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Ich bedanke mich bei den unten aufgeführten Kolleginnen und Kollegen für ihre wertvolle Mitarbeit, die sie in den vergangenen zwei Jahren geleistet haben.

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Interdental cleaning and gingival injury potential of interdental toothbrushes

A laboratory investigation

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interdental cleaning;
 sonic toothbrush,
 gingiva

SUMMARY

The effective cleaning of interdental spaces using toothbrushes is a challenge. The aim of the present in vitro study was to evaluate on the one hand the interdental cleaning efficiency and on the other hand the gingival injury potential of an electric single-headed sonic toothbrush (Waterpik) and two single-tufted manual toothbrushes (Curaprox 1009; Lactona Interdental Brush).

Brushes were evaluated using a brushing device. Test dental casts (maxillary sextants) consisting of black teeth coated with white paint were brushed using standardized horizontal movements. Thereafter, black (i.e. cleaned) areas were measured planimetrically. The soft tissue injury potential was evaluated using front segments of porcine mandibles. In the same brushing device, test brushes were moved over the gingiva. Before and after each treatment, the porcine mucosa was stained with a plaque disclosing agent to visualize injured areas, which could then be measured planimetrically as well. These evaluations were each made after 15, 30, 60, and 120 sec-

onds of brushing. The statistical analysis was performed using non-parametric Mann-Whitney tests, and the level of significance was set at 5%. The best cleaning performance of 46% across all interdental spaces assessed was found with the electric sonic toothbrush (Waterpik), while the performances of the manual brushes from Lactona and Curaprox were 14.8% and 5%, respectively. At each point of evaluation, the gingiva was injured most markedly by the powered sonic toothbrush (Waterpik), followed by the manual Curaprox brush. The smallest damage of the porcine gingiva was produced by the manual Lactona brush. When comparing the manual toothbrushes, the Lactona product revealed a better cleaning performance combined with a smaller injury potential than the Curaprox brush. Thus, the prophylactic goal to achieve high degrees of cleaning while producing minimal damage is important and should have priority when evaluating and selecting toothbrushes.

Introduction

Inflammatory diseases of the periodontium such as gingivitis and periodontitis are primarily caused by the establishment of a polymicrobial biofilm on tooth surfaces. The reaction of the adjacent tissues is individual and modulated by acquired and genetic factors.

The pattern of plaque formed without hindrance was investigated in a study of Lang and co-workers (LANG ET AL. 1973) in 32 dental students. It was found that plaque formation starts in the interdental spaces of molars and premolars, subsequently progresses in the interdental spaces of the front teeth and finally proceeds to the buccal surfaces. Last formed and least prominent were deposits on oral tooth surfaces. These findings were later confirmed in a further study (LANG ET AL. 1977), which additionally demonstrated that interdental surfaces are most difficult to clean. For this reason, the interdental space constitutes a predilection site for hard and soft tissue diseases such as caries and gingivitis/periodontitis, particularly if unhindered plaque accumulation is permitted. Therefore, mechanical means are necessary to ensure a primary prophylaxis and to actively remove mature plaque, which cannot be eliminated by rinsing only (CLAYDON 2008).

Unfortunately, normal manual toothbrushes do not ensure an efficient interdental care. This constitutes a problem particularly when establishing and maintaining secondary oral health, for example in cases of recessions, loss of papillae, and inadequate restoration margins, which are even more difficult to clean. Nevertheless, among oral hygiene aids manual toothbrushes are the preferential choice of most patients. Concerning the brushing technique with manual toothbrushes, there is a multitude of methods. Commonly, simple horizontal techniques (scrubbing) or circular movements are preferred, although the latter can easily change to horizontal scrubbing. Comparative long-term studies demonstrating advantages and disadvantages of one or the other method are scarce (CLAYDON 2008). The Bass technique seems to be inferior to the Charters technique regarding the interdental cleaning capacity. An average individual practices oral hygiene for about 60 seconds and thereby removes approximately 6% of all plaque (CLAYDON 2008). The optimization of tooth cleaning efficiency in terms of simple practicability is,

therefore, still an important prophylactic and therapeutic goal in dental medicine. Improvements in the design of the head of conventional toothbrushes do not seem to have been promising (FRANSEN 1986). In contrast, electric toothbrushes enable enhanced plaque removal in less time and are thus ideal for the use by the general public (SAXER ET AL. 1997). An improved cleaning potential could also be demonstrated in systematic overviews (DEACON ET AL. 2010). Nevertheless, experience shows that using powered toothbrushes alone, cleaning of the interdental area is also problematic, especially if patients adopt the pattern of movements which is common with manual toothbrushes. Studies investigating the interdental cleaning effect of electric brushes under standardized conditions are rare.

