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ORIGINAL ARTICLE

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Improving the mechanical properties of multiuse dental floss holders

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Abstract: *Objectives:* This study was designed to determine the effect of using a tensioning device and various winding techniques on the tension of a polytetrafluorethylene (PTFE) floss in a multiuse holder. The hypothesis of this study is that the use of a tensioning device improves the handling and mechanical properties of floss holders. *Materials and methods:* The floss holder was modified so that four different degrees of tension (single-/double-wound; with/without tensioning device) were obtained and tested in an *in vitro* model approximating dental proximal contact resistance. The following parameters were measured: (I) the force (N) necessary to pass through the proximal contact after the 30th passage, (II) the displacement of the floss (mm), (III) the loosening of the floss (offset, mm), (IV) the change in distance between the branches (mm). *Results:* (I) passage force. All modifications reached 11 N (median). For the double-wound modification using the tensioning device, the smallest displacement (II) was 3.6 mm; the single-wound modification without the tensioning device had the highest displacement (7.6 mm, medians) (III). The offset of all four different modifications ranged between 0 and −2 mm (medians). For the modification without the tensioning device, there was a difference in offset of −2 mm (single-wound) and 0.5 mm (double-wound) (medians). Modifications with the tensioning device did not produce any offset differences.
(IV) A change in distance between the branches between −3 mm and −2 mm, respectively (with the tensioning device), and 0 mm (without the tensioning device) was observed (median). The results indicated that double-wound floss and the use of a tensioning device both lead to a constant tension of the floss in the floss holder. *Conclusions:* Technical modifications such as those shown in this study should improve the mechanical properties of multiuse floss holders, which, in turn, could lead to more user-friendly floss holders and hence to higher user acceptance.

Key words: dental floss holder; floss; flossing aid; flossing device; interdental cleaning aid

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Introduction

The use of floss has long been established as an option for interdental plaque removal (1–3). However, the use of floss among the population is limited (4, 5). The underlying reasons can be regarded as multifaceted.

Recent literature indicates that flossing has only limited benefits for achieving good oral health (6, 7). This might be attributed to the difficulties in using floss. In particular, good manual skills are required for achieving the right tension and passing through the proximal contact. Furthermore, wrapping the floss around one's fingers is often reported as painful, and users have difficulty reaching the second molars (8–13). Hence, devices such as holders, which should ease the use of floss, are of heightened importance. However, studies have shown that the mechanical properties that are so necessary for effective handling of the floss holder are often insufficient. Deficiencies were especially noted regarding the all-important tension necessary to force the floss through the proximal contact with only minimal displacement of the floss (14). The construction of all dental floss holders, while differing in their realization, is based on fastening a piece of dental floss between two branches of the holder. In the case of single-use holders, the floss is permanently fused into the plastic material of the branches. Multiuse holders are designed to fix and tighten the floss in different ways. One can distinguish between the single-use and reusable holders by whether the floss is firmly stretched between the branches or is sagging loosely between them.

Despite the advantages of PTFE floss's passing through the proximal contact (15, 16), most multiuse floss holders are sold in combination with nylon floss (waxed or unwaxed) (14). In this study, the modifications of the floss holder Curaprox 918 (CPX 918; Curaden, Stutensee, Germany) using a tensioning device and different winding techniques combined with the corresponding PTFE floss were explored.

Materials and methods

The CPX 918 is sold without accompanying floss. In this study, unwaxed PTFE floss (Curaprox, F 820), recommended by Curaden, was used with this floss holder. Grooves were made on each end of the branches of the floss holder into which fitted the self-designed tensioning device (Fig. 1a and b). By employing this tightener, the force needed to flex the branches when tightening the floss was minimized. After removal of the tensioning device, the branches relaxed and stretched the floss until a balance of forces was reached (Fig. 1c–l).

DF 820 floss in the floss holder was tested with the following modifications: (i) single-wound, without using the tensioning device (SWT−); (ii) double-wound, without using the tensioning device (DWT−); (iii) single-wound, using the tensioning device (SWT+); and (iv) double-wound, using the tensioning device (DWT+).

The mechanical properties of these four modifications were tested using the universal testing device Zwicki 1120 (Type TMZ 2.5/TN 1P; Zwick, Ulm, Germany) (Fig. 2) and a simulator for proximal contact strength (16, 17).

