Investigative Study

TENSILE STRENGTH AND OTHER MECHANICAL PROPERTIES OF DENTAL FLOSS: AN EXPERIMENTAL STUDY

G. Valentini[1] and S. D'Agostino[1,2*]

[1]Department of Medical, Oral and Biotechnological Sciences, University G. d'Annunzio, Chieti, Italy;
[2]Department of Interdisciplinary Medicine, University of Bari "Aldo Moro", Bari, Italy

Correspondence to:
Silvia D'Agostino, DDS
Department of Medical, Oral and Biotechnological Sciences,
University G. d'Annunzio,
66100 Chieti, Italy
e-mail: silvia.dagostino@unich.it

ABSTRACT

This in vitro study aimed to investigate the tensile strength and other parameters of various interdental floss types to provide insights into their mechanical properties. A selection of representative dental flosses, encompassing different structures and coatings, was subjected to a controlled experiment. Tensile strength measurements were conducted using a testing apparatus, assessing each floss's ability to withstand forces during simulated use. Results indicated significant variability in tensile strength among the tested interdental flosses. The study also explored passage force and displacement of the force using a universal dental holder. Further research is warranted to explore the long-term implications of these mechanical properties on interproximal plaque removal and overall oral health.

KEYWORDS: *dental floss, interproximal devices, tensile strength, proximal contact*

INTRODUCTION

Oral hygiene is the cornerstone of any dental treatment plan and removing plaque using a toothbrush is recommended for most tooth surfaces as the most effective means of cleaning (1). Several studies have demonstrated that relying solely on a toothbrush for at-home oral hygiene procedures yields suboptimal outcomes when compared to incorporating any interproximal cleaning method, such as dental floss, interdental brushes, or toothpicks, in combination with regular toothbrushing (2). Dental floss is often considered a challenging instrument to wield, demanding proficient manual dexterity to navigate the proximal contact points in a gentle manner and achieve the appropriate tension, which is crucial for its effectiveness (3); additionally, patients reported pain due to wrapping the floss around their fingers, and difficulties in reaching the second/third molars and carrying out the correct movement in these very posterior areas (4).

Although patients usually prefer toothpicks and interproximal brushes over dental floss, due to their ease of use (5, 6), these types of devices can not be prescribed for every patient: only those patients with sufficient embrasure space for their positioning can use these instruments. Patients with their intact gingival papillae filling the interproximal spaces are usually instructed to use dental floss for plaque removal on the proximal surfaces. Dental floss is the most recommended device for interproximal plaque control, useful to plaque removing and effective in decreasing marginal inflammation (7, 8).

Some papers addressed the plaque-removing ability or the plaque removal at different sites of different types of floss; even if flosses diverge enormously in structure, size, materials, and adjuvants, no significant clinical differences were found between several flosses (9).

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Although some illustrious scholars have tried over the years to propose the perfect physical characteristics of a dental floss, more research should be done to investigate the relationship between physical characteristics and clinical effectiveness of dental floss; furthermore, the control of physical properties in the production of dental floss should be more studied in deep (10). Dental floss has been described as the best and most recommended device for cleaning anterior teeth interproximal surfaces, while their effectiveness on the posterior ones is not so certain (11). They have been found to cleanse coronal portions better than apical ones, buccal portions of the interproximal areas better than lingual ones, and distal surfaces better than mesial ones (12). These differences in the effectiveness of interdental cleaning may indicate a difficulty in using floss or account for self-injuries due to improper use of the floss (injuries stemming from an uncontrollable force required to navigate the proximal contact point), which is frequently noted (13).

According to Hanes et al., a patient's acceptance of floss and consistency in its use may be related to the capacity of dental floss to pass the proximal contact point (10). In accordance with Torkzaban et al. flossing may improve gum health through periodontal indices enhancement. Flossing before brushing could potentially be more effective for plaque control, as brushing afterwards might remove loosened plaque deposits (14).

