MISCELLANEOUS

THE OPTIMUM CHARACTERISTICS OF TOOTHBRUSHES FOR PERSONAL ORAL HYGIENE*

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Maintenance of dental health and of reasonable oral cleanliness can be accomplished only by effective personal oral hygiene. To prevent the initiation and further progress of caries and periodontoclasia, one must clean his teeth right, every night before retiring. However, cleaning the teeth at other times also promotes still greater oral cleanliness. The teeth can be cleaned well enough to prevent disease and to maintain reasonable oral cleanliness only by the proper use of the right kind of both toothbrush and dental floss. Both the brush and the floss must have the characteristics which are necessary for the functions they respectively serve.

The functions of dental floss and specifications for the most effective and most appropriate floss for personal oral hygiene, are presented in a companion paper.[1] The functions of the toothbrush and the optimum characteristics of brushes for personal oral hygiene are presented herein.

FUNCTIONS OF THE TOOTHBRUSH

Proper use of the toothbrush is necessary to clean all the exposed surfaces, pits, grooves and spaces about teeth, which can be reached by the bristles of the brush. The material to be removed consists of (a) food material of all kinds that may have been retained about the teeth since the previous cleaning, (b) microorganismal material that has grown and accumulated at these locations since the previous cleaning, or prior thereto.

NEED FOR THE TOOTHBRUSH IN CLEANING THE EXPOSED SURFACES OF TEETH

The enamel crown is covered by a very thin delicate keratin-like membrane, the enamel cuticle. At locations where functional friction cleans off the surface, the cuticle there is free from anything more than a few bacteria and microscopic particles. Moving away from such area, which is frequently cleaned by functional friction, we find that the enamel cuticle has more or less bacterial film on it at all times.[2] In the still more protected area this bacterial film is thicker and is sufficient to fill grooves and pits

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completely on the occlusal surfaces and to make up a considerable pad between teeth and around the contact point (Fig. 1). The outer edge of the biconcave disc of bacterial material around the contact point comes to the sides of the two contacting teeth and, at this location, is within reach of the bristles of the toothbrush. Deeper in, the space is too narrow for the bristles to enter.

Fig. 1

Fig. 2

Fig. 1. Extracted tooth, stained, showing bacterial film around contact point. 1. Contact plane almost free from bacterial material. 2. Bacterial film on the tooth, much of which was accessible to the application of toothbrush bristles. 3. Zdeac. 4. Epithelial cells of the epithelial attachment remaining attached to the tooth. 5. Heavier portion of epithelial attachment extending to the cemento-enamel junction

Fig. 2. Decalcified section showing filamentous nature of film pack upon the tooth. 1. Dentin. 2. Space previously occupied by enamel, into which film pack collapsed. 3. Bacterial film pack broken apart in preparation. 4. Enamel cuticle to which filamentous bacterial pad is attached

An important feature of the bacterial film on teeth is that the deeper part of it generally consists largely of long rods or filaments closely packed together (Fig. 2). One end of the organism is attached to the enamel cuticle[2] from which it extends outward toward the surface of the film. At the surface of this constantly present bacterial film there are many bacteria of different types, varying largely with the oral flora. These are on the surface and among the growing ends and fruiting heads of the rod-shaped

and filamentous organisms of which the deeper part of the pad is composed.

Food material, during mastication, is thoroughly and heavily inoculated with the many and different bacteria in the saliva, derived from all the different surfaces within the mouth. These bacteria, in material retained about the teeth, rapidly multiply, some more rapidly than others, according to the favorability of the substrate, number and variety of bacterial cells in the inoculum, and many other variable factors.

Fig. 3. Decalcified section showing the foreign material on the tooth within the gingival crevice which must be disloged by the bristles of the toothbrush. 1. Dentin. 2. Enamel space. 3. Enamel cuticle. 4. Gingival crevice. 5. Foreign material (bacteria and concretion) attached to the cuticle upon the tooth. 6. Gingival margin

Whenever favorable carbohydrates are applied to the surface of the bacterial film pad, either in solution or in particles of food, production of acids occurs. Some carbohydrates, when applied in solution to the accumulated film pad, produce acids quickly.[3] On the other hand the same carbohydrates mixed with other food material in particles of food inoculated and lodged upon the bacterial pack in grooves, pits and sulci about teeth, break down more slowly; acids are thus produced more slowly over a longer period of time.

