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In vitro cleaning potential of waist-shaped interdental brushes

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SUMMARY

There are many interdental cleaning aids available for patient use, including toothpicks, dental floss and interdental brushes (IDBs). Most are available in various shapes and sizes. The aim of this laboratory study was to evaluate and compare the cleaning efficacy of waist-shaped interdental brushes to those of cylindrical shape. Four groups of IDBs, ranging in diameter from 2 mm to 9 mm, were tested. To reduce production and material bias, all brushes tested were from the same manufacturer. Cleaning efficacy was tested on two different devices: 1) a geometrical model, using opposing rectangular blocks at separation distances of 1 mm to 4 mm and 2) an anatomical model, displaying a standardized maxillary segment from canine to 3rd molar. The surfaces in both devices were coated with a titanium oxide slurry, then cleaned under standardized conditions and planimetrically evaluated. The measurements took place after 1, 5 and 10 cleaning strokes, respectively. Both models showed significant superiority in the cleaning efficacy of the waist-shaped brush ($p < 0.001$), at 1, 5 and 10 strokes. Based on the present results, it can be concluded that interdental brushes with a waist-shaped form showed cleaning potential superior to their cylindrical-shaped counterparts, under standardized laboratory conditions.

Introduction

Hard-to-reach interdental spaces and line angles are often neglected by patients in their daily home care efforts and may be seen as the nidus for development of caries and gingivitis (Cumming & Löe 1973). A toothbrush alone is insufficient to clean these hard-to-reach areas. Patients are advised to use supplemental aids such as dental floss, single-tuft brushes and/or interdental brushes (IDBs) for adequate plaque removal (Vogel et al. 2014). Of the aids available, IDBs have been shown to be more effective than floss (Jackson et al. 2006; Bergenholtz & Olsson 1984). In a systematic review of 2008, Slot et al. deduced that IDBs are not only better than floss or toothpicks for cleaning interdentally but are necessary plaque removal adjuncts to toothbrushes and for attaining and maintaining gingival health. Imfeld (2010) in a literature review set forth the evidence for IDB use as a means of secondary prophylaxis. When either caries develop interdentally or when periodontal disease is recognized, the daily use of IDBs is indicated.

Interdental brushes are available in a variety of shapes and sizes. They can be had in varying diameters, geometrical forms (cylindrical, conical or waist-shaped), filament arrangement and hardness. Studies have shown that the filament hardness does not play a significant role in a brush's ability to remove plaque, while the diameter of the brush does (Wolff et al. 2006). Further studies have shown that the brush's geometrical form also influences its ability to effectively remove plaque from interdental spaces, with a conical shape removing more plaque than a cylindrically shaped brush (Jordan et al. 2014). However, a study by Larsen et al. (2016) came to the contrasting conclusion that cylindrical IDBs are the form of choice for interdental cleaning. It appears that a lack of consensus in the literature remains as to which IDB form will provide optimal cleaning results. Chongcharoen et al. (2012) showed in their study that a waist-shaped interdental brush provided superior cleaning efficacy to that of a cylindrical IDB. However, there are few studies which have evaluated this modified IDB form and the Chongcharoen study also mentioned limitations that could have played a deciding role in their results: the IDB form, the lack of comparable diameters tested or the force applied to access the interdental space. Because of these limitations, it remains unclear to which characteristic the higher cleaning efficacy should be attributed. Therefore, the goal of the current laboratory study was to evaluate the cleaning efficacy of a waist-shaped IDB as compared to a cylindrical IDB in a standardized interdental space, while keeping the force used to penetrate the interdental space at realistic levels. Our working hypotheses were that: the waist-shaped brush, due to its form, will require less force than a cylindrical brush for insertion into interdental spaces, and the cleaning efficacy of the waist-shaped brush will be greater than that of an interdental brush of comparable diameter with a cylindrical form.

Materials and Methods

Four test groups with different brush diameters were defined (Tab. I). Each group consisted of one waist-shaped IDB (Circum® Interdentalbrush, Topcaredent®, Zürich, Switzerland) and two cylindrical IDBs (Topcaredent®, Zürich, Switzerland), one of which had a diameter equal to the larger sections of the waist-shaped brushes and the other had a diameter equal to the smaller section of the waist-shaped brush. The filament size, distribution, end cuts, hardness and wire supports were all identical. The brushes differed only in their outer silhouette (Fig. 1). To determine the cleaning potential of the brushes, all IDBs were tested on geometrical forms (two opposing rectangular blocks, Fig. 2) and on an anatomical model (Fig. 3). A new brush was used for each test.