In young individuals without interproximal bone resorption, precise oral hygiene regimens incorporating either a manual toothbrush alone or supplemented with interdental cleaning aids, such as dental floss, interdental brushes, or interdental rubber picks, can demonstrably attenuate both dental plaque accumulation and gingival inflammation. However, the utilization of interdental brushes or rubber picks exhibits a statistically significant superiority in the reduction of interproximal plaque compared to the sole implementation of manual toothbrushing (15).

Adjunctive interdental cleansing implements assume a paramount role in the preservation of optimal gingival health and the promotion of comprehensive oral hygiene, particularly in individuals undergoing orthodontic therapy. Compelling research data suggests that the utilization of dental floss or interdental brushes in conjunction with a careful toothbrushing regimen confers a multitude of advantages in comparison to the singular implementation of a manual toothbrush. It is crucial to highlight the significance of proper utilization techniques and the need for individualized treatment plans when recommending oral hygiene tools and practices for patients undergoing orthodontic treatment (16).

The accurate control of dental plaque accumulation is demonstrably essential in maintaining peri-implant health. Several mechanical plaque removal modalities, including dental floss, interdental brushes, and irrigating oral hygiene devices, may prove efficacious in achieving plaque control and reducing the incidence of gingival inflammation near implant-supported single crowns, as evidenced by research documented by Almoharib et al. (17).

Despite being widely recommended as an integral part of oral hygiene, the use of floss presents certain limitations that warrant consideration to optimize its effectiveness and minimize potential risks. The primary limitation lies in the manual dexterity required by the patient, particularly in the posterior regions of the mouth. The angulation and curvature of posterior teeth make it challenging to correctly position the floss and effectively reach interdental spaces (18). The shape of floss has proven effective in removing food debris lodged between teeth. However, its ability to cleanse and remove plaque beneath the contact point between teeth remains a subject of debate. Some research suggests that floss cannot adequately reach and clean these areas, leaving bacterial plaque undisturbed (15, 17).

The scientific literature on the efficacy of flossing in preventing gum disease is controversial. Some studies demonstrate that its use, in addition to regular brushing, improves gingival health (14, 16, 18). Others, however, maintain that flossing is ineffective in removing plaque, and that improper use can even damage the gums, causing gingival recession due to bone loss (19, 20).

Experimental research about physical properties of dental floss, such as tensile strength and percentage of elongation, is still unexplored; most of the data is provided by manufacturer, used for commercially claim purpose, which make them controversial and really hard to interpret. The aim of this study was to compare several types of waxed and unwaxed dental flosses and test them with a universal testing machine to evaluate some mechanical properties.

MATERIALS AND METHODS

This study involved the use of 17 dental flosses of different brands and types. Nine of them were waxed, and eight were unwaxed. The mechanical properties were tested via three parameters, using the universal testing device Lloyd Instruments LR 30K Stress Test Machine (AMETEK® Test and Calibration Instruments) supported by the Nexyen Plus Software: tensile strength, passage force, and displacement of the floss in a holder.

To evaluate two of these parameters (passage force and displacement), we employed an experimental design previously used in 2010 (6), with some variations due to the diversity of wires used (the original study utilized dental floss holders of different shapes and usage modalities - disposable or reusable - whereas this study aims to analyze simple interdental flosses, with no holders). The model involved the use of a simulator constructed with two extracted human molar elements, devoid of restorations or caries, positioned adjacent to each other respecting the existing physiological contact point between these elements; to adhere as closely as possible to reality, the two elements were constantly moistened with artificial saliva, just as it occurs inside the oral cavity.

Tensile strength

Segments of thread 20 cm long were obtained tied with the same type of knot (surgical knot). The wire loops were subjected to unidirectional tensile stress through the Lloyd Instruments LR 30K Stress Test Machine (AMETEK® Test and Calibration Instruments) supported by the Nexyen Plus Software. The machine was set up with the following settings (Fig. 1):
preload = not applicable;
speed = 50.0 mm/min;
useful trait = not applicable;
area = not applicable;
breaking point = the load gives way quickly;
initial load = - 0.00 N; elongation = 0.01%.