Such acids produced at the surface of the bacterial film pack are carried, as if by a sponge or wick, through the filamentous material down to the

cuticle at the surface of the tooth and pass through the cuticle to the enamel. If these conditions are frequently renewed and continued long enough, microscopic decalcification of enamel occurs, giving rise to the early, "white spot," stage of caries. If continued much longer the enamel at this point breaks down producing a cavity—the advanced stage of caries.

Fig. 4. Seven-thousands inch rounded end bristles mounted by the side of .014" bristles, angular cut, from serrated trim brush

Food particles containing little or no fermentable carbohydrates, but a larger proportion of protein, favor the growth of other bacteria including putrefactive bacteria. Little or no acid is produced but instead the foul smelling products of putrefaction are formed giving rise to unclean and malodorous conditions. Although caries is not produced, this kind of decomposition about the teeth is quite as objectionable in other ways. A most important effect is promotion of the deposition of concretions or calculus on the tooth and the resulting periodontoclasia.

Decomposing food about teeth can be removed by the proper use of the toothbrush to the extent that the bristles can be forced into the spaces containing it. The action is mechanical by which the material is broken up and dislodged by the digging action of the ends of the bristles when the brush is held firmly against the place to be cleaned and is moved back and forth, or from side to side, by several short strokes, so as to force the bristles into the pits, grooves and spaces as far as their diameter will allow them to go.

During the period since the previous cleaning, considerable growth of bacteria has taken place in the outer portion of the film pad, even if no food material rested upon it, and still more, if remnants of food were there. Proper use of the brush breaks up, dislodges and thus removes much of this

most rapidly growing part of the bacterial material. Although not all of it has been removed, most of the actively growing part has been, and at the same time most of the food material. Such brushing should always be followed by vigorous rinsing to remove loosened particles of bacterial or food material. In an area cleaned in this way from food which could serve as

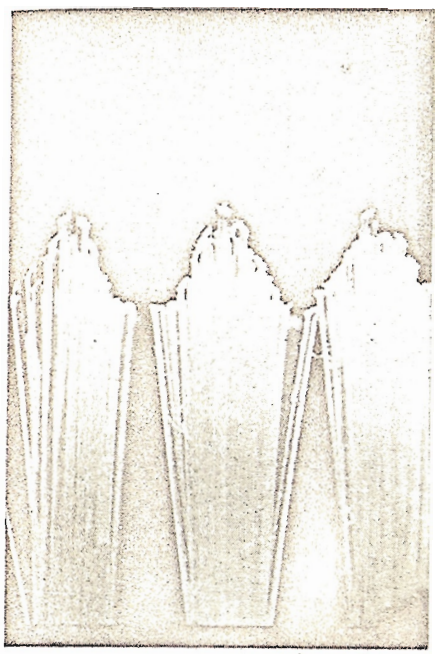

Fig. 5

Fig. 6

Fig. 5. Three typical tufts of rough cut serrated trim brush
Fig. 6. High magnification of end of tuft of .014" bristles, serrated trim. Note sharp chisel shapes

bacterial nutritive material and from a large part of the most viable bacteria, not much growth of bacteria takes place, there is no appreciable further decomposition of food and no harmful acids are produced, until more food material is lodged again at this same place.

The two most important locations for the occurrence of enamel caries are (a) at and about the occlusal pits and fissures, (b) at and about the proximal contact points between teeth. The toothbrush is the sole dependence for cleaning and preventing caries at the occlusal surfaces. It is of much use in cleaning the approximal surfaces. When properly used, it dislodges food material that is lodged upon the edge of the bacterial film pack between teeth, and also the bacterial material itself, to the extent or depth

the bristles can penetrate the space. To this extent the toothbrush can contribute largely to the checking of further progress after early stage lesions have developed.