Experimental set-up

A holding device, with standardized horizontal and vertical cleaning planes was constructed. This device was able to accommodate the anatomical model as well as the geometrical forms. The brushes were attached to a gliding arm (Fig. 2), whereby the force required for insertion of the IDBs between the rectangular blocks and teeth of the anatomical model was measured in grams. This arm also ensured a standardized movement (insertion point and length of motion) on the surfaces being evaluated.

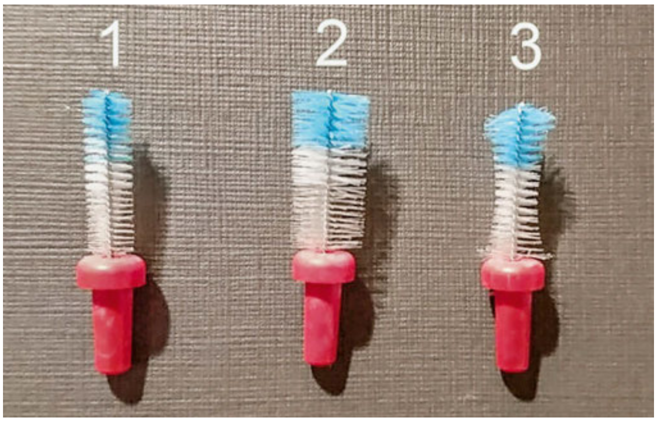

Fig. 1 One test group consisted of one waist-shaped and two cylindrical brushes with comparable sizes. The cylindrical brushes were chosen to represent the narrowest and widest diameter of the waist-shaped brush, respectively. Group 1 and Group 4 could not be tested in the anatomical model because the results were not informative (either the brush diameter was often too small to touch the surfaces or too wide, which resulted in unrealistically high forces for brush insertion). Each brush-tooth model configuration was tested with 1, 5 and 10 strokes using six replicates, respectively.

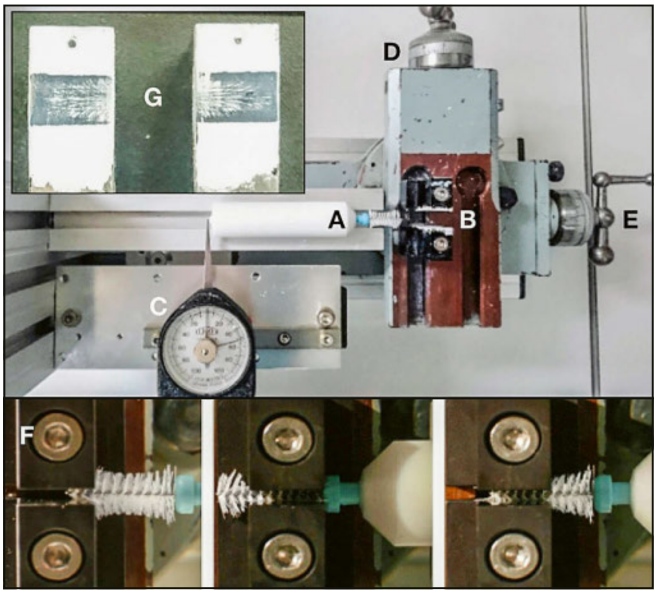

Fig. 2 The experimental geometrical model set-up (A: brush holder, B: geometric model with set distance, C: pressure gauge for measuring entry force, D/E: X- and Y-axis setting, F: cleaning range and motion of a brush, G: opposing surfaces after brush contact, cleaning stroke and resulting slurry removal)

Geometrical Model

The rectangular blocks, made of black metal and coated with white slurry mixed from titanium oxide and 26 vol% ethanol, were fixed at predefined distances from each other to create flat opposing parallel test surfaces. For each brush diameter group tested, the different distances between the blocks were tested for the amount of slurry the IDBs could remove. For Group 1 the distances were 1, 2 and 3 mm; for Group 2 the distances were 1, 2, 3 and 4 mm; and for Groups 3 and 4 the distances were 2, 3 and 4 mm. Further, each brush type was tested with 1, 5 and 10 strokes between the blocks at each measure of separation distance setting. A corresponding measure of force needed for the IDBs to enter the space between the blocks was simultaneously recorded. After each run, the blocks were unmounted, planimetrically analysed (Imfeld 2004) with custom greyscale software to determine the area cleaned (slurry removed and underlying black base visible) as a percentage of the total possible area each brush could clean (length × diameter; Fig. 2G). The blocks were then cleaned, coated with a new layer of slurry and remounted for the next trial. Each brush type was tested six times at each separation distance and with the varying number of strokes. A new brush was mounted for each of these experiments.