The use of a brushing device and determining the ability of a brush to make contact with tooth surfaces is suitable for pre-clinical experiments testing the plaque removal capacity of toothbrushes under standardized conditions. The aim of the present in vitro study was to investigate on the one hand the cleaning efficiency and on the other hand the gingival injury potential of manual and electric toothbrushes in the interdental area. The working hypothesis was that electric toothbrushes clean better than manual products, but that this advantage is associated with an increased gingival injury potential, especially if horizontal movements are performed.

Materials and Methods

In this investigation, commercially available products were used. An electric single-headed sonic toothbrush and two manual single-tufted brushes were tested with respect to their cleaning and gingival injury potential. Below, these brushes are identified using the generic designations (Tab. I, Fig. 1). All products evaluated were purchased on February 13, 2012 at the TopPharm Center Pharmacy (CH-8105 Regensdorf, Switzerland).

Cleaning potential (ability of contact with tooth surfaces)

Brushes were investigated using a specially manufactured brushing device. Test dental casts corresponded to a maxillary sextant comprising three anatomically shaped molars, two

Tab. I Overview of materials used in the present study and their specifications

Generic designation	A	B	C
Product	Waterpik Sensonic Professional SR 1000E	Curaprox 1009 "single"	Lactona Double Single Tuft Interdental Brush
Type	Sonic toothbrush	Manual interdental toothbrush	Manual interdental toothbrush
Serial number	120523/23	CS 1009 WW-0710	670717
Manufacturer	Water Pik Inc. 1730 East Prospect Road, Fort Collins, CO 80553-0001, USA	Curaden AG Postfach 1063 CH-6011 Kriens Switzerland	Lactona Corporation, Hatfield, PA 19440, USA
Movements/oscillations	Level 1: 27,600×/minute Level 2: 30,500×/minute	-	-
Bristle field	Single tuft, tapering		
Filament length	4.6–7.6 mm	9 mm	7.5–10 mm
Filament diameter	0.11 mm	0.15 mm	0.2 mm
Filament number	500	500	185