Fig. 1. *Universal testing device Lloyd Instruments LR 30K Stress Test Machine (AMETEK® Test and Calibration Instruments).*

For each wire, the experiment was conducted as follows: a segment of wire of the established length was passed through the movable hook located at the bottom of the machine and secured with a vise, then it was tied to the fixed hook positioned at the top. At that point, each wire was stretched and brought to zero tension; the machine was then activated. Individual tests were carried out by a single operator to make the results comparable. The stages, such as cutting the wire, placing it inside the machine, and especially the technique and type of knot used, were performed by a first operator, while a second operator analyzed the data displayed on the apparatus screen and recorded them. The calibration of the machine was performed using a wire that was not included in the experiment.

Passage force and displacement

The experimental design was carefully formulated to align with both user requisites and the specifications delineated by the manufacturer. Thirty interdental passages were systematically conducted for each dental floss variant, diligently inserted into a multi-use holder (Healifty®, floss holder). The secure fastening of the dental floss within the holder was accomplished using a standardized apparatus, ensuring uniformity in revelation for the subsequent assessment of mechanical properties.

This experimental setup precisely corresponds to the number of proximal contacts inherent to a fully dentate individual, accounting for 15 contacts in the upper jaw and an equivalent number in the lower jaw. In adherence to stringent protocols, synthetic saliva (BIOXTRA®, Biopharm srl) was consistently applied to the proximal contacts throughout the entirety of the measurement process. This accurate procedural approach was employed to simulate physiological conditions and maintain an environment reflective of realistic usage scenarios, enhancing the validity of the mechanical property assessments conducted. This investigation adhered to stringent criteria established in accordance with anatomical and clinical considerations, ensuring a detailed evaluation reflective of realistic conditions.

Specifically, the predefined parameters were defined to encompass a displacement of less than 4 mm after 30 passages, coupled with a requisite passage force exceeding or equaling 10.0 N. The application of such stringent benchmarks enhances the study's scientific rigor and the validity of its findings in delineating the performance attributes of the tested dental floss.

The force exerted during the passage of dental floss is influenced by proximal contact strength, the friction between the dental floss and the dental surface (whether enamel or restoration materials), and the inherent properties of the dental floss. As the force is applied, it causes displacement of the dental floss within the floss holder, resulting in alterations to its length and a reduction in diameter. This displacement continues until the force, perpendicular to the stretching direction, reaches a level adequate to traverse the proximal contact point. The passage force is contingent upon the material properties of the dental floss, including variations such as nylon, Teflon, or PTFE.

To facilitate a standardized performance test of the dental floss holder, it is imperative to devise a procedure that mimics the mechanical stability of the dental floss holders, regardless of the specific parameters of the dental floss. Additionally, this procedure should replicate a physiologically oriented force to ensure comprehensive and reliable testing.

The evaluation of passage force, for each model, occurred after completing each cycle (30th passage) through the utilization of the LR 30K Lloyd Instruments universal testing device. The dental floss holder was positioned in a way that ensured a consistent vertical deflection of the floss during the application of reproducible mechanical force. The set maximum force applied to the holder was 10 N, with a precision of force measurement maintained at 0.1 N. Each measurement concluded either upon reaching a force of 10 N or after traversing a path of 10 mm. Measurements 2-29 were emulated using a physiological proximal contact, established with two extracted human lower jaw molars devoid of cavities or fillings. These molars were securely affixed to each other with an interdental force of 8 N, achieved through a spring balance (9). The force recorded at the conclusion of each cycle was then subject to evaluation.

Displacement, denoting the extent of floss movement when subjected to the passage force, is quantified as a measurable length in millimeters (mm). This measurement is precisely taken at the pivotal moment of traversing the proximal contact. Employing the testing device, the 30th passage of each dental floss was meticulously assessed. To account for anatomical considerations, the material testing device's measurement head was limited to a maximum travel of 10 mm. Substantial floss displacement during the application of passage force presents an escalated risk of potential harm to both the papilla and gingiva. The maintained positioning accuracy for these measurements was upheld at an impressive 0.01 mm.

RESULTS

The data recorded for tensile strength, passage force, and displacement are shown in Tables I, II and III.