Anatomical Model

The anatomical model used replicated a maxillary segment reaching from the canine to the wisdom tooth. The teeth in this model, like the geometrical model, were black and provided a sharp contrast to the white titanium oxide slurry coating. The test procedure was similar to that described above, with the difference that two interdental segments were cleaned one after the other with the same brush; first between the first and second molars and then between the first and second premolars (Fig. 3A). In this model, the interdental spaces remained constant. Only the number of strokes with each brush varied. Likewise, a concurrent measurement of entry force on the IDB in grams was recorded for each of these strokes (1, 5 and 10 per run, as in the geometrical model). After each run, the teeth were unmounted, rolled over the scanner (Fig. 3B) with an automatic arm to render the curved tooth surfaces flat for the planimetrical analysis, whereby the possible surface that could be cleaned extended beyond the interproximal line angles onto the buccal and oral surfaces of the teeth. In this analysis, the greyscale masks used for calculating the maximal possible area to clean were also extended to reflect this fact. The teeth were

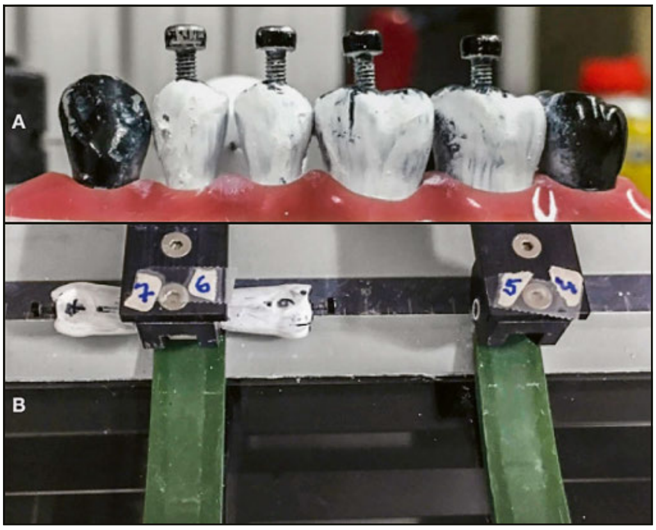

Fig. 3 A: Anatomical model consisting of black plastic teeth coated with a titanium dioxide/ethanol slurry. B: The teeth were removed and rolled over the scanner for evaluation.

then cleaned, recoated with slurry and fixed in the model for the next test. Each test was undertaken with a new brush and as above, the brushes were fixed to a gliding arm to ensure standardized entry into the interdental spaces (angle and length). Each run was repeated six times. Cleaning efficacy was measured once with respect to the entire interproximal surface (buccal, approximal and oral) and once in view of the oral surface alone.

Statistics

Data preparation

For the geometrical model, the force required to insert the brushes between the parallel rectangular surfaces was sometimes less than the minimum measurable 10 grams of the spring-loaded system (in 26 out of 702 runs). For simplicity, the force was recorded as 5 grams in these cases.

When using the anatomical model, a force of more than 70 grams was sometimes required to insert the IDB in Group 4 between the fixed teeth. This caused the gliding arm holding the IDB to derail. From a clinical point of view, this amount of force would be traumatic and not recommended for use. Therefore, the brushes in Group 4 were not evaluated on this model. Along this line, the brushes in Group 1 were also eliminated

Tab. I Overview of the interdental brush diameters tested

	Brushes			Tooth models	
	Brush 1 (cylindrical)	Brush 2 (cylindrical)	Brush 3 (waist-shaped)	Geometrical model (distance settings)	Anatomical model (entire surface and oral surface)
Group 1	2 mm	4 mm	4 – 2 – 4 mm	1, 2 and 3 mm	not tested
Group 2	4 mm	7 mm	7 – 4 – 7 mm	1, 2, 3 and 4 mm	tested
Group 3	5 mm	8 mm	8 – 5 – 8 mm	2, 3 and 4 mm	tested
Group 4	6 mm	9 mm	9 – 6 – 9 mm	2, 3 and 4 mm	not tested

from final analysis in this model, as they were often of too small a diameter to touch the tooth surfaces and did not provide informative measurements (cf. Tab. I).

Thus, three data sets were analysed, corresponding to: the experiments on the geometrical model (Fig. 4), the experiments on the anatomical model in view of the oral surface (Fig. 5) and the experiments on the anatomical model in view of the entire (buccal/approximal and oral) interdental area (Fig. 6).

Graphic and Descriptive Analyses

The datasets are displayed in three box plot graphics (Fig. 4, 5 and 6), and descriptive statistics (mean, standard deviation) of the cleaning effect and the applied force were calculated.

