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ORIGINAL ARTICLE

Experimental study determining the mechanical properties of dental floss holders

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Abstract This study determined the mechanical properties of 19 dental floss holders. Eight single-use holders and 11 reusable ones were tested. An in vitro model with dental proximal contact strength of 8 N was created. Every device had to pass the proximal contact 30 times. We measured (1) the displacement of the floss [mm], (2) the force [N] necessary to pass the proximal contact after the 30th passage, (3) the loosening of the floss (offset [mm]), and (4) the change in the distance between the branches [mm]. Each measurement was repeated seven times. The results are displacement of the floss after 30 passages, 2.0 to 9.2 mm; passage force, 2.6 to 11 N; increases in branch distance, 0–2.9 mm; offset of the floss, 0–1.8 mm (all numbers are medians). Based on cleaning a full dentition (30 passages), we suggest introducing minimal requirements of <4 mm for the displacement of the floss, ≥11 N for the force, and <0.1 mm for the difference in branch distance and the offset. Only two products fulfilled our criteria. The tests show that dental floss holders vary extremely in their mechanical properties. Their effective use seems often impossible due to limited mechanical properties.

Keywords Dental floss holder · Interdental cleaning aid · Flossing aid · Flossing device · Floss

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Introduction

Plaque removal with a toothbrush can be regarded for most surfaces of the tooth as the most effective way of cleaning [1]. Numerous studies, however, have shown that the cleaning of teeth solely with a toothbrush achieves inferior results to tooth brushing combined with methods of interdental cleaning [2–7], such as interdental brushes and dental floss. Floss is often perceived as difficult to use. In particular, good manual skills are required for passing the proximal contact and for achieving the right tension [8]. Furthermore, wrapping the floss around ones fingers is often reported as painful, and users have problems in reaching the second molars [9]. Those difficulties are seen as one of the main reasons why neither with regard to caries prevention [10] nor with regard to the reduction of gingivitis [11] any significant improvement could be noted through the use of dental floss at home. Hence, devices such as holders, which ease the use of floss, are of heightened importance. Dental floss holders and hand-held floss show similar cleaning efficacy [12–15]. In 1923, Eldon Winger received the first patent for inventing a y-shaped tool, which had a mechanism at the end of its tips to allow floss to be stretched between the branches. In 1990, Kleber et al. made participants of their study answer a questionnaire detailing the difficulties they experienced in using floss holders. Participants mainly criticized that the floss in the holders did not maintain its tension or that it was difficult to change the floss [16].

The mechanical properties of a floss holder is an important prerequisite for easy handling by its users. So far, no studies comparing different models have been published, and no details on minimal requirements for the mechanical properties of dental floss holders have been established. The aim of this study was to create the foundation for the development of a profile of mechanical requirements for dental floss holders by evaluating the mechanical properties of 19 holders.

Materials and methods

We tested 19 different dental floss holders (source of supply of all floss holders see Table 1): eight models designed for single use (of which two were explicitly labeled for children) and 11 models for multiple use. They can be divided into f- and y-shaped devices. The majority of holders—five of the eight single-use holders and eight of the 11 multiple-use holders—were y-shaped. Three of the single use and three of the multiple-use holders were f-shaped. All single-use holders were built-in holders. For the multiple-use holders, the provider also supplied floss with the package. We used the floss that was supplied with the holders. Only in one case was the floss holder (Curaprox DF 918) sold without accompanying floss. We used the floss "Glide" (W.L. Gore & Associates, Flagstaff, USA) for this case. Two holders for multiple use (Dr. Best Professional and Curaprox DF 918) were tested with two different tensions of the floss. The tension of the floss was constructed according to the manufacturer's instructions. In cases where no manufacturer's instructions were available, we used a standardized device for tightening the floss (model DF918 Curaprox, Dr. Best Professional).

For all holders, the experimental design was determined according to the manufacturer's design and user needs. Thirty interdental passages were used per floss holder to test the mechanical properties, thus corresponding to the number of proximal contacts of a fully dentate person (15 in the upper jaw and 15 in the lower jaw). In order to simulate the use of a holder during a full week, the procedure was repeated seven times in the case of multiple-use holders and with seven specimens in the case of single-use models. The descriptive statistical analysis is based on the measurements taken during the $n=7$ repetitions. Throughout the process of measuring, the proximal contacts were constantly moistened with synthetic saliva (Glandosane®, Cellpharm, Bad Vilbel, Germany).