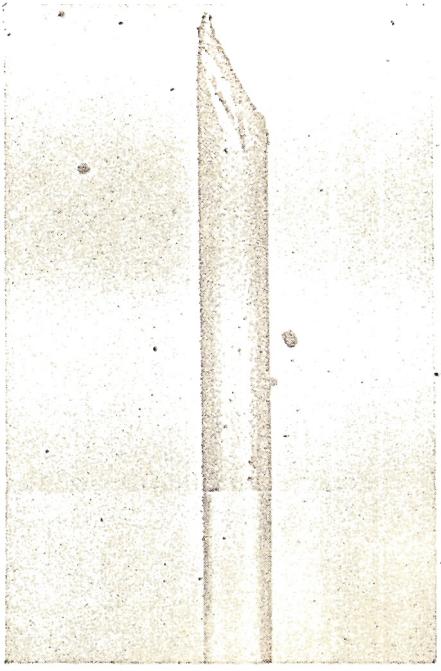

Fig. 7

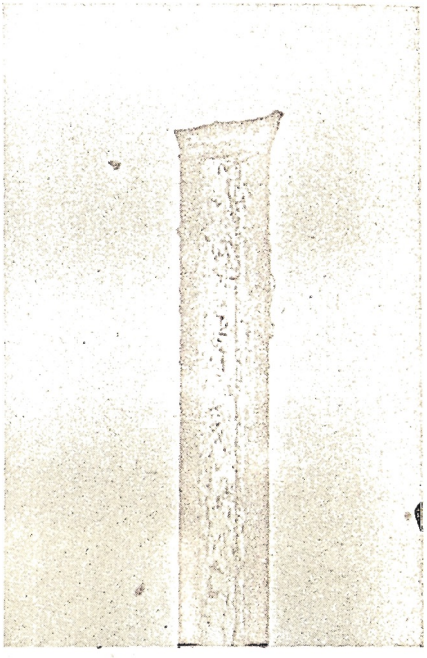

Fig. 8

Fig. 7. Typical pointed rough end of bristle cut at an angle in serrated trim brush. (By transmitted light). Note sharp point

Fig. 8. Appearance of cut-off end of nylon bristles. (By transmitted light). Note sharp edges

NEED FOR THE TOOTHBRUSH IN CLEANING THE TOOTH WITHIN THE GINGIVAL CREVICE

Normally the edge of the gum rests upon the soft, smooth, nonirritating enamel cuticle. Bacterial material allowed to accumulate and remain at this location for long periods of time tends to produce a hard rough incrusted material (calculus) which has the effect of a foreign body upon the gum, against which it rests, in place of the normal enamel cuticle. Irritation and inflammation of the gingiva at the entrance to the gingival crevice, microscopic at first, constitutes the very earliest stage of periodontoclasia.[4] As the concretion and roughness on the tooth at the entrance to the gingival crevice increases, it extends into the crevice and is a constant source of ir-

ritation and inflammation of the free gingiva, which rests against it. (That part of the gum extending from the level of the bottom of the gingival crevice occlusalward, to the gingival margin, is appropriately called the free gingiva). As the condition progresses a larger and larger area of the tooth within the gingival crevice is covered with foreign material constitut-

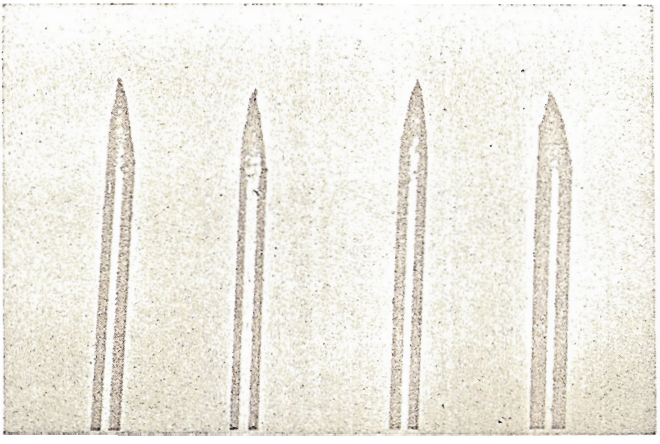

Fig. 9. Seven-thousandths inch bristles sharpened to long keen points for tattoo experiment. They bend instead of puncturing enough to tattoo

ing a foreign body against which the crevice side of the free gingiva must rest (Fig. 3).

The significance of this foreign body effect was recognized by Dr. John W. Riggs[5] in 1876 who correctly asserted, at that time, that the early stage of suppurating inflammation (early stage periodontoclasia) is caused by the accumulation of accretions and roughened surfaces on the teeth at the gingival margins. He substantiated his claims by the prompt relief he secured by carefully removing the concretion, tartar or roughness and polishing the tooth.

Attached to, and resting upon, the surface of the concretion(calculus) within the crevice there is a pad of bacterial material consisting largely of rod and filamentous forms. One end of many of the organisms making up the pad is attached to the tooth or to the concretion upon it. At the outer surface of the bacterial pad within the gingival crevice there are the growing ends and fruiting heads of these rod and filamentous bacteria, among which there are large numbers of other bacteria of many varieties, spirochetes and often ameba (Endamoeba buccalis).[6] This bacterial material extends to, and overlaps to some extent, the zone of disintegrating

epithelial attachment cuticle—zdeac*—and probably promotes the disintegration which goes on there.