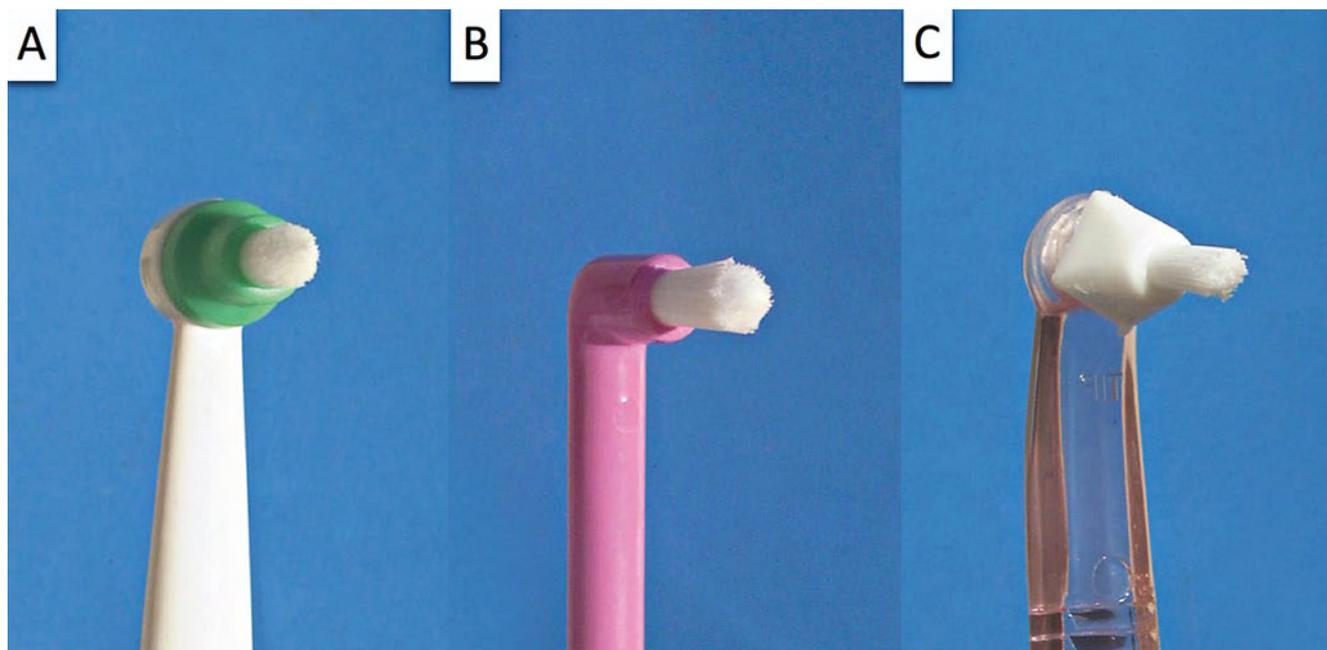


Fig. 1 Detail views of the brush heads used in the present study: A) Waterpik Sensonic Professional SR 1000E interstitial brush head (filament length: 4.6–7.6 mm, filament diameter: 0.11 mm, filament number: 500), B) Curaprox 1009 “single” (filament length: 7.5–9.3 mm, filament diameter: 0.15 mm, filament number: 500) and C) Lactona Double Single Tuft Interstitial Brush (filament length: 7.5–10 mm, filament diameter: 0.2 mm, filament number: 185)

premolars, and one canine. Buccal surfaces were aligned and interdental spaces modeled slightly open, so that they corresponded to those of a middle-aged adult (Fig. 2). Prior to the experiments, the black model teeth were coated white using a suspension of titanium oxide in 26 vol% ethanol at a ratio of 1:3. This powdery coating cannot be peeled off extensively, but is removed selectively from sites which are touched by the brushes. Tooth areas lacking the white coating and appearing black or gray after the brushing experiment were regarded as brushed and thus potentially cleaned (IMFELD ET AL. 2000). Buccal and interdental surfaces were treated with each brush in four rounds on four different model casts. Thus, 16 teeth, i.e. four teeth each on four casts, were evaluated per brush, yielding a sample size of $n=16$, each. For each round, new brushes were employed. In the case of the single-headed powered toothbrush, the same handpiece was used with varying attachments. Brushing was performed at level 2, i.e. at the most powerful level of this appliance. Along the vertical axis, brushes are displaced at a rate of 35,000 movements per minute. Brushes B and C were operated using a contact pressure of 250 g, brush A using one of 150 g. The movement amplitude was 32 mm, the contact angle 90° , and the duration of brushing 1 minute. For the manual

brushes, 60 cycles per minute of horizontal swaying movements, and for the electric sonic toothbrush, 16 cycles were selected. This corresponds to the way an average patient uses these toothbrushes. Following each round of brushing, teeth were removed from the model casts and their approximal surfaces imaged using a scanner. For this purpose, teeth were revolved over the optics of the scanner, so that curved approximal areas were projected on a plane without distortion. Using specially designed software, gray levels of the scanned teeth were analyzed and areas lacking the white coating recorded quantitatively. Parts of the approximal surfaces brushed by the bristles (black/gray) were expressed as percentages of the entire mesial and distal surfaces. The respective line angle defined the border between buccal and approximal surfaces. Terminal teeth (canines and wisdom teeth) were disregarded in the analysis.

Gingival injury potential

Four samples of each test brush were analyzed with a brushing device. Using the horizontal oscillations described above, they were moved over the gingiva of fresh front sextants of porcine mandibles obtained from the animal hospital of the University of Zurich. During the transport and storage at 5°C , porcine jaws



Fig. 2 Standardized test models consisting of a pink plastic basis and inserted black prosthetic teeth (three molars, two premolars, one canine). Prior to each brushing experiment, black teeth were coated with white titanium oxide. After brushing, cleaned tooth areas appear again black (or gray). Pictures exemplarily show the cleaning performance of the various toothbrushes: A) Waterpik, B) Curaprox, C) Lactona

were kept moist. Tests were carried out no later than 24 hours after slaughtering. The brushing device used allowed to simultaneously mount three mandibular segments and all three types of brushes. This ensured that all brushes investigated were tested at the same time. Toothbrushes were first moistened with saliva substitute according to Klimek and then moved without toothpaste/slurry at the level of the gingival margin. The total duration of brushing was 120 seconds. Prior to treatment, the porcine gingiva was stained using a dental plaque disclosing agent (Paro Plak 2-tone disclosing pellets, ESRO AG, CH-8800 Thalwil, Switzerland) and rinsed with running tap water. This visualized preexisting injured gingival sites or areas: superficial intraepithelial damages comparable to dermabrasion were stained red, while deep transepithelial injuries appeared bluish. For the analysis of the gingival injury potential, only jaws were used which, based on the initial staining, did not exhibit clear preexisting injuries. After 15, 30, 60, and 120 seconds of brushing, the porcine jaws were stained, rinsed, and photographed. Thus, in addition to an initial finding, there were four injury findings for each specimen. Using a digitizer, the extent of gingival damage was recorded planimetrically on standardized photographs and expressed as absolute value in mm² and as percentage of the entire brushed surface (Fig. 3).