Use of the floss holder for 1 week was simulated with 210 contact passages. Thirty interdental passes were made per floss holder to test its mechanical properties, which corresponds with the number of proximal contacts of a fully dentate person (15 in the maxilla and 15 in the mandible). The procedure was repeated seven times. Throughout the measuring process, the proximal contacts were repeatedly moistened with synthetic saliva (Glandosane; Cellpharm, Bad Vilbel, Germany) (Fig. 3).

It was measured (I) the force (N) necessary to pass through the proximal contact after the 30th passage, (II) the displacement of the floss (mm), (III) the loosening of the floss (offset,

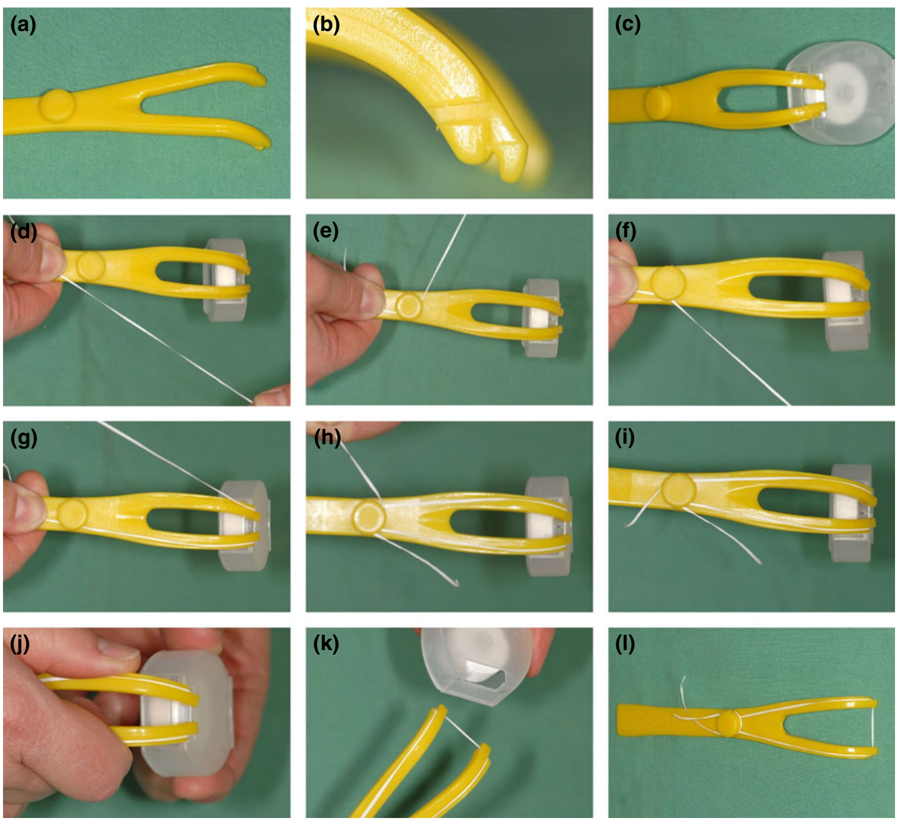

Fig. 1. shows how to adjust the tension of the floss with a tensioning device. (a) Floss holder Curaprox DF 918. (b) Grooves in the branches (red arrow). (c) Floss holder into which we fitted our self-designed tensioning device. (d) Position of the PTFE floss before winding. (e) and (f) Floss should be wound only once (!), first around the fixing knob. (g) Position of the floss in the grooves. (h) Floss wound several times around the knob (9); floss wound in floss holder (i) and (j). After removal of the tensioning device, the branches relax and stretch the floss until a balance of forces is reached. (k) Floss with good tension in the floss holder view of the entire instrument ready for use (l).

mm) and (IV) the change in distance between the branches (mm). These were analysed according to the parameters outlined in a previous publication (14) which are as follows:

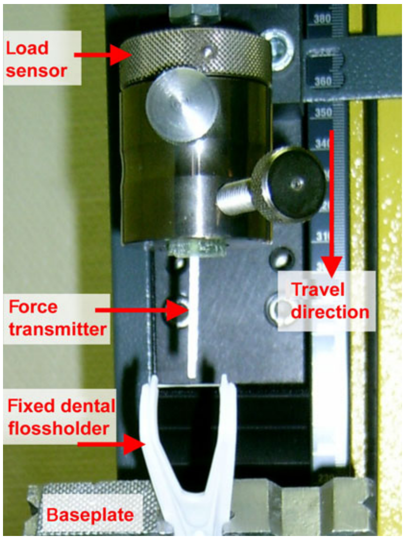

Fig. 2. Universal testing device Zwicki 1120, Type TMZ 2.5/TN 1P (Zwick, Ulm, Germany).