An important function that is served by an appropriate toothbrush, properly used, is to dislodge and remove the soft microscopic material at the entrance to, and within, the gingival crevice, to the extent that these are accessible to the application of the brush.

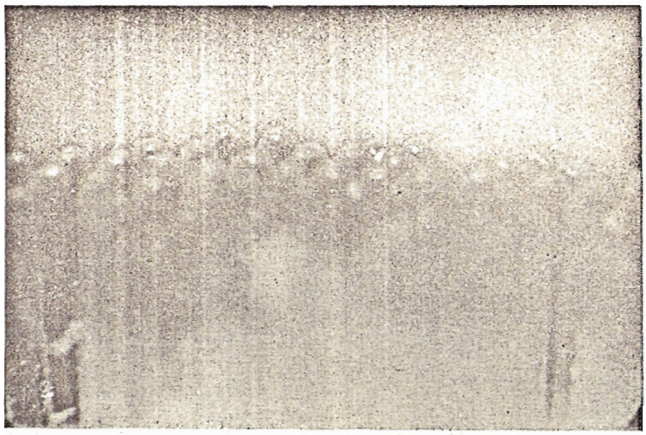

Fig. 10. Rounded ends of bristles, in straight trim brush, viewed from the side. (Compare with Figure 15)

Having this general view of the functions of the toothbrush we may proceed to consider the characteristics which are necessary for the most effective and practical brush.

MATERIAL

During recent yars, synthetic plastic materials, have taken the place, almost completely, of all other material for the stock or body of the toothbrush. They are entirely satisfactory from every standpoint and superior in many particulars.

Prior to the last war, natural bristles were used for toothbrush bristling. This material was imported largely from China and Russia but the supply became limited during the war. For several years just prior to and during the war, manufacturers turned to synthetic plastic filaments for toothbrush bristles. Most of these were unsatisfactory. More recently high quality nylon has become available and these nylon bristles are so superior, in most respects, that it is the only material to consider at the present time. The high quality nylon now available to manufacturers should be used for toothbrush bristling, to the exclusion of all other material.

*Zdeac is an abbreviation for zone of disintegrating epithelial-attachment cuticle, first described by me in the *Jour. of Dent. Res.*, 25:301, 1946.

Some of the advantages of this high quality nylon filament now available are: (1) bristles are uniform in cross section (natural bristles are not); (2) uniform in size; (3) available in a wide range of diameters; (4) do not split; (5) do not become soggy but remain lively and resilient; (6) high abrasion resistance against wear; (7) ends of bristles can be made smooth and round by mechanical means; (8) withstand many months of daily usage without appreciable deterioration.

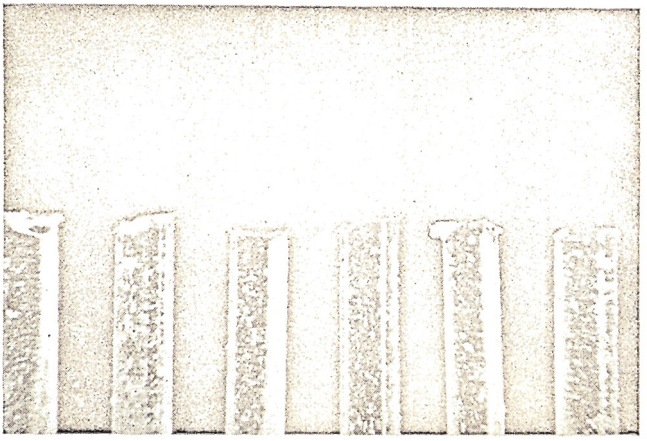

Fig. 11. Square cut nlyon bristles. Note sharp rough corners

GENERAL FORM AND SIZE

The size and shape of the stock (handle and head) should be designed for easy and natural manipulation in applying the brush to the surface of the teeth, and the areas about them, to be cleaned. A plain straight-handle design can be used more successfully and more effectively than any other. There is no good excuse for crooked, twisted or other distorted shapes of toothbrush handles. The over-all length should be about 6″ and the width about 7/16″. There should be three rows of bristles, six tufts to the row, evenly spaced.

The stapling and setting of the bristles are standard manufacturing procedures and need not be considered here. No manufacturer can afford to make brushes in which the bristles shed.