The mechanical properties were tested via four parameters, using the universal testing device "Zwicki 1120" (Firm

Table 1 Product, shape (the form of the holders corresponding to the shape of the letters F or Y), and manufacturer of the dental floss holder (nos. 9 and 19 were tested in two different tensions of the floss)

No.	Single-use floss holder	Shape	Manufacturer
1	Curaprox DF 966 Flosspic	F	Curaden (Kriens, CH)
2	Dentopik	F	Migros (Lörrach,D)
3	Flossette	Y	Oral B (Schwalbach, D)
4	Floss 'n Toss	Y	Dedeco (New York, USA)
5	Glide	Y	Blendamed (Schwalbach, D)
6	Kolibri	Y	Oral B (Schwalbach, D)
7	Stages Kids Flossette (children)	F	Oral B (Schwalbach, D)
8	Wildlife Flossups (children)	Y	Ranir (Grand Rapids, USA)
	Multiple-use floss holder		
9	Curaprox DF 918 Flosser (two different tensions of floss)	Y	Curaden (Kriens, CH)
10	Dentax Flosser	Y	Carewell (Shenzhen, China)
11	Flossbrite	F	Bergman (Rodgau, D)
12	Flossbrush	Y	Butler (Kriftel, D)
13	Flossfix	Y	Innova Dent (Halle, D)
14	Flossy Grip	Y	Flossy (Berlin, D)
15	Megafloss	Y	Wellsamed (Leipzig. D)
16	PHB Flosser	F	PHB (Osseo, USA)
17	Pocket Flosser	F	One drop only (Berlin, D)
18	The Ultimate Flosser	Y	Ultimate Flosser LLC (Beaverton, USA)
19	Dr. Best Professional (two different tensions of floss)	Y	GlaxoSmithKline (Hamburg, D)

Zwick, Ulm, Germany, Type TMZ 2.5/TN 1P) (see Fig. 1): (1) passage force, (2) displacement of the floss in the holder, (3) difference of the offset (loosening of floss), and (4) differences of branch distance (deformation of the holder) (see Fig. 2). For the experiment, the floss holder was fixed on the base plate. The load sensor of the universal testing machine traveled in the vertical direction measuring with a high resolution of the travel and the load that the displaced floss exerts on the load sensor.

Passage force

Passage force is determined by proximal contact strength, friction between dental floss and dental surface (enamel or restoration material), and the properties of the dental floss. The applied force displaces the dental floss (changing the length and decreasing its diameter) in the floss holder and deforms its branches (in an elastic or plastic way) until the force orthogonal to the direction of stretching is sufficient to pass the proximal contact. The passage force depends, therefore, on the material properties of the dental floss. In order to be able to conduct a standardized performance test of the dental floss holder, we chose a procedure that simulated the mechanical stability of the dental floss holders independent from the parameters of the dental floss, while also simulating a physiologically oriented force. For each model, the passage force was tested at the end of each cycle (30th passage), using the universal testing device Zwicki 1120. The dental floss holder was fixed in a way that ensured a vertical deflection of the floss during reproducible mechanical force application. The maximal force applied to the holder was set to 11 N. The accuracy of measurement for the force was 0.1 N. Every measurement was ended either when the force of 11 N was reached or after a traverse path of 10 mm. Measurements 2–29 were simulated using a physiological proximal contact consisting of two extracted human lower jaw molars that had neither cavities nor filling and were fixed to each other with an interdental force of 8 N using a spring balance [17]. We evaluated the force scored at the end of every cycle.