Regression Analysis

For each data set (geometrical, anatomical-oral aspect and anatomical-entire interdental space), the cleaning efficiency of the waist-shaped and cylindrical interdental brushes was analysed. In each case, a beta regression with the target variable "percentage cleaned" and the explanatory variables "force" (continuous), "cleaning cycles" (categorical), "brush group" (categorical) and "brush shape" (categorical) was calculated in order to determine the influence of brush shape and cleaning cycles, controlled for the influence of the other variables. The heterogeneous variance, typical for percentage data, was also modelled by the predictor variables, with the target variable being transformed to y ' = y * (n-1) + 0.5)) / n. The three regression models were checked by careful residual analysis, whereby no important violations of modelling assumptions could be detected. Further analyses and tests were then carried out by contrasts on the marginal means (LSmeans method). That is to say, the statistical difference in the cleaning effect of the two different brush shapes with the different number of strokes could be estimated through explicit consideration of the other influences (force and brush group). P values for multiple testing were corrected according to Tukey and the significance level α was set to 0.05 for all tests. All analyses and graphs were created using the open-source statistical environment R (R Core Team 2016) and the packages ggplot2 (Wickham 2009), gamlss (Rigby & Stasinopoulos 2005) and emmeans (Russell 2018).

Results

Geometrical Model (Fig. 4)

In the geometrical model, 702 measurements with the various brush diameters (Tab. I) at varying distances between the opposing block surfaces (Fig. 4) were used to determine the cleaning efficacies of the two exterior brush geometries (waist-shaped and cylindrical). On average, the force required for insertion and movement of the waist-shaped brushes (mean ± SD: 44 ± 16 g) was identical to that of the cylindrical brushes (44 ± 16 g). With 1 stroke, the waist-shaped brush already showed a better cleaning efficacy (24 ± 17%) than the cylindrical form (21 ± 17%). This remained so with both 5 and 10 cleaning motions, where the waist-shaped brush achieved better cleaning values (49 ± 21% and 56 ± 20%, respectively) than did the cylindrical form (41 ± 22% and 47 ± 23%, respectively). Further, by controlling for the variables "force" and "brush group" in the beta regression model, the cleaning efficacy according to the

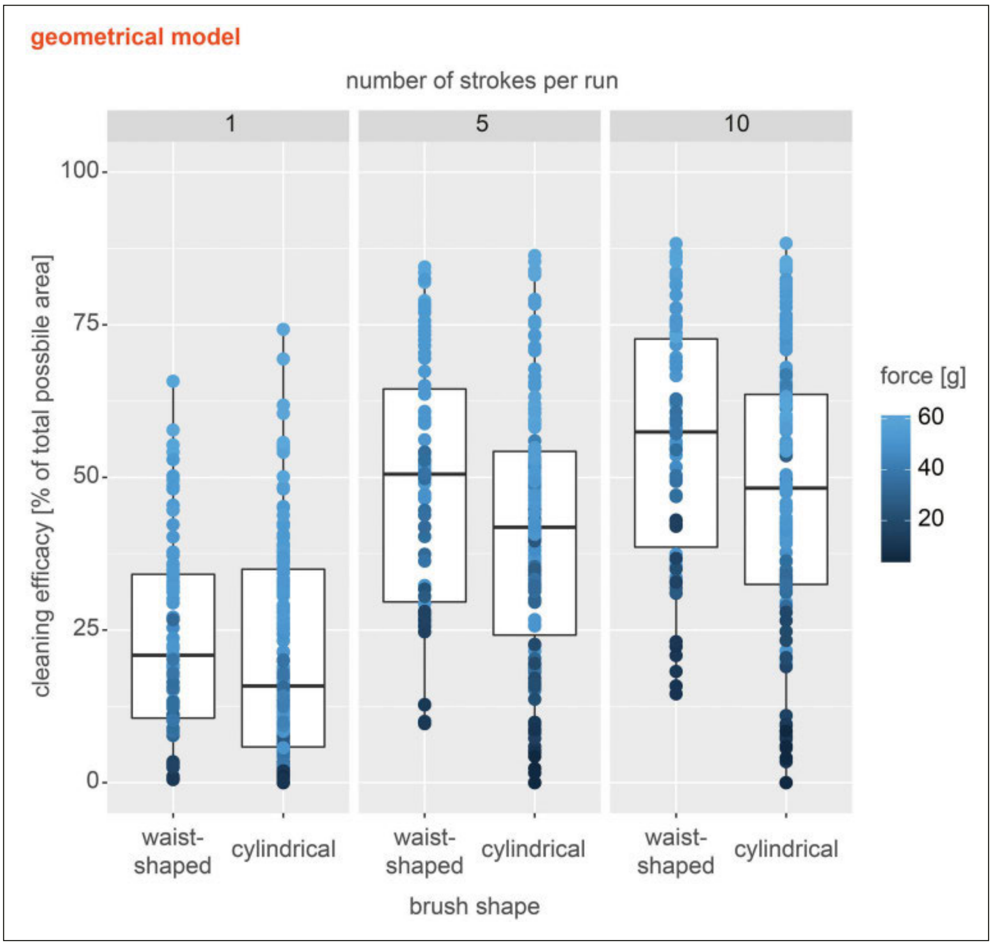

Fig. 4 Cleaning efficacy (box plots) of the waist-shaped and cylindrical brushes on the geometrical model, in conjunction with the applied force, after 1, 5 and 10 strokes.