Table I. *Tested flosses, maximum load at breaking in N, waxed/unwaxed floss.*

Dental Floss Code	Maximum Load in N	Waxed/Not waxed
DF 1	102.655N	Waxed
DF 2	89.502N	Waxed
DF 3	82.682N	Waxed
DF 4	82.297N	Waxed
DF 5	78.623N	Waxed
DF 6	78.001N	Not Waxed
DF 7	75.449N	Not Waxed
DF 8	72.557N	Waxed
DF 9	69.839N	Waxed
DF 10	65.783N	Not Waxed
DF 11	61.553N	Not Waxed
DF 12	61.467N	Waxed
DF 13	52.623N	Not Waxed
DF 14	45.358N	Waxed
DF 15	41.662N	Waxed
DF 16	39.340N	Waxed
DF 17	36.513N	Waxed

[1]*From maximum to minimum load in N.*

Table II. *Dental flosses ranked from maximum to minimum passage force value after thirty passages.*

Dental Floss Code	Minimum (N)	Maximum (N)	Median (N)[1]
DF 4	10.0	10.0	10.0
DF 2	10.0	10.0	10.0
DF 14	9.8	10.0	10.0
DF 10	10.0	10.0	10.0
DF 5	10.0	10.0	10.0
DF 6	10.0	10.0	10.0
DF 16	10.0	10.0	10.0
DF 7	10.0	10.0	10.0
DF 13	10.0	10.0	10.0
DF 17	9.9	10.0	10.0
DF 15	9.7	10.0	10.0
DF 12	10.0	10.0	10.0
DF 1	9.8	10.0	10.0
DF 3	10.0	10.0	10.0
DF 9	9.7	9.9	9.9
DF 8	9.6	9.9	9.8
DF 11	9.2	9.8	9.7

[1]*Median is shown from maximum to minimum.*

Table III. Dental flosses ranked from maximum to minimum displacement of the floss in the holder value after thirty passages.

Dental Floss Code	Minimum (mm)	Maximum (mm)	Median (mm)[1]
DF 2	3.7	4.0	3.8
DF 14	3.6	4.0	3.8
DF 4	3.7	3.9	3.9
DF 16	3.7	4.1	3.9
DF 5	3.7	4.2	3.9
DF 10	3.9	4.1	4.1
DF 7	3.9	4.2	4.1
DF 1	3.8	4.3	4.1
DF 6	3.9	4.1	4.1
DF 12	3.8	4.3	4.1
DF 13	3.7	4.2	4.2
DF 17	3.7	4.1	4.1
DF 15	3.8	4.1	4.2
DF 8	4.0	4.4	4.2
DF 3	3.9	4.5	4.2
DF 9	4.0	4.4	4.2
DF 11	4.1	4.5	4.3

[1]*Median shown from minimum to maximum.*

The passage force values ranged from a maximum of 10 N to a minimum of 9.2 N (Table II). Only three flosses had not reached the cut off of 10 N but were very close to this value (values could not exceed 10 N because this was set at the beginning of the test).

The software connected to the Stress Machine was able to process a graph during each test that showed the trend of the floss tension and the breaking point, just as seen in Fig. 2.

