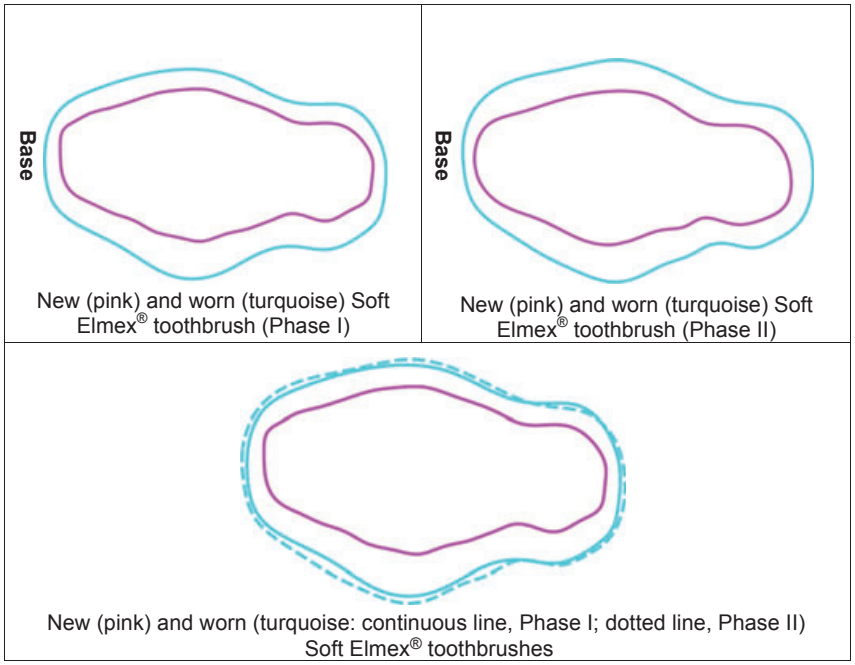

Figure 4. Outlines of brushing areas in new and worn Soft Elmex® toothbrushes tested in Phases I and II.

Table 2 Residual plaque index values assessed using the Turesky *et al.* [7] modification of the Quigley–Hein plaque index (TQHPI) at baseline and at the last tooth-brushing using Soft Elmex® toothbrushes with the same duration of brushing and the same toothpaste

Tooth surface		Minimum	Maximum	Mean	SD	*P*-value
Buccal surfaces						
12	Baseline	0.0	4.0	1.1	1.0	< 0.01
	Last use	0.0	4.0	2.0	1.2	
21	Baseline	0.0	2.0	0.4	0.8	< 0.01
	Last use	0.0	3.0	1.4	1.1	
26	Baseline	0.0	2.0	0.5	0.8	< 0.01
	Last use	0.0	3.0	1.3	1.0	
36	Baseline	0.0	2.0	0.4	0.8	< 0.01
	Last use	0.0	3.0	1.2	0.9	
Lingual surfaces						
16	Baseline	0.0	3.0	1.1	0.9	< 0.01
	Last use	0.0	3.0	1.7	0.9	
46	Baseline	0.0	2.0	0.7	0.9	< 0.01
	Last use	0.0	4.0	1.3	0.9	
Plaque index*						
	Baseline	0.0	1.8	0.7	0.5	< 0.01
	Last use	0.2	2.7	1.5	0.5	

SD, standard deviation.
*Corresponds to the mean (total plaque index).

toothbrushes. Although dental professionals recommend the regular replacement of toothbrushes, no clinical study has offered acceptable evidence to indicate that replacement after a period of 3 months is beneficial[5]. In any case, it is not logical to recommend that toothbrushes be replaced after a fixed period because people use their toothbrushes differently and thus the degree of wear differs. Toothbrush wear has been shown to depend on toothbrush design[4] and materials[5], the habits of the user (brushing techniques,

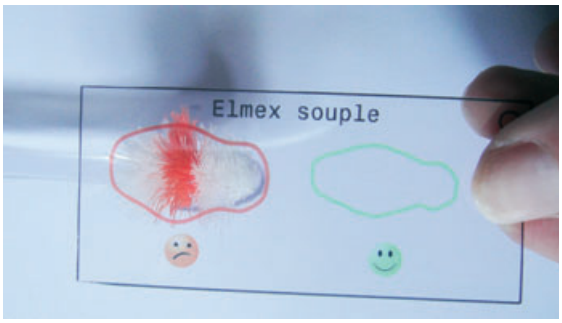

Figure 5. Outlines of brushing areas in new and worn Soft Elmex® toothbrushes on a plastic plate intended to help the user decide when to replace the toothbrush.

tooth-brushing force)[10] and individual variations in the shape of the dental arch and other anatomical factors[11]. Thus, a simple drawing seems more suitable than a quantitative method based on the number of months a toothbrush might have a useful life. That the frequency of tooth-brushing varies supports this notion. The only factor that does not vary significantly in the general population is average brushing time, which is reported to be around 45–60 s[12–14]. This contrasts with the general consensus of oral health care professionals that effective brushing should last about 2 min and should take place at least twice per day[5,15]. This general consensus appears to have been respected in the present study, in which mean ± SD brushing time was 118.6 ± 54.0 s, although this is lower than the brushing time of 3 min recommended in France[1].