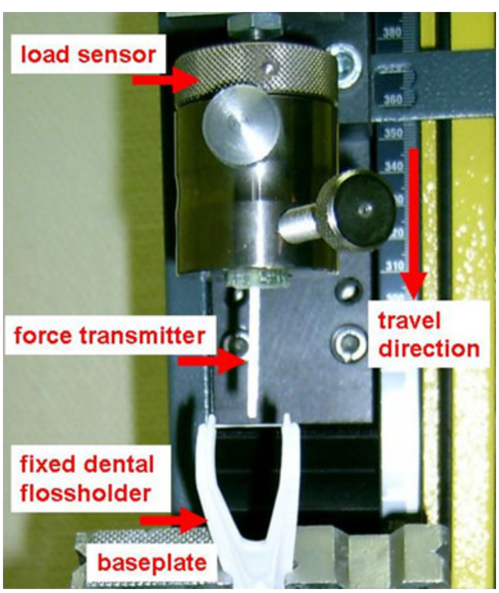

Fig. 1 The universal testing device Zwicki 1120 (Firm Zwick, Ulm, Germany, Type TMZ 2.5/TN 1P)

Displacement

The displacement is defined as the travel of the floss during application of the passage force, measurable as a length (mm). We measured the displacement length of the dental floss, occurring at the moment of passing the proximal contact. Using the material testing device Zwicki 1120, the 30th passage of every dental floss holder was measured. The maximal travel of the material testing device's measurement head has been limited to 10 mm for anatomic reasons. Strong displacement during the application of passage force result in an increased risk of injuring the papilla and gingiva. The positioning accuracy was 0.01 mm.

Offset difference

The construction of all dental floss holder models, while differing in its realization, is based on fixing a piece of dental floss between two branches. In the case of single-use holders, the floss is permanently welded in the plastic material of the branches. Multi-use holder uses different ways of fixing and tightening the floss. One can distinguish for both single- and reusable holders between specimen that have been manufactured with the floss firmly stretched between the branches and those where the floss is sagging loosely between the branches. The term "offset" designates the degree to which the floss is "sagging" between the branches when no force is applied. In the case of holders with free-length floss, offset is initiated when touching the proximal contact, before the user applies direct force to overcome the proximal contact. In the case of holders with tightened floss, by definition, no offset exists at the beginning of the passage. However, an offset can develop during the repeated passage of the proximal contact. This indicates deterioration of mechanical properties of the floss holder and can result in difficulties for users.

We measured the offset in relation to the force put on the holder while passing the proximal contact after the 30th passage using a caliper (accuracy of reading 0.1 mm). On this basis, we determined the difference in offset between the first and 30th passage for single- and multiple-use holders.