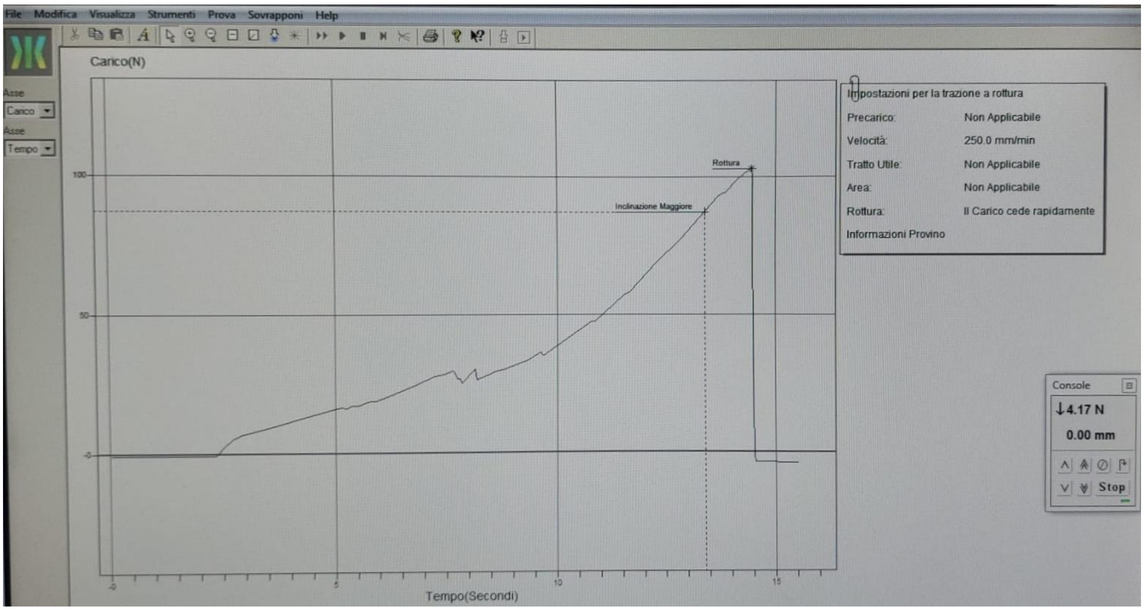

Fig. 2. *Graph developed by Nexyen Plus Software, which supports the universal testing device. The line rises, more or less linearly, up to a peak: here, the floss breaks, followed by a steep fall in the straight line. The small peaks present during the ascending phase signal the fraying of the floss but not its complete breakage, indicated by the highest point. The tensile strength expressed as maximum load in N differed between 102.655 N (DF 1) and 36.513 N (DF 17). There was a big gap between the best performance of 102.655 N (DF 1) and the second position of 89.502 N (DF 2); from the third position, there was a progressive decrease until the last performance of 36.513 N.*

The minimal median displacement for the 30th proximal contact passage was 3.8 mm (DF 2), while the maximal median displacement was 4.3 mm (DF 11).

DISCUSSION

The regular removal of dental plaque from interproximal tooth surfaces is an important component of any oral hygiene regimen that is designed to prevent or control dental caries and periodontal disease (1). Due to the relative ineffectiveness of toothbrushes in interproximal sites, other devices such as floss, toothpicks and interproximal brushes are recommended as adjuncts to toothbrushing.

According to ISO 28158:2010, dental floss is defined as “the multiple filaments gathered into thread, spun yarn, single filament or tape, commonly synthetic fiber, with or without coating material(s), designed for the removal of plaque or debris, or both, from the proximal surfaces of natural or artificial teeth and the gingival surfaces of pontics of fixed prostheses”. This document goes into more details and establishes what material dental floss should be made of (“…free from extraneous matter when examined according to visual inspection by normal acuity without magnification”... “Materials intentionally added to dental floss, such as wax, pigments or flavoring agents, shall be considered as part of the device”), the shape it should have (“the integrated dental floss shall not have any sharp surface or parts…”), and its strength (“…shall withstand the static load of 10 N for 10 s without a breakage of the floss”) (21).

Other very important parameters that may influence the mechanical properties of dental floss are tensile strength and percentage of elongation: the first one has an impact on the maximum load supported by the floss to pass the interdental contact point, while the percentage of elongation sets the maximum length of the floss before tearing apart. (22). There are several types of dental floss available: silk, nylon, or PTFE (polytetrafluoroethylene floss), with or without wax. Nylon is used for multifilament dental floss, while monofilament floss is usually made of PTFE. Other investigations have previously assessed the clinical efficacy of waxed and unwaxed dental floss, and they have consistently reported no significant variations concerning their capability to eliminate interproximal plaque (23).