As a result of our study protocol, the individual duration of tooth-brushing did not vary between

baseline and the last brushing occasion, whereas the corresponding values for residual plaque increased (*Table 2*). These results confirm that a worn toothbrush, regardless of age, removes less plaque than a new one[4,9,16,17]. The studies of outcomes using laboratory-worn toothbrushes[9,16], cited by van der Weijden *et al.*[5], may be unrealistic because artificially worn toothbrushes may not mimic those with natural wear; their wear will inevitably be highly uniform. Our results are likely to reflect the variation in wear seen in normal toothbrush use by adults. They do not accord with the results of a sole randomised cross-over clinical trial[18], but the study population in the latter differed by including only 7- and 8-year-old children. The discrepancy between our findings and those of Sforza *et al.*[19] may reflect differences in the evaluation criteria used. Using the WI of Rawls *et al.*[20], based on different maximum lengths of toothbrush, Sforza *et al.*[19] exaggerated toothbrush wear and did not consider the duration of tooth-brushing. Thus, the absence of a significant difference between plaque left after using a new toothbrush and that found after using a worn toothbrush of the same design was probably compensated for by an increased duration of tooth-brushing because the volunteers in this study were students[19]. Daly *et al.*[21] showed a significant decrease in plaque scores as the WI increased. However, these results, unlike ours, may be explained by either or both the duration of follow-up (9 weeks) and the Hawthorne effect. Different consequences of the Hawthorne effect in our study and that by Daly *et al.*[21] may reflect differences in the study objectives: Daly *et al.*[21]focused on the effect of toothbrush wear on plaque control, whereas the present study concentrated on developing a wear drawing to help consumers recognise when to replace a toothbrush. Tan and Daly[11] did not find a significant difference in residual plaque after the same duration of tooth-brushing (30 s) with a new Sensodyne® 3.5 toothbrush compared with the same 3-month-old toothbrush. This may be because the average increase in WI, assessed as 63.1 ± 38.1%, was lower than the cut-off point of 68% established as indicating that a toothbrush should be replaced[6]. In the context of our simple average wear drawing, we might nevertheless speculate about the merits of using this WI value of 68% as a trigger to replace a toothbrush. In fact, this WI value was derived from a particular population in a cohort study in which the level of proof is debatable[6]. Lastly, the significant difference between plaque index values at baseline and those at the end of follow-up in our study was observed at a higher mean ± SD WI (88.7 ± 34.1%). Our study is a preliminary attempt to test a new method of evaluating toothbrush wear to help users decide when to replace their toothbrushes. Its conclusions should be confirmed by a randomised clinical trial.

By observing the drawing of the worn Soft Elmex® toothbrush (*Figures 2–4*), we confirmed its particular shape, dependent on its initial design[4]. Indeed, its initial oval shape, and, more particularly, different bristle lengths, resulted in irregular wear of the tooth brushing surface. This wear seemed to be greater at the level of the longest orange bristles, which bend faster than the shorter white bristles. This phenomenon may be explained by the behaviour of a user who tries to make all bristles contact the tooth surface, thereby bending the longest bristles, which are intended to clean the interproximal space. It is clear from our observations in Phases I and II that the drawing of the worn toothbrush must be adapted to the initial design. There are many toothbrush designs, although they may often be of equivalent efficiency in eliminating plaque[3]. The drawings of the worn Soft Elmex® toothbrush (*Figure 4*) were similar at a comparable WI and period of use in both phases of our study. We noticed asymmetric wear with regard to the main axis of the tooth brushing surface on the orange bristles. This may reflect the fact that most participants were right-handed and made frequent use of the roller method of brushing that is classically recommended in France. As a consequence of our findings, we envisage developing two wear drawings for right-handed and left-handed individuals, respectively.

The plastic plate designed to help the user (*Figure 5*) should thus contain an additional drawing intended for left-handed persons. Regular use of this plate would help the consumer to use his or her toothbrush better and thus prolong its useful life.

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Conflicts of interest

The toothbrushes used in this study were supplied without charge by Gaba Laboratoires, Paris, France. All analyses were conducted at Nice Sophia Antipolis University.

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Correspondence to:
Professor Michèle Muller-Bolla,
Faculté de Chirurgie Dentaire,
24, Avenue des Diables Bleus,
Université de Nice Sophia Antipolis,
06357 Nice Cedex 4,
France.
Email: michele.muller@unice.fr