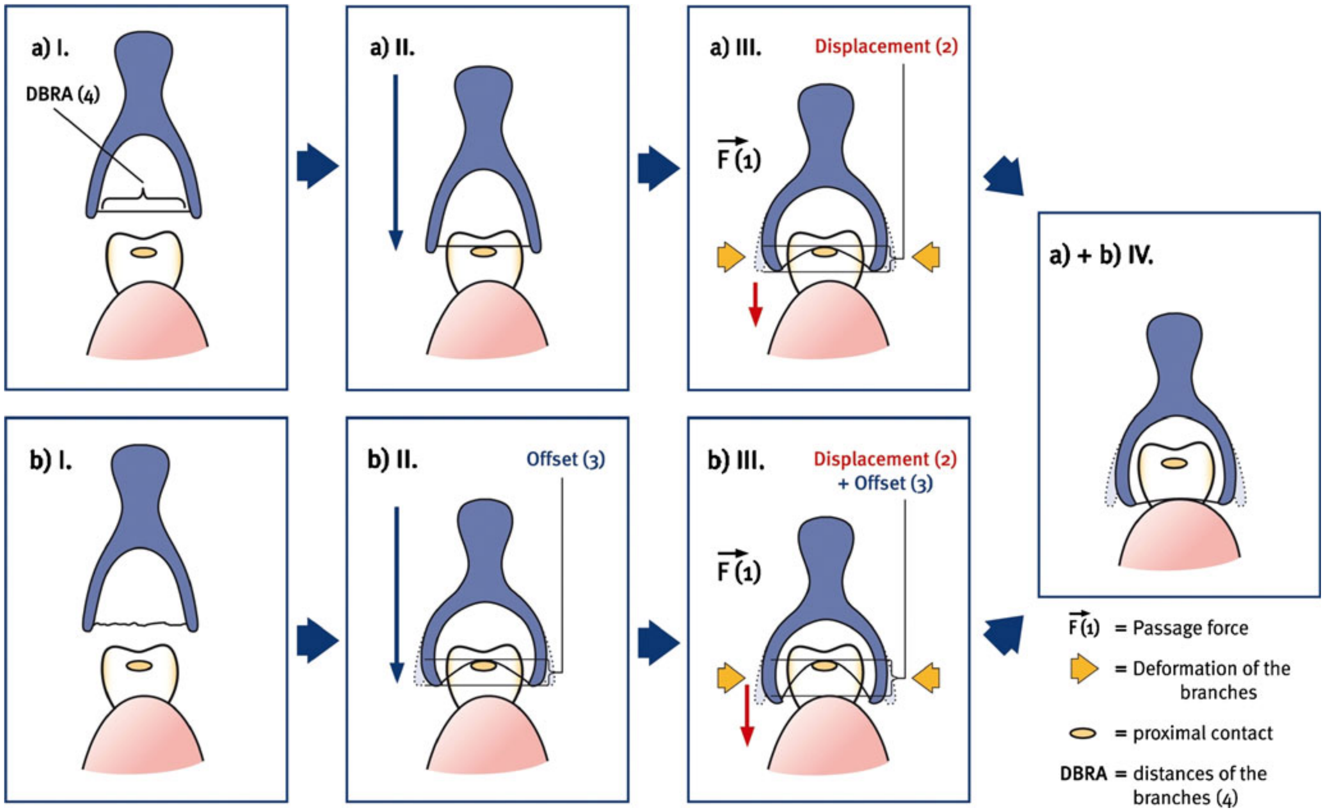

Fig. 2 Schematic picture from sagittal. Passage of the proximal contact with a floss holder (*I–IV*). Floss holder with pre-tightened floss (**a**); floss holder without pre-tightened floss (**b**). *Blue arrow* Movement of the floss holder without force: for floss holders without pre-tightened floss, an offset (*3*) occurs. *Red arrow* Movement of the floss holder with force (*1*). The floss fixed in the floss holder is displaced (displacement (*2*)). Definition of the distance of the branches (*4*)

Differences of branch distance

We measured the interval between branches before the first and after the 30th passage with a caliper (accuracy of reading 0.1 mm) and determined the difference in interval between the first and 30th passage. Changes in branch material can be observed.

Distributions of all measurements for the mechanical load properties cannot be assumed to be symmetric and therefore are described by median as well as minimum and maximum. The mechanical force properties are further shown in scatterplots, in order to juxtapose the distribution of measurements for the different holders. We used SPSS 10.0 for Windows software (SPSS Inc, Chicago, IL, USA) for our statistical calculations.

Results

The data for the mechanical parameters displacement, force, offset difference, and branch interval are shown in Tables 2, 3, 4, and 5. The sort sequence was established in a way that the holder with the best result was always displayed first. Additional information is provided through the display of measurements in scatterplots (Figs. 3 and 4). To ensure graphic comparability, the order of holders corresponds to the ranking established by the parameter for displacement.

Passage force

The mechanical property passage force differed after 30 passages between 11.0 N (Kids Flossette) and 2.6 N (Dr. Best without pre-tightened floss) (Table 2). Thirteen of the tested holders fulfilled the criterion of ≥11.0 N (median). Among these were six y-shaped and three f-shaped multiple-use holder, as well as four y-shaped single-use holders.

The scatterplot of passage force (Fig. 3, upper graph) was divided into several groups. The first group contained holders 1–11, 13, and 16. These holders achieved the abort criterion of 11 N, chosen for all measurement, with minimal dispersion during repeated measurements. The remaining holders did not achieve the abort criterion during any measuring round (with one exception).