I Passage force: Passage force is the amount of force needed to overcome the friction between the dental floss and the contact material (enamel or restoration) and depends on the material characteristics of the dental floss. The applied load stresses the dental floss (altering its length and diminishing its diameter) in the floss holder and warps the branches (in an elastic or plastic way) until the force orthogonal to the direction of stretching is sufficient to traverse the contact point. To conduct a standardized performance test of the dental floss holder, a procedure that simulates the conditions to which the mechanical stability of the holder is subjected, independent of the parameters of the floss, while at the same time simulating a physiologically oriented force was chosen. For each model, the passage force was tested at the end of each cycle (30th passage), using the material testing device Zwicki 1120. The dental floss holder was fastened to ensure a vertical deflection of the floss during reproducible mechanical force application. The maximal force applied to the holder was set at 11 N, according to previous *in vitro* studies measuring the passage force of proximal contacts, which determined mean values of 9.9 ± 0.5 N (17). The accuracy of force measurement was 0.1 N. Every measurement was stopped when either the force of 11 N or a traverse path of 10 mm was reached. Measurements 2–29 were simulated each time under identical condi-

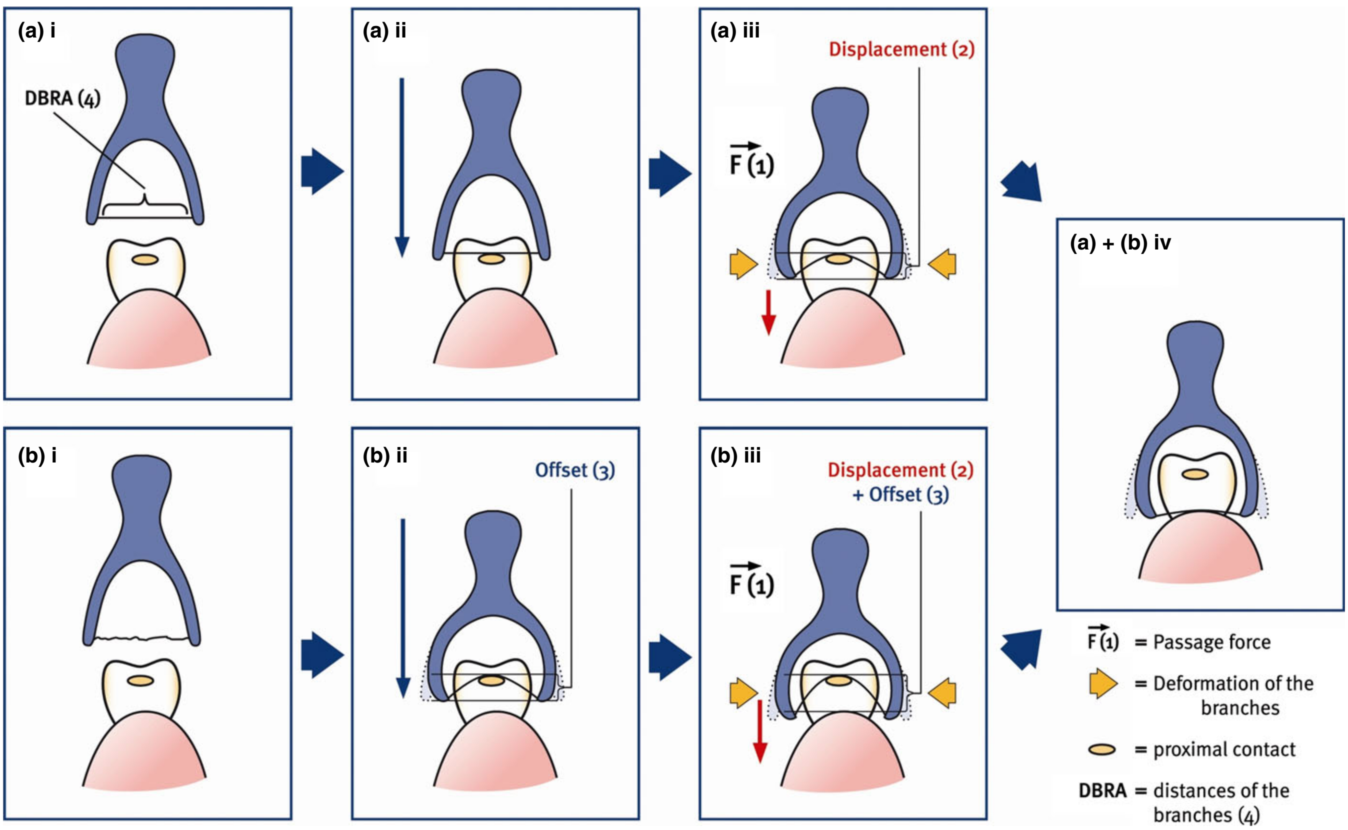

Fig. 3. Schematic drawing, sagittal view. Passage of the proximal contact with a floss holder (I–IV). Floss holder with tensioned floss. (a) Floss holder without tensioned floss. (b) Blue arrow: Movement of the floss holder without force: for floss holders without tensioned floss, an offset (3) occurs. Red arrow: Movement of the floss holder with force (1). The floss fixed in the floss holder is displaced (displacement). Definition of the distance of the branches (4).

tions using a physiological proximal contact consisting of two extracted human mandibular molars, without cavities or fillings, connected with an interdental force of 8 N using a spring balance (17). The force was evaluated at the end of every cycle.

II Displacement: Displacement is defined as the amount of travel of the floss at the moment of passing through the contact (measured in mm). By means of the testing device Zwicki 1120, the force needed for the 30th passage of each length of floss was measured. For anatomical reasons (increased risk of injuring the papilla and gingivae by sudden displacement of passage force), the maximal travel of the testing device's measurement head was limited to 10 mm. The positioning accuracy was 0.01 mm.