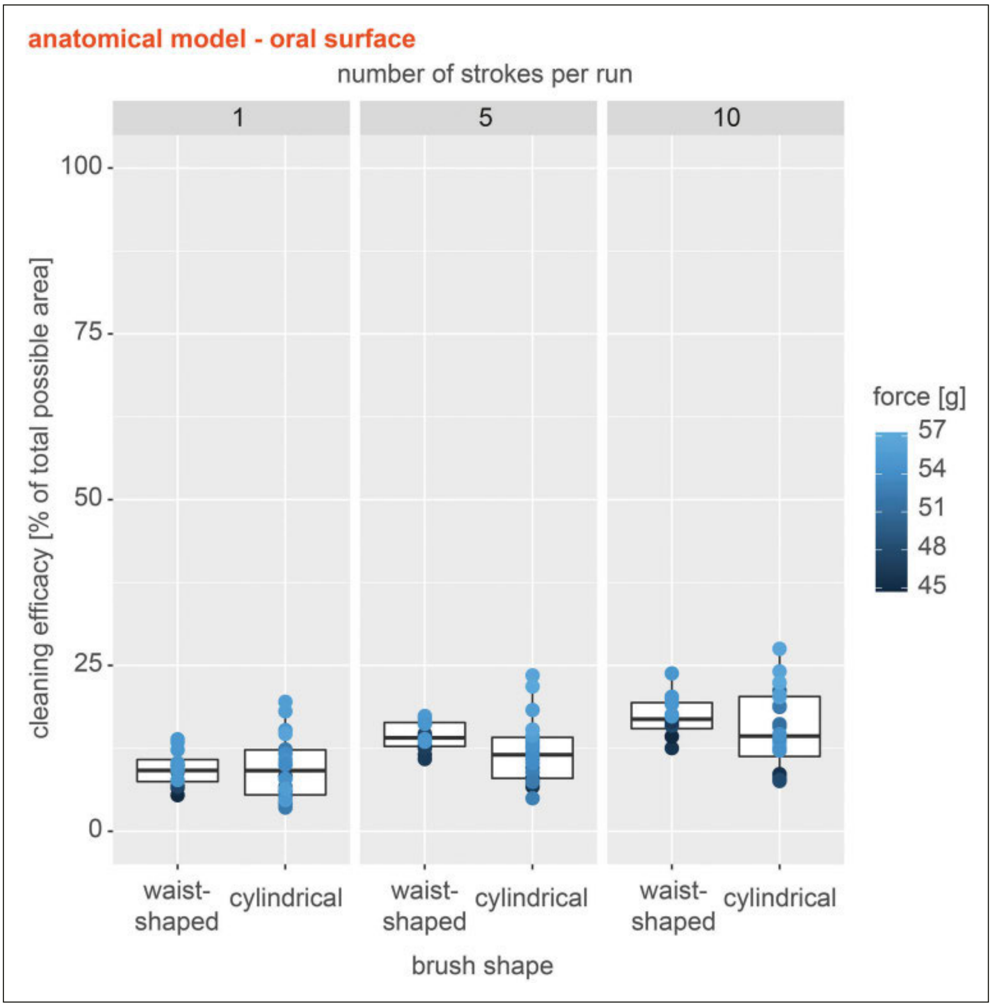

Fig. 5 Cleaning efficacy (box plots) of the waist-shaped and cylindrical brushes on the oral surfaces of the anatomical model, in conjunction with the applied force, after 1, 5 and 10 strokes.

outer silhouette, averaged across the brush groups, showed a generally better cleaning performance for the waist-shaped brushes. Whether with 1, 5 or 10 cleaning motions, the waist-shaped brushes removed significantly more slurry ($p < 0.001$) than the cylindrical brushes. Interestingly, with 5 strokes, the waist-shaped brush was statistically not distinguishable from the cylindrical brush form with 10 cleaning motions ($p = 1$), indicating similar cleaning performance of the waist-shaped brush to the cylindrical brush with only half the number of strokes.