Table 2 Ranking of the floss holder according to the passage force after 30 passages

Rank	Floss holder	Median [N]	Min [N]	Max [N]
1	*Kids Flossette*	*11.0*	*11.0*	*11.0*
2	*Wildlife Flossups*	*11.0*	*10.9*	*11.00*
3	*Floss 'n Toss*	*11.0*	*11.0*	*11.0*
4	*Pocket Flosser*	*11.0*	*11.0*	*11.0*
5	*Flossfix*	*11.0*	*10.9*	*11.00*
6	*Flossbrush*	*11.0*	*10.9*	*11.0*
7	*Flossbrite*	*11.0*	*10.9*	*11.0*
8	*Glide*	*11.0*	*10.5*	*11.0*
9	*Flossy Grip*	*11.0*	*9.4*	*11.0*
10	*Megafloss*	*11.0*	*10.9*	*11.0*
11	*PHB*	*11.0*	*9.3*	*11.0*
12	*Ultimate*	*11.0*	*10.9*	*11.0*
13	*DF918 with pre-tightening*	*11.0*	*10.9*	*11.0*
14	Kolibri	9.8	9.1	10.0
15	Flossette	9.1	8.6	11.0
16	DF 966	8.7	7.4	9.0
17	Dentopic	7.5	4.4	8.2
18	Dentax	6.5	6.1	6.8
19	DF918 without pre-tightening	5.5	3.8	5.9
20	Dr. Best without pre-tightening	2.6	2.4	2.8
21	Dr. Best with pre-tightening	2.6	2.6	2.6

Medians are displayed in decreasing order; $F \geq 11$ N (median) are in italics. Values cannot exceed 11 N due to the experimental setup

Table 3 Ranking of the floss holder for the displacement of the floss after 30 passages

Rank	Floss holder	Median [mm]	Min [mm]	Max [mm]
1	*Kids Flossette*	*2.0*	*1.6*	*2.0*
2	*Floss 'n Toss*	*3.7*	*3.5*	*4.0*
3	Wildlife Flossups	4.2	4.0	5.1
4	Glide	5.1	4.9	7.5
5	Flossbrush	5.2	4.2	5.6
6	Pocket Flosser	5.2	5.0	5.6
7	Flossbrite	5.7	5.4	5.9
8	Ultimate	5.9	5.3	8.3
9	Megafloss	6.1	5.6	6.6
10	Flossfix	6.6	6.0	6.8
11	Flossy Grip	7.1	6.5	7.6
12	DF918 without pre-tightening	7.3	6.5	8.4
13	DF918 with pre-tightening	7.6	7.3	9.3
14	Dentax	8.1	7.5	8.7
15	DF 966	8.3	8.0	8.9
16	PHB	8.5	6.6	9.7
17	Dentopic	8.7	7.3	9.1
18	Flossette	8.7	7.8	9.7
19	Dr. Best without pre-tightening	9.1	8.6	9.5
20	Dr. Best with pre-tightening	9.1	9.1	9.1
21	Kolibri	9.2	8.3	9.9

Medians are displayed in increasing order. Displacement <4 mm are in italics

Table 4 Ranking of floss holders according to difference in offset between the first and 30th passage

Rank	Floss holder	Median [mm]	Min [mm]	Max [mm]
1	*DF 966*	*0.0*	*0.0*	*0.0*
2	*Dentax*	*0.0*	*0.0*	*0.0*
3	*Dentopic*	*0.0*	*0.0*	*0.0*
4	*DF918 with pre-tightening*	*0.0*	*0.0*	*0.0*
5	*DF918 without pre-tightening*	*0.0*	*0.0*	*0.0*
6	*Dr. Best with pre-tightening*	*0.0*	*0.0*	*0.0*
7	*Dr. Best without pre-tightening*	*0.0*	*0.0*	*0.0*
8	*Flossbrite*	*0.0*	*0.0*	*0.0*
9	*Flossbrush*	*0.0*	*0.0*	*0.0*
10	*Flossfix*	*0.0*	*0.0*	*0.0*
11	*Floss 'n Toss*	*0.0*	*−0.5*	*0.0*
12	*Flossy Grip*	*0.0*	*−6.7*	*0.0*
13	*Glide*	*0.0*	*0.0*	*0.0*
14	*Kids Flossette*	*0.0*	*−0.1*	*0.0*
15	*Megafloss*	*0.0*	*−0.7*	*0.0*
16	*Pocket Flosser*	*0.0*	*0.0*	*0.0*
17	*PHB*	*0.0*	*0.0*	*0.0*
18	*Ultimate*	*0.0*	*0.0*	*0.0*
19	Kolibri	−0.7	−1.4	0.3
20	Wildlife flossups	−1.6	−2.0	1.9
21	Flossette	−1.8	−2.0	−1.5