III Offset difference: Offset refers to the amount of sagging exhibited by the floss when no force is being applied. In the case of holders with free-length floss, offset occurs when engaging the proximal contact, before the user applies direct force to enter the contact. In the case of holders with tightened floss, by definition, no offset exists at the beginning of the passage. However, an offset can occur after the repeated passage through the proximal contact. This is considered a weakness in the mechanical properties of the floss holder; it can cause difficulties for users. The offset was measured in relation to the force placed on the holder while engaging the proximal contact after the 30th passage, using a calliper (reading accuracy, 0.1 mm). On this basis, the difference in offset between the 1st and 30th passage was determined for single- and multiple-use holders.

IV Differences in branch distance: The intervals between branches before the 1st and after the 30th passage were measured with a calliper (reading accuracy, 0.1 mm) to determine their differences.

Data analysis

The mechanical force properties are displayed in scatter plots (Figs 4 and 5) to collocate the distribution of measurements for the different holders. SPSS 10.0 for Windows software (SPSS, Chicago, IL, USA) was used for the descriptive statistical calculations.

Distribution of all measurements for the mechanical load properties cannot be expected to be symmetrical, so they are delineated as median as well as maximum and minimum.

Results

Data for the mechanical parameters, (I) passage force, (II) displacement, (III) offset difference and (IV) branch interval are shown in Tables 1–3 (median, maximum and minimum) and displayed in scatter plots (Figs 4 and 5). To ensure graphic comparability, the order of tested modifications corresponds to the ranking established by the parameter for displacement.

I Passage force: All single measurements reached the upper limit of 11 N (scatter plot, Fig. 4).

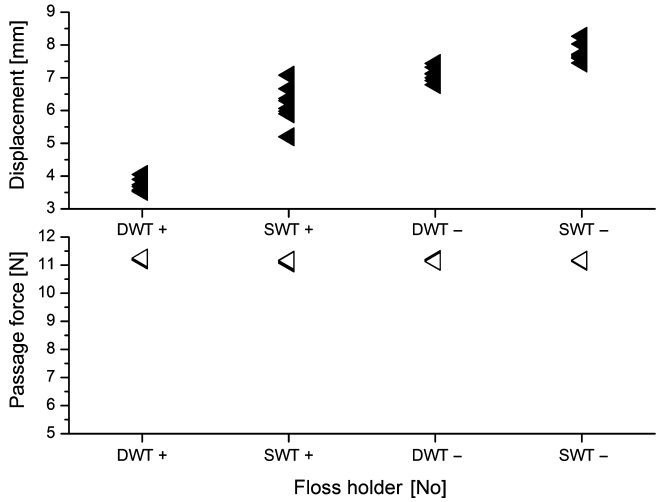

Fig. 4. Graph of measurements of the passage force (lower graph, open symbols) and the displacement (upper graph, closed symbols) for the 30th passage of all floss holders. Enumeration of the floss holders corresponds to the ranking of the mechanical property displacement (Table 1).