Statistical evaluation

Data were analyzed using a statistics program (SPSS 11.0, SPSS Inc., Chicago, USA). For each interdental surface, median values of the cleaning performance and gingival injury potential as well as the respective interquartile ranges (IQRs) were calculated, because there was no normal distribution of the data. The statistical significance of differences was determined using the Kruskal-Wallis test as well as the Mann-Whitney test with the Bonferroni adjustment. Results of the analysis revealing p-values ≤ 0.05 were regarded as statistically significant.

Results

Cleaning potential (ability of contact with tooth surfaces)

Across all interdental spaces assessed, brush A showed the best cleaning performance with 46%, while the efficacy of brushes C and B amounted to 14.8% and 5%, respectively.

Median values of the cleaning performance of the brushes associated with specific approximal surfaces revealed the following results (Tab II): The mesial interdental surface of the premolar was cleaned best by brush A, yielding a value of 56.7%, followed by brush B with 12.2% and brush C with 8%. Also the distal interdental surface was cleaned best by brush A. At this site, brush C exhibited a cleaning efficacy of 24.7% and brush B one of 2.3%. The mesial interdental surface of the molar was again cleaned best by brush A with 38.6%, followed by

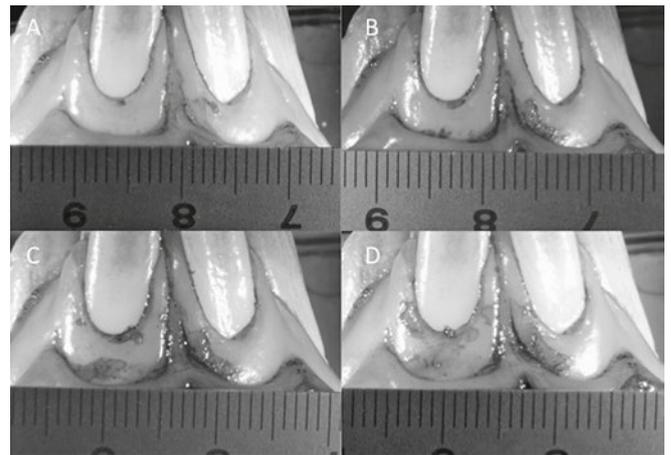


Fig. 3 Example of a porcine jaw after 15, 30, 60, and 120 seconds of brushing with the electric toothbrush. The extent of gingival injury in the region of the attached mucosa was recorded planimetrically at each point of time: A) after 15 seconds, B) after 30 seconds, C) after 60 seconds, and D) after 120 seconds. The increase in dark areas (exposure of subepithelial dyeable tissue) and, hence, the injury potential are clearly visible.

brush C with 13.2%, while the cleaning performance of brush B amounted to 5.4%. Finally, the distal interdental surface of the molar, too, was cleaned most effectively by brush A, exhibiting a value of 42.1%. At this site, brush C yielded a cleaning performance of 13.4%, while the poorest cleaning with a value of 0.3% was obtained with brush B (Tab. II).

Overall, brush A exhibited a significantly better cleaning performance than brush B at the mesial ($p < 0.06$) and distal ($p < 0.02$) surfaces of the premolar and at the distal surface of the molar ($p < 0.001$). At the latter surface, brush A was also significantly superior to brush C ($p < 0.02$). No significant difference in cleaning efficacy was found between brushes B and C.

Gingival injury potential

At every evaluation point, the gingiva was injured most markedly by brush A (Tab. III), followed by brush B. The least damage of the porcine gingiva was produced by brush C. Significant differences between the various toothbrushes at specific evaluation points were found only between brushes A and C after 15 seconds and at the subsequent points of time ($p < 0.05$). Notably, no significant difference existed between brushes at baseline ($p = 0.4533$).