Anatomical Model

In the anatomical model, 216 measurements were taken in Groups 2 and 3. Two different interdental spaces (molars and premolars) were used to compare the cleaning efficacy of the waist-shaped and cylindrical IDBs. First, the cleaning efficacy oral to the line angle (Fig. 5) was calculated, then from the entire interdental space (Fig. 6). As in the geometrical model, the force required for entry into the interdental space and the back-and-forth movement was on average comparable between the waist-shaped brush (51 ± 4 g) and the cylindrical brush (53 ± 3 g).

Oral Cleaning Efficacy (Fig. 5)

On the oral aspect, both brush geometries showed comparable cleaning efficacy (waist-shaped: 9 ± 3%, cylindrical: 9 ± 5%) for 1 stroke. However, with 5 strokes, the waist-shaped brushes showed a better cleaning efficacy (14 ± 2%) than the cylindrical ones (12 ± 5%). This remained the case after 10 cleaning strokes as well (waist-shaped: 17 ± 3%, cylindrical: 15 ± 6%).

After controlling for force and brush group, the regression model again revealed clear and significant differences between the waist-shaped and cylindrical brush geometries. The waist-shaped brushes showed a significantly better cleaning action as compared to the cylindrical brushes in each of the three stroke categories ($p < 0.001$, respectively). In other words, using equal force, the cylindrical brushes required more back-and-forth strokes to clean to the same degree as the waist-shaped brushes. There was no significant difference in cleaning efficacy between 5 strokes with a waist-shaped brush and 10 strokes with a cylindrical brush ($p = 0.95$).

Cleaning Efficiency for the Entire Interdental Space (Fig. 6)

When considering the entire interdental space, the superiority of the waist-shaped (27 ± 3%) over the cylindrical (21 ± 7%) brush geometry was again evident with just 1 cleaning stroke. This was confirmed again after 5 and 10 strokes (waist-shaped: 36 ± 4% and 39 ± 4%; cylindrical: 31 ± 6% and 35 ± 8%, respectively).

Here, too, the regression model clearly showed the differences between the two brush geometries. For all three stroke categories, the waist-shaped brushes showed a significantly better cleaning efficacy than the cylindrical brushes ($p < 0.001$). There was no significant difference between the waist-shaped brush