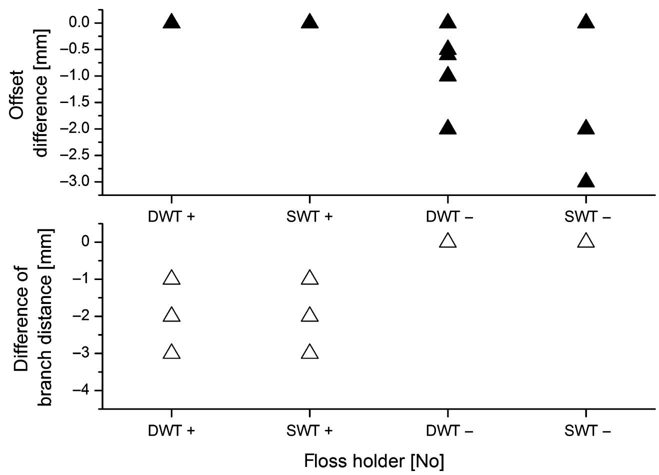

Fig. 5. Graph of measurements of the offset difference (upper graph, closed symbols) and the difference of the branch distance (lower graph, open symbols) of all floss holders. Enumeration of the floss holders corresponds to the ranking of the mechanical property displacement (Table 1).

II Displacement: The displacement of the DWT− modification showed the smallest displacement, 3.6 mm (Table 1; Fig. 4). The minimum and maximum for this double-wound modification ranged between 3.5 and 4.0 mm. There was a broad difference between the medians for the DWT+ floss and the other modifications; their medians ranged from 6.3 to 7.6 mm and are thus almost twice as large. The range between minimum and maximum was distributed almost equally (SWT−: 7.4–8.2 mm; DWT−: 6.7–7.4 mm; SWT+: 5.2–7.0 mm; DWT+: 3.5–4.0 mm).

IIIOffset: For the modified SWT− floss, a difference in offset of −2 mm (Table 2) was measured. The modified DWT− floss displayed an offset difference of −0.5 mm. The

Table 1. **Ranking of floss holder DF 918 for displacement after 30 passages through approximal contact**

Rank	Floss holder modifications	Median (mm)	Min (mm)	Max (mm)
1	Twice wound with tensioning facility (DWT+)	3.6	3.5	4.0
2	Once wound with tensioning facility (SWT+)	6.3	5.2	7.0
3	Twice wound without tensioning facility (DWT−)	7.3	6.7	7.4
4	Once wound without tensioning facility (SWT−)	7.6	7.4	8.2
	Range of median, min and max by products on the market, mm (14)	2.0–9.2	1.6–9.1	2.0–9.9

To visualize the link between these data and those of the previous study (14), see bottom row.

Table 2. **Ranking of floss holder DF 918 for offset difference (mm) between 1st and 30th approximal passages**

Rank	Floss holder modifications	Median (mm)	Min (mm)	Max (mm)
1	Twice wound with tensioning facility (DWT+)	0	0	0
2	Once wound with tensioning facility (SWT+)	0	0	0
3	Twice wound without tensioning facility (DWT−)	−0.5	−2	0
4	Once wound without tensioning facility (SWT−)	−2	−3	0
	Range of median, min, and max by products on the market, mm (14)	−1.8 to 0.0	−6.7 to 0.0	−1.5 to 1.9

To visualize the link between these data and those of the previous study (14), see bottom row.

Table 3. **Difference in branch interval (mm) between first and 30th approximal passage**

Rank	Floss holder modifications	Median (mm)	Min (mm)	Max (mm)
1	Twice wound with tensioning facility (DWT+)	−2.0	−3.0	−1.0
2	Once wound with tensioning facility (SWT+)	−3.0	−3.0	−1.0
3	Twice wound without tensioning facility (DWT−)	0.0	0.0	0.0
4	Once wound without tensioning facility (SWT−)	0.0	0.0.	0.0
	Range of median (mm), Min [mm] und Max (mm) by products on the market (14)	−2.9 to 0.0	−5.0 to 0.0	−2.0 to 1.4

To visualize the link between this data and the data of the previous study (14) see bottom row.

scatter plot (Fig. 5) shows that several measured values are involved. All other modifications showed no offset difference.