Medians are displayed in increasing order. ΔOffset ≤|0.1| mm (median) are in italics

Table 5 Ranking of all floss holders according to the difference in branch interval between the first and the 30th passage (in increasing order)

Rank	Floss holder	Median [mm]	Min [mm]	Max [mm]
1	*Kolibri*	*0.0*	*−0.6*	*0.6*
2	*Flossbrush*	*0.0*	*0.0*	*0.6*
3	*Ultimate*	*0.0*	*0.0*	*0.0*
4	*Pocket Flosser*	*0.0*	*0.0*	*0.0*
5	*Flossfix*	*0.0*	*0.0*	*0.0*
6	*Flossbrite*	*0.0*	*0.0*	*0.0*
7	*DF918 without pre-tightening*	*0.0*	*0.0*	*0.0*
8	*Kids Flossette*	*0.0*	*−0.1*	*0.2*
9	*Flossette*	*0.0*	*−0.1*	*0.0*
10	*PHB*	*0.0*	*−0.2*	*0.0*
11	*Floss 'n Toss*	*0.0*	*−0.3*	*0.1*
12	Dr. Best with pre-tightening	−0.2	−0.2	−0.2
13	Dentopic	−0.2	−0.5	0.0
14	Dr. Best without pre-tightening	−0.2	−0.9	−0.1
15	Wildlife Flossups	−0.2	−1.9	1.4
16	Glide	−0.3	−0.4	0.0
17	DF 966	−0.3	−0.4	0.5
18	Megafloss	−0.7	−1.1	−0.2
19	Flossy Grip	−1.0	−2.4	0.0
20	Dentax	−1.2	−1.5	−0.9
21	DF918 with pre-tightening	−2.9	−5.0	−2.0

Branch interval (median) Δ≤|0.1| mm are in italics

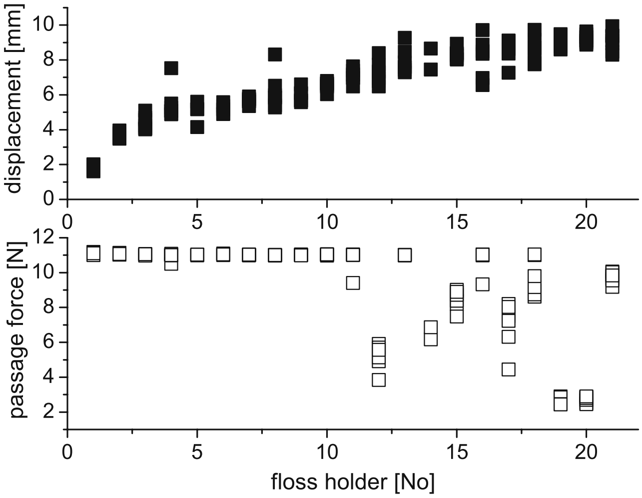

Fig. 3 Graph of measurement values of the passage force (*lower graph*, *open symbols*) and the displacement (*upper graph*, *closed symbols*) for the 30th passage of all floss holders. The enumeration of the floss holders corresponds to the ranking for the mechanical property displacement. Enumeration: *1* Kids Flossette, *2* Floss 'n Toss, *3* Wildlife Flossups, *4* Flosspick/Glide, *5* Flossbrush, *6* Pocket Flosser, *7* Flossbrite, *8* Ultimate, *9* Megafloss, *10* Flossfix, *11* Flossy Grip, *12* DF 918 without tightening, *13* DF 918 with tightening, *14* Dentax, *15* DF 966, *16* PHB, *17* Dentopic, *18* Flossette, *19* Dr. Best without tightening, *20* Dr. Best with tightening. *21* Kolibri

Displacement

The minimal median displacement for the 30th proximal contact passage was 2 mm (Kids Flossette), and the maximal median displacement is 9.2 mm (see Table 3).