This research sought to scrutinize specific mechanical attributes of dental floss, driven by the existing literature's limitation in providing a comprehensive overview of this subject. A portion of the experimentation necessitated the utilization of dental floss holders to facilitate and standardize the measurement procedures. The flosses analyzed in this study are of various manufacturing types (waxed and unwaxed), different structures (expanding, ribbon, standard), and various brands, ranging from well-known dental brands to less common household names. In accordance with findings from previous in vivo investigations (13), wherein the average passage force required to traverse interproximal contact points was established at 9.4 ± 0.5 N (representative of the force a patient employs to navigate proximal contacts without causing harm to gums and soft tissues), the universal testing machine was configured to operate at 10 N. Simultaneously, the maximum displacement of the floss was confined to 10 mm. This setup ensures alignment with established physiological benchmarks while maintaining a margin of safety within the experimental parameters. The dental floss holder underwent a recurrent force application of 11.0 N, considering prior in vivo studies that ascertained mean passage force values at 9.9±0.5 N. These findings indicated the force anticipated to be exerted by patients (24) during the traversal of proximal contacts.

Due to inherent anatomical characteristics and construction-related attributes of the holders, we imposed constraints on the maximal displacement of the floss, restricting it to 10 mm. Additionally, we established a limitation on the maximum force applied, capping it at 11.0 N. These measures were implemented to ensure that the experimental conditions remained within physiological bounds and adhered to the designed parameters of the study. The integration of two experimental configurations, namely the LR 30K Lloyd Instruments universal testing device and the proximal contact strength simulator, enabled the simulation of proximal contact passage and accurate determination of the floss displacement within the holder. This combined approach facilitated a comprehensive evaluation of the mechanical aspects associated with proximal contact interactions.

Tensile strength

The performance of the different tested flosses was not influenced by whether they were waxed or not (excluding the wire that showed significantly better performance than others, where subsequent positions included both waxed and unwaxed wires). Furthermore, two reactions were observed in the tested wires during the trial: either breaking sharply once the tolerated tensile limit was reached or fraying before ultimately breaking.

Displacement

A minimal floss displacement, specifically below 4 mm, is deemed favorable as it signifies the ability of the holder to navigate the proximal contact without inducing excessive elastic or plastic deformation in either the floss or the holder. This criterion is established based on anatomically relevant considerations of the proximal space. Numerous studies (25-27) indicate that the average length of the clinical crown measures 10.19 mm in men and 9.39 mm in women.

Proximal contact strength is situated approximately 1-2 mm below the tooth's shoulder, exhibiting dimensions dependent on the tooth type, typically ranging from 1-2 mm. In individuals with periodontal health, the proximal space is occupied by the papilla, extending cervically as an epithelial attachment into the proximal region. This delineation adheres to anatomical norms and contributes to a comprehensive understanding of desirable floss displacement parameters within the proximal space (28).

The results of this part of the experiment reveal a maximum difference between the means of 0.5 mm, with all values very close to the 4 mm cutoff; this suggests that the value is not particularly influenced by the wire type, but rather by the type of flosser used. In the reference study, indeed, the values were much more heterogeneous, due to the utilization of many flossers of different shapes and uses.

Passage force

The findings reveal substantial similarity among the flosses concerning their response to passage force. The majority of the sample exhibited adequate strength, attaining the requisite 10 N; only three flosses exhibit slightly lower, yet still acceptable, values compared to the established cutoff value. Consequently, by comparing the obtained values to those of the reference study, we infer that this parameter is also influenced by the flosser rather than the wire itself.

CONCLUSIONS

While this study examines numerous interdental flosses with different characteristics and specificities, being an in vitro study provides a precise snapshot related solely to the parameter of tensile strength. In vivo, within the oral cavity, interdental floss is subjected to the action of a greater number of multidirectional forces (not replicable in an experimental model of this kind) that stress the floss at multiple points. Furthermore, friction with various restorative materials (amalgam, composite, gold) or orthodontic materials (steel), as well as friction at contact points and the presence of saliva that saturates the floss, can influence its resistance.

Moreover, the utilization of a single type of universal dental floss holder standardized the values, preventing the observation of significant differences among the various flosses. It would be intriguing to assess each floss with different types of holders and analyze the obtained results.

Following the results found in literature, dental flosses with greater tensile strength should also be the best in clinical removal of dental plaque. However, in vivo, dental floss is subjected to a combination of multiple types of forces: friction at contact points, rubbing on restorations of different materials, bidirectional tensile forces. In light of these considerations, there is a need for further in vivo studies to be able to associate greater tensile strength with advantageous clinical characteristics.

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