IV Distance between branches: The scatter plot (Fig. 5) shows how the results differ, depending on whether a tensioning device was used. All modifications using the tensioning device had similar differences in branch distance. Minimum and maximum ranged between −3 and −1 mm (Table 3).

Discussion

Floss holders as an aid to approximal oral hygiene is still a subject of interest (13); hence, it is important to encourage patient use. The results showed that a small displacement, no offset, no branch difference and a high passage force are desirable properties in a floss holder. The products on the market show different mechanical properties, but the major problem of most of the tested models is the lack of reproducible tightening and fixing of the floss in the floss holder (14). To develop solutions to these difficulties, two modifications establishing a reproducible and constant tension of PTFE floss in a multiuse floss holder were described herein.

The results showed that there is no difference between the modifications regarding the passage force. To compare with the results of a previous publication (14), the range of medians was 2.6–11 N. The minimum ranged from 2.4 to 11 N and the maximum was 11 N (medians). The proximal contact can be overcome by all modifications when 11 N is reached. The application of the force of 11 N to pass the proximal contact is normally well tolerated by the patient. It corresponds to the force needed to hold little more than the mass of 1 kg against gravity. But that amount of force inside a patient's mouth is a challenge. After passing through the proximal contact with the required force, the patient must retard the force before the branches of the floss holder have traumatized the gingiva (13). By focusing on the parameter 'displacement' in the interpretation of our results, it has been found that the need for such modifications is obvious. By achieving a passage force of 11 N using a smaller displacement, use of the floss holder has been made easier for the patient. In Fig. 5, one can discriminate between the use of a tensioning device and the windings of the floss. Using the tensioning device leads to a smaller displacement for both the single- and double-wound modification compared with no tensioning device with single- and double-wound modifications, respectively. The measurements show that the achievement of a small displacement was correlated with the use of the tensioning device and the number of floss windings, double-wound floss enhancing the tension of the floss considerably. Double-wound floss furthermore permits distribution of the force necessary to overcome the resistance of the proximal contact by halving the pressure on the floss and distributing it across two pieces of floss. Thus, in order not to lose the enhanced performance of the prepared floss holder, the double-wound floss should be used for repeated passage of the contacts. The number of floss windings decreases as the diameter of the floss passing through the contact point increases (15).

This offset difference can occur when the floss is not held tightly enough in the holder or undergoes elastic or plastic deformation. The tensioning device maintains the tension and avoids an offset difference (Fig. 1). The tension applied to the floss generated by the arms of the floss holder and the tensioning device is sufficient to withstand 28 passes through the proximal contact. The effect of the tensioning device is also reflected in the differences of branch distance (Fig. 5). Without the tensioning device, both the single- and double-wound modifications show an offset difference, but no difference in branch distance. In addition to improving mechanical properties, the use of the tensioning device has increased the reproducibility of the achieved results, leading to reduced variations in measurements.

Conclusion

The modifications have improved the mechanical properties of the floss holder CPX 918 in combination with PTFE floss DF 820. It was concluded that a tensioning device and the double-winding of floss enhance the use of this floss holder by ensuring both a constant tension and easier handling of the floss while fastened in its holder. This could be vital to encourage users, such as elderly people, having reduced manual force to implement interdental cleaning. Manufacturers of floss holders should therefore be urged to incorporate these results into their product design.

Clinical relevance

Scientific rational for the study

It is known that floss holders often seem difficult to use because of their limited mechanical properties. The aim of this study was to improve the effectiveness of a tensioning device and different floss winding techniques on the tension of PTFE floss in a multiuse holder to optimize its mechanical properties.

Principal findings

Both double-wound floss and the use of a tensioning device lead to consistent tension of the floss in the floss holder.

Practical implications

Facilitation of floss holder use.

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Author's contributions

Anna Wolff and Hans Jörg Staehle conceived and analysed the experiments. Anna Wolff carried out the experiments and wrote the paper. Hans Jörg Staehle reviewed the paper.

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