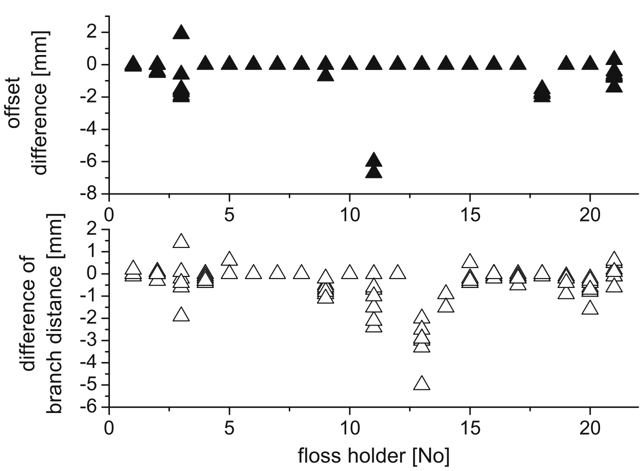

Fig. 4 Graph of measurement values of the offset difference (*upper graph*, *closed symbols*) and the difference of the branch differences (*lower graph*, *open symbols*) of all floss holders. The enumeration of the floss holders corresponds to the ranking for the mechanical property displacement. Enumeration: *1* Kids Flossette, *2* Floss 'n Toss, *3* Wildlife Flossups, *4* Flosspick/Glide, *5* Flossbrush, *6* Pocket Flosser, *7* Flossbrite, *8* Ultimate, *9* Megafloss, *10* Flossfix, *11* Flossy Grip, *12* DF 918 without tightening, *13* DF 918 with tightening, *14* Dentax, *15* DF 966, *16* PHB, *17* Dentopic, *18* Flossette, *19* Dr. Best without tightening, *20* Dr. Best with tightening, *21* Kolibri

Only two holders, Kids Flossette and Floss 'n Toss, fulfilled our set criterion of displacement. Both were y-shaped single-use holders.

Offset difference

For 16 holders, no median offset difference could be observed. Three holders showed a difference between −0.7 and −1.8 mm (see Table 4). Negative value indicates that the offset before the first passage was smaller than the offset after the last passage. This was observed for y-shaped single-use models.

The scatterplots (Fig. 4) show the offset difference and the branch interval difference (see below) between the first and the 30th measurements. The majority of holders were not affected by offset difference. Moreover, the difference was (apart from one measurement) always negative. The offset increased as a result of the load.

Differences of branch distance

An analysis of branch distance in Table 5 shows that holders ranked 1–11 did not show a difference in interval. Holders ranked 12–21 on the other hand showed branch interval differences before the first and after the 30th measurement of up to |2.9| mm.

Four y-shaped single-use holders did not show a branch interval difference. Among the multiple-use holders, no difference was observed for four y-shaped and three f-shaped models.

Discussion

With this study, we explored the mechanical properties of 19 dental floss holder models. Existing research has so far not established any sufficient quality criteria for the mechanical properties of dental floss holders.

Dental floss holders are composed of dental floss on the one hand and a fixing and holding mechanism on the other. As the interaction of these individual components is crucial for the mechanical durability—and therefore usability—of dental floss holders by patients, we treated the holders as an entity (functional unit). The dental floss holder was exposed to a repeated force of 11.0 N, because previous in vivo studies measuring the passage force of proximal contacts revealed mean values 9.9±0.5 N and as this was the force expected to be used by patients [17, 18] when passing the proximal contact. Due to anatomical qualities and the holders' construction-related properties, we restricted the maximal displacement of the floss to 10 mm, in addition to limiting the maximal force to 11.0 N.

The combination of two experimental setups, the material testing device Zwicki 1120 and the simulator for proximal contact strength developed by C. DÖRFER [17], allowed to simulate the proximal contact passage and to determine precisely the displacement of floss in the holder.

In order to develop a requirement profile for testing the strength of dental floss holders, we analyzed the four criteria listed above (passage force, displacement, offset difference, and branch distance). This study was based on the minimal requirements, which were determined by anatomical, i.e., clinical conditions. In detail, the parameters were set to a displacement after 30 passages of <4 mm, a passage force of ≥11.0 N, and differences of branch interval and offset of <0.1 mm. Given that the study's character is explorative and that the number of repeated measurements was minor compared to the elevated number of dental floss holders and that, moreover, no choice or prioritization of any singular hypothesis could justifiably be made before the start of the study, we decided not to calculate further statistical parameters. We also decided not to conduct additional tests or to calculate confidence intervals.