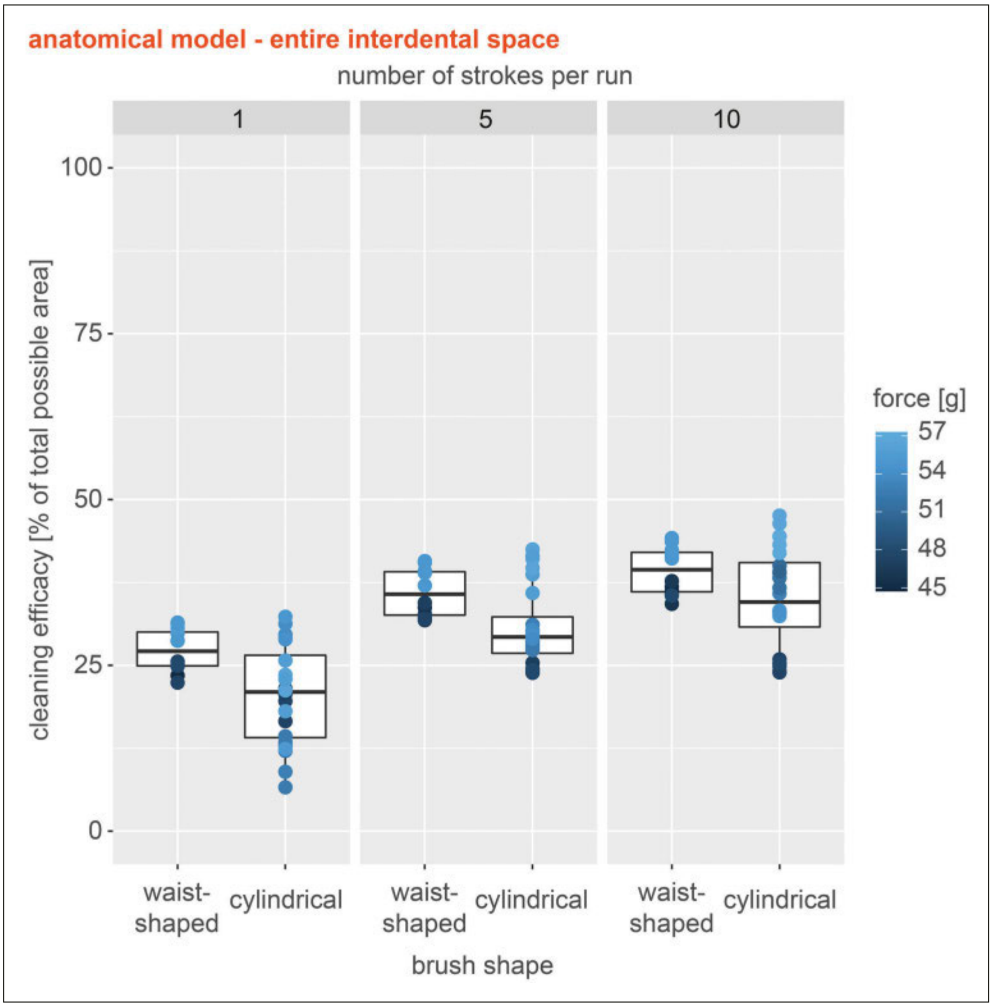

Fig. 6 Cleaning efficacy (box plots) of the waist-shaped and cylindrical brushes on the full interdental space, in conjunction with the applied force, after 1, 5 and 10 strokes.

with 1 back-and-forth stroke and the cylindrical brush with 5 strokes ($p = 0.36$).

Discussion

The aim of this study was to determine whether a waist-shaped interdental brush (IDB) is better able to clean interdental tooth surfaces than a conventional cylindrical IDB. Thus, both brush forms were compared using comparable diameters (cf. Tab. I). The hypothesis that a waist-shaped brush, due to its form, will require less force than a cylindrical brush for insertion into interdental spaces could not be proven. Although an earlier study examining insertion and cleaning stroke force for triangle-shaped IDBs (Wolff et al. 2006) showed lesser force needed, the cylindrical and waist-shaped forms in the current study required on average similar forces for entry between both the geometrical forms and the teeth in the anatomical model. The second hypothesis, that the cleaning efficacy of the waist-shaped brush will be greater than that of an interdental brush of comparable diameter with a cylindrical form was confirmed by the results of this study. One explanation for the better cleaning efficacy of the test IDBs could be that a waist shape allowed the brush's bristles to better fold upon entry into the buccal aspect of the interdental space and fully spread again upon exit on the oral side. This would lead to increased adaptation during withdrawal of the brush, allowing these bristles a better contact with the oral aspect of the adjoining teeth and provide a better cleaning action for this hard-to-reach segment of the dentition.

Clinical studies have shown differences in the cleaning efficacy of different brush types (Larsen et al. 2016; Chongcharoen et al. 2012). However, in these studies, the brushes came from different manufacturers and did not have uniform bristle filament morphologies and types. Although Wolff et al. (2006) showed that bristle hardness has no direct influence on cleaning efficacy, it was also shown that the arrangement, density and shape of the bristle ends can certainly have an influence. It must therefore be assumed that since different manufacturers use different bristle filaments (shapes, sizes, hardness and orientation), the cleaning efficacy between brushes and manufacturers differ. In addition, the absolute objectivity of clinical studies examining cleaning efficacy is hampered by the accuracy with which the tested parameters may be determined. For example, measuring residual plaque in areas not directly visible, such as interdentally, is not possible. Also, there is no standardized method for measuring the amount of bleeding on probing; it remains a matter of subjective evaluation.

In order to avoid bias in terms of manufacturing differences and bristle type and quality, all the IDBs in this study were from the same manufacturer. Two cylindrical IDBs with diameters corresponding to the inner and outer diameters of the waist-shaped brushes were included in each group for testing. The filament diameters and arrangement corresponded to those of the test brush. The planimetrical evaluation took place with validated software, using scans of the test surfaces and was reproducible at any time.

The results presented here confirm the findings of other studies (Wolff et al. 2006), specifically that larger interdental brushes provide a higher cleaning efficacy, which is not surprising. The current study also showed that the insertion of larger IDBs (Group 4) was associated with increased force, which is also not surprising.

The models used in the current study provided for varying distances between opposing surfaces to be cleaned. Varying IDB diameters were tested at these varying separation distances, which allowed for a direct comparison of the difference in cleaning efficacy between the waist-shaped and cylindrical brushes. Within each model, it was also shown that the average force needed to insert and move the waist-shaped and cylindrical brushes differed only slightly. Therefore, it can be concluded that the only remaining variable responsible for differing cleaning efficacies between the IDBs tested must be the outer shape of the brushes.

Both models used for testing showed the superiority of a waist-shaped brush over a cylindrical form, regardless of the number of cleaning strokes. It was also interesting to note that the cylindrical brush required 10 back-and-forth strokes to achieve a cleaning efficacy comparable to the waist-shaped IDB with 5 strokes, in both the geometrical and anatomical model on the oral aspect.