Discussion

The aim of the present study was to evaluate on the one hand the cleaning efficacy and on the other hand the gingival injury potential of a powered single-headed sonic toothbrush and two manual single-tufted brushes with respect to cleaning of the

Tab. II Median values and, in brackets, IQRs characterizing the cleaning performance of the various toothbrushes in the areas evaluated (mes = mesial, dist = distal, PM = premolar, M = molar). Significant differences between the various toothbrushes (within an individual column) are marked with identical superscript lower case letters ($p < 0.05$; Mann-Whitney with Bonferroni adjustment).

	mes PM	dist PM	mes M	dist M
Brush A	56.7 (29.4) ^{ab}	46.8 (32.4) ^a	38.6 (35.1) ^a	42.1 (22.9) ^{ab}
Brush B	12.2 (27.8) ^a	2.3 (16.3) ^a	5.3 (33.1) ^b	0.31 (1.1) ^a
Brush C	7.9 (39.9) ^b	24.7 (32) ^b	13.2 (29.4) ^c	13.4 (20.3) ^b

Tab. III Findings regarding gingival injury (percentage of injured area; median values and, in brackets, IQRs) resulting from the tested interdental brushes at the various points of evaluation. Significant differences between the various toothbrushes at a specific point of evaluation (within an individual column) are marked with identical superscript lower case letters ($p \leq 0.05$; Mann-Whitney with Bonferroni adjustment).

	Baseline	15 seconds	30 seconds	60 seconds	120 seconds
Brush A	0.0 (0.0) ^a	5.0 (1.0) ^a	12.1 (2.7) ^a	31.6 (19.8) ^a	54.4 (35.1) ^a
Brush B	0.0 (0.0) ^b	2.0 (3.1) ^b	8.9 (5.2) ^b	18.0 (9.4) ^b	26.7 (20.4) ^b
Brush C	0.0 (0.9) ^c	0.9 (1.8) ^a	3.0 (3.2) ^a	6.2 (9.0) ^a	11.1 (13.7) ^a

interdental space. The working hypothesis was that the electric toothbrush cleans the interdental area more efficiently than the manual brushes, but that this advantage is associated with an increased gingival injury potential, especially if horizontal movements are performed. This hypothesis was confirmed by the present study.

It could be demonstrated that the interdental cleaning efficacy of brush A is better than that of brushes B and C. As to the manual brushes, brush C performed better than brush B. Regarding the injury potential, brush A was inferior to brushes B and C. When comparing the manual products, brush C performed better than brush B. Hence, the Lactona brush enabled better cleaning in relation to the injury potential than the Curaprox brush.

It remains unclear, whether the selection of the lower intensity level (electric toothbrush, level 1) would have resulted in a lower damage potential and possibly similar efficacy in comparison to the manual toothbrushes. However, the most powerful level available with brush A was chosen deliberately to simulate a worst case scenario. Furthermore, contrary to deviating instructions of usage, a horizontal brushing movement was simulated, because the average patient utilizes the device in this way and with time adopts the movement pattern of the manual toothbrush.

Irrespective of high clinical relevance, only few publications so far have dealt with means for cleaning of interdental spaces. This could be accounted for by the fact that in vivo, approximal spaces in a closed dental arch are not directly visible. Therefore, clinical studies can only provide indirect measurements of the cleaning performance, such as the degree of inflammation based on bleeding on probing or the inaccurate assessment of the approximal residual plaque with the naked eye (SJÖGREN ET AL. 2005). Hence, a direct investigation of the cleaning performance in vivo is not possible, and one has to rely on in vitro models which allow to remove the teeth and to visualize approximal surfaces facing each other. In the present in vitro investigation, teeth were removed from the model casts after each brushing round. Then, their buccal and approximal surfaces were imaged using a scanner. For this purpose, teeth were revolved over the optics of the scanner, so that curved approximal areas were projected on a flat plane and still produced standardized and exactly reproducible images. Also various shapes of interdental spaces were depicted by inserting prosthetic teeth into the model casts in such a way that they corresponded to a maxillary sextant comprising three anatomically shaped molars, two premolars, and one canine.

Nevertheless, every model has its limitations. The simulation of the interdental plaque constitutes one disadvantage. The coating of titanium oxide hardly bears similarity to real inter-

dental plaque. However, for the question of the present study, this was not absolutely relevant, because the brushes' ability to make contact with tooth surfaces and the accessibility of interdental spaces were of primary interest. From numerous clinical experiments it is known that brushes efficiently remove plaque from sites where a direct contact between filaments and tooth surfaces takes place (JOERSS ET AL. 2006). Therefore, the size of the contact area between the filaments of an interdental brush and the approximal surfaces is crucial. Hence, it can be assumed that the cleaning performance is the better the more contacts with a tooth surface are established by the filaments. A further drawback of in vitro models is the simulation of gingival elasticity in a plastic cast. In clinical practice, the papilla is compressed during interdental cleaning. In our model, the papilla was reproduced at slightly reduced height to minimize the difference between the clinical and in vitro situation.