The consequences discussed below resulted from our measurements.

Passage force

The results show that the holders vary greatly with regard to their reaction to passage force. The majority of the sample reached the necessary 11 N, including both construction forms of multiple-use holder and the y-shaped single-use models. F- and y-shaped single- and multi-use holders were found in the medium range. A smaller number of f-shaped single-use holders, however, showed significantly lower values with regard to passage load. We, therefore, concluded that both f- and y-shaped multiple-use holders are sufficiently stable. The tested f-shaped single-use holder that failed the test showed definite mechanical deficiencies in the transition from handle to branches.

Displacement

A low displacement of floss (under 4 mm) can be regarded as positive, as the holder can pass the proximal contact without too high an elastical or plastical deformation of floss or holder. The definition of a desired low displacement is derived from anatomically meaningful conditions of the proximal space. According to several studies [19–25], the average length of clinical crown is 9.39 mm (women), i.e., 10.19 mm (men). The proximal contact strength is located ca 1–2 mm below the tooth's shoulder. Its dimension (laterally or lengthwise oval) depending on the type of tooth is at 1–2 mm. In case of periodontally healthy patients, the proximal space is filled by the papilla, which reaches cervically as an epithelial attachment into the proximal space [25].

Most of the holders showed a displacement >4 mm. This can be caused both by the insufficiency of the mechanisms that fix and fasten the floss to the holder as well as by soft material used for the branches. The two y-shaped single-use holders that show a minor displacement have branches of inelastic material and a firmly welded piece of floss, whose length cannot be varied.

Offset difference

The mechanical processes involved in overcoming the proximal contact with a dental floss holder indicate that the floss' tension is essential for the functioning of the holder. Hence, this study analyzed the existing tension and the changes in tension as a result of the force applied. The majority of holders proved to remain stable. The smaller the difference between pre- and post-application offset, the better were the mechanical components of the holder adapted to use/force. The endurance of the three holders that showed a change in offset could be improved by choosing a more stable material.

Branch interval difference

A number of previous studies analyzed the conductivity of dental floss during proximal contact passages [17, 18]. These studies fixed the dental floss in a holder made from stainless steel. The high stability of the holder's material made deformations of the stainless steel branches in principle negligible. However, when studying dental floss holders made from plastic, the deformation of branches must be taken into account in the experimental design. It is reflected in the difference of branch interval and was, therefore, measured.

The study had shown that differences in branch interval occur independently of the construction form and that roughly half of the products studied were affected. This means that the choice of plastic material used to produce the holder is important for its mechanical properties and quality.

Given that the mechanical needs of a holder lie in the combination of properties of passage force, displacement, difference in branch interval, and offset, a summary of these individual findings would be useful.

Doing so, only two among the 19 holders fulfilled the four parameters described (displacement after 30 applications of <4 mm, passage force ≥11.0 N as well as the difference in branch width and offset of <0.1 mm): "Kids Flosette" and "Floss 'n Toss". They had branches made from relatively inflexible plastic. The floss was securely welded into the branches of these holders.

The multiple-use holders were often deficient with regard the mechanisms, which fix and tighten the floss. The holders that allowed the floss to be tightened more firmly obtained better results. The modifications of tension applied to the holder “Dr. Best Professional” and “DF 918” demonstrated these observations.

Holders that showed a displacement that was stronger than 4 mm in the experiment and those that had a smaller force value than 11 N revealed deficiencies with regard to the stability of dental floss, the branches, of the connection between floss and holder, or of the mechanism for tightening the floss.

Among the models studied, significant difference with regard to the reaction to force and displacement could be observed. Holders with a reproducible reaction to displacement largely showed a reproducible reaction to force (see Table 2).

This study showed that dental floss holders vary extremely in their mechanical properties and that their effective use seems unlikely due to their limited stability. It would be desirable to further explore the data gained experimentally through in vivo studies. Furthermore, a requirement profile that fulfills the parameters analyzed above could be used to offer manufacturers indications on how to improve their products. As a result, further confirmatory studies should be conducted with the aim of testing whether the dental floss holders fulfill a minimal requirement profile and how different products compare with regard to certain requirements.

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Conflict of interest The authors declare that they have no conflict of interest.

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