A limitation of the current study was the use of titanium oxide in place of dental plaque. While a titanium oxide slurry does not have the same mechanical characteristics as plaque, its use does allow at least for a standardized measurement of cleaning efficacy. It has also been used in previous studies examining cleaning efficacy (Imfeld et al. 2000; Vogel et al. 2014). However, while it must be noted that the results of this study cannot be directly translated to the clinical situation, it still provides important evidence for the cleaning efficacy of different brush designs.

The superior cleaning efficacy of the waist-shaped brushes in this study, combined with the comparable force needed for insertion in interdental spaces corresponding to both the larger and smaller diameters of this brush type, indicate that one IDB can be used to clean interdental surfaces within a range of separation distances. Thus, the number of IDBs that a patient may require to clean his entire dentition may be reduced, thereby lowering one hurdle for regular use. However, the most important factors for adequate oral hygiene remain, especially for the difficult-to-access interdental space: consistency, motivation and the manual skills of the patient, as well as regular recalls with appropriate monitoring (Votta et al. 2018) and repeated oral hygiene instruction.

Conflict of interest and source of funding statement

The present study was undertaken without external funding. All authors state that they have no conflict of interest.

Zusammenfassung

Einleitung

Es gibt viele Interdentalreinigungshilfen (z.B. Zahnstocher, Zahnseide und Interdentalbürsten [IDB]), die für den Patientengebrauch verfügbar sind. Die meisten sind in verschiedenen Formen und Grössen erhältlich. Ziel dieser Laborstudie war es, zylindrische und taillierte Interdentalbürsten mit verschiedenen Durchmessern auf ihre Reinigungseffizienz zu untersuchen und zu vergleichen.

Material und Methoden

Vier Gruppen von IDB mit einem Durchmesser von 2 bis 9 mm wurden getestet. Um mögliche Produktions- und Materialabweichungen zu reduzieren, wurden nur Bürsten von demselben Hersteller verwendet. Die Reinigungswirkung wurde an zwei Modellen getestet: 1) einem geometrischen Modell mit gegenüberliegenden parallelwandigen Blöcken in Abständen von 1 bis 4 mm und 2) einem anatomischen Modell bestehend aus einem standardisierten Oberkiefersegment vom Eckzahn bis zum 3. Molar. Die Oberflächen beider Vorrichtungen wurden mit einer Titanoxidsuspension beschichtet, dann unter standardisierten Bedingungen gereinigt und planimetrisch gemessen. Diese Messungen erfolgten nach jeweils 1, 5 und 10 Reinigungsbewegungen.

Resultate

Beide Modelle zeigten eine signifikante Überlegenheit bezüglich der Reinigungswirkung der taillierten Bürsten ($p < 0{,}001$) bei 1, 5 und 10 Bewegungen.

Diskussion

Die vorliegende Studie zeigte – unter standardisierten Laborbedingungen –, dass taillierte Interdentalbürsten ein höheres Reinigungspotenzial aufweisen als zylindrische Bürsten.

Résumé

Introduction

Le nettoyage interdentaire peut être réalisé par le patient à l'aide de différents moyens (par exemple cure-dents, soie dentaire, brossettes interdentaires ou BID). La plupart de ces auxiliaires sont proposés en différentes tailles et formes. L'objectif de cette étude de laboratoire était d'investiguer et de comparer l'efficacité du nettoyage par des brossettes interdentaires cylindriques ou cintrées, de différents diamètres.

Matériel et méthodes

Quatre groupes de BID de 2 à 9 mm de diamètre ont été testés. Afin de réduire les écarts potentiels dus à la production et aux matériaux utilisés, toutes les brossettes testées avaient été réalisées par le même fabricant. L'effet nettoyant a été testé sur deux modèles : 1) un modèle géométrique avec des blocs opposés à parois parallèles, espacés de 1 à 4 mm. 2) un modèle anatomique consistant en un segment standardisé du maxillaire supérieur allant de la canine à la troisième molaire. Les surfaces des deux dispositifs ont été recouvertes d'une suspension d'oxyde de titane, puis nettoyées dans des conditions standardisées, après quoi l'épaisseur résiduelle de la couche d'oxyde de titane a été mesurée par planimétrie. Dans chaque situation, les mesures ont été effectuées après 1, 5 et 10 mouvements de nettoyage.

Résultats

Dans les deux modèles, une supériorité significative ($p < 0{,}001$) de l'effet nettoyant obtenu avec des brossettes cintrées après 1, 5 et 10 mouvements a été mise en évidence.

Discussion

La présente étude a montré – dans des conditions de laboratoire standardisées – que les brossettes interdentaires cintrées ont un potentiel de nettoyage plus élevé que les brossettes cylindriques.

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