For ethical, temporal, and financial reasons it is not always possible to investigate the gingival injury potential of all toothbrushes in vivo and in humans. In addition, the in vitro model ensures better reproducibility. Nevertheless it should be noted that for the reasons mentioned, the obtained results are not applicable to clinical practice without reservations.

The extent of injuries was assessed planimetrically after staining of the epithelium (IMFELD ET AL. 1986). Epithelial staining was carried out using Paro Plak 2-tone disclosing pellets. These contain erythrosine (10 parts) and patent blue (3 parts). Erythrosine is a vital dye selectively staining cells which have lost their membrane integrity. It is therefore suitable for rapid detection of cell injuries (KRAUSE ET AL. 1984, WALKER ET AL. 1984). Paro Plak 2 is comparable to the product Dis-Plaque (Pacemaker Corp., Portland, USA), which was used during the 1970s for visualizing tooth brushing traumas of the gingiva in humans (BREITENMOSER ET AL. 1979), as well as to the product Mira-2-Tone (Hager & Werken GmbH, Duisburg, Germany), which is currently applied for the same purpose by other study groups (DANSER ET AL. 1998).

Unfortunately, for the obtained results there are no direct reference values from other studies. Insofar as clinical studies exist, results have not been derived from periodontitis patients, but from orthodontically treated subjects. NIEDERMANN and co-workers (1997) could demonstrate that in patients wearing fixed brackets, a sonic toothbrush (Sonicare) was superior to a conventional manual toothbrush with respect to reductions in plaque and gingivitis. Another study group (KOSSACK ET AL. 2005) arrived at the result that in orthodontic patients wearing fixed brackets, a sonic toothbrush (Waterpik) did not better clean approximal and vestibular tooth surfaces than a manual short-headed toothbrush (Elmex interX). These examples further illustrate that a comparison of products tested in different studies

is difficult, because the spectrum of brands, the study populations, the questions, and the methods of investigation vary widely. This observation in turn argues for the implementation of laboratory investigations under standardized conditions, irrespective of some methodological deficiencies and points of discussion.

In summary, it can be noted that based on the cleaning potential, the electric sonic brush is superior to manual toothbrushes, also (or especially) when purely horizontal movements are performed. This advantage, however, is associated with an increased gingival injury potential. When comparing the manual toothbrushes, the Lactona brush revealed a better cleaning performance combined with a smaller injury potential. From a clinical point of view, it is necessary to emphasize individual instruction and selection of means for oral hygiene with a view to attaining a high level of cleanliness and thereby doing little harm to both soft and hard tissues (abrasion).

Résumé

Le nettoyage efficace des espaces interdentaires avec des brosses à dents est un défi. Le but de cette étude *in vitro* était d'étudier l'efficacité du nettoyage interdentaire ainsi que le potentiel de traumatisme gingival de deux brosses à dents manuelles (Curaprox 1009 et Lactona brosse interdentaire) et d'une brosse à dents sonique électrique (Waterpik).

Les brosses à dents ont été évaluées dans une machine à brosser, en utilisant des modèles de test (sextants maxillaires) dont les dents noires ont été revêtues de couleur blanche et traitées avec des mouvements horizontaux standardisés. Ensuite, les surfaces noires (c.-à-d. nettoyées) ont été enregistrées par planimétrie. Le risque de blessure gingivale a été étudié avec des segments antérieurs de mandibules de porc. Les brosses à dents tests, étant de nouveau fixées dans la machine à brosser, passaient sur la gencive. Avant et après chaque traitement, la gencive fut colorée avec un indicateur de plaque. Les zones blessées furent ainsi rendues visibles et mesurées. Les évaluations ont eu lieu après 15, 30, 60 et 120 secondes.

Cette étude a montré que le potentiel de nettoyage interdentaire de la brosse à dents sonique électrique est meilleur que celui des brosses à dents manuelles. Cependant, le risque de blessure gingivale de la brosse à dents sonique électrique est plus élevé qu'avec les brosses à dents manuelles. La Lactona a mieux nettoyé et moins blessé la gencive en la comparant avec la Curaprox.

Le but est d'atteindre un maximum de propreté tout en produisant un minimum de dommage. Ceci est d'une grande importance et devrait primer au moment de choisir la brosse à dents appropriée.

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