SIZE OF FILAMENT

High quality nylon filament for toothbrushes is available in sizes from .014″ down by .001″. Most toothbrushes are now made with .012″, .013″ or .014″ bristles. Much experimenting with all sizes, and study over a

considerable period of time, has led the author to conclude that .007″ filament is the right size for the purpose. Although no doubt slight deviation from this size may be permitted without serious impairment, any such deviation reduces the over-all effectiveness and suitability of the brush in proportion to the extent of such deviation. It will be noted that this size—.007″—is exactly one-half the diameter of the coarser .014″ bristles now generally used in "hard" brushes (Fig. 4). It is desirable to consider here some of the advantages and indications in favor of the smaller size.

Fig. 12. Good example of the appearance of bristles that have been smoothed and rounded as required in this paper

USUAL INJURY BY BRUSHING

Injury to the gums is the most general harmful effect of improper use of inappropriate toothbrushes. Frequent traumatizing and injuring the border of the thin gingiva upon the enamel covered crown gradually wears it off from the enamel and forces it to recede beyond the cemento-enamel junction. This occurs especially on the labial and buccal surfaces and on those teeth which are most exposed to the usual long stroke harmful type of brushing. Normally the epithelial attachment extends from the cemento-enamel junction occlusalward to its outer border at the zone of disintegrating epithelial attachment cuticle—zdeac[7]—within the gingival crevice. Were it not for disease (periodontoclasia) or injury (mostly by the toothbrush) there would be no change from this location throughout life.

Most people who have brushed their teeth for at least a few years, with the current types of brushes, have already sustained more or less permanent damage to the gingiva about some of their teeth. The margin is worn back more and more and the epithelial attachment recedes until the cemento-

enamel junction is passed and a narrow strip of cementum is exposed. Now, as the brushing is continued, grooves are cut in the exposed softer cementum and underlying dentin. The rapidity of cutting, and the extent of these grooves is influenced largely by the vigor and character of the stroke of the brush, given by different individuals, and by the abrasive effect of the

Fig. 13. Representative bristles selected from a .012" bristle brush, serrated trim, that had been used daily, generally with prepared chalk, for more than four months. Note that the sharp rough edges have finally been smoothed off considerably, thereby lessening their harmfulness

dentifrice the individual uses. While enamel is not cut or injured by any except the hardest abrasives, exposed cementum and dentin may be worn or cut by long continued use of even very mild abrasives.

This condition in which the gum has been worn back entirely from the enamel and more or less abrasion at the necks of some of the teeth can be recognized, represents an advanced stage of toothbrush damage. While it is easy to recognize now, there was an earlier stage and less deviation from the normal which would have been uncertain or difficult to recognize.

Under these circumstances it is hardly practical to determine accurately the frequency of this kind of injury. Different observers will be governed by different criteria. One will recognize earlier stage lesions than another. Actually one who looks for this injury and is alert to recognize it, will find it, to a diagnosable degree, in practically all people who have used current types of toothbrushes for any considerable period of time. It is practically universal among users of current toothbrushes.

Anyone who is interested can confirm this statement by looking for brush injury on his own teeth and on those of others whom he examines. Few people, who have used toothbrushes, will be found whose gums have not

been worn back more or less on some of their teeth. Based upon a study of 200 individuals, Kitchin[8] found abrasion of some extent in 42 per cent of individuals in the 20 to 29 year group and 76 per cent in the 40 to 49 year group. Exposure (gum recession) conditions capable of developing abrasion were determined as 58 per cent in the 20 to 29 year group, 84 per cent in the 30 to 39 year group and 96 per cent in all over 40.

Fig. 14. End of bristle smoothed and rounded by grinding. Consider how much less scratching and damage would be done by this as compared to sharp cut bristles. (By transmitted light)

It is true that this type of injury is promoted largely by improper, long stroke, vigorous use of the toothbrush applied excessively at certain locations, and would not occur to such an extent if everyone used his brush more cautiously. Nevertheless, most people do not know how, or do not take the care, to use their brush so as to minimize the damage. Neither do they recognize the microscopic injury they produce with it. It is especially desirable, therefore, that the scratching strength or stiffness of the bristles of the toothbrush should not be sufficient to injure the gums, however it is used.

THE "SCRATCHING STRENGTH" OF BRISTLES

The diameter of bristles of a given length determine their stiffness and

resistance to bending; and this in turn indicates the strength with which they can scratch and injure the thin tissue at the thin outer gingival border. Table 1 shows the weight, when applied at the middle, required to deflect, for a distance of 1/8", a beam of nylon toothbrush filament 11/16" and 13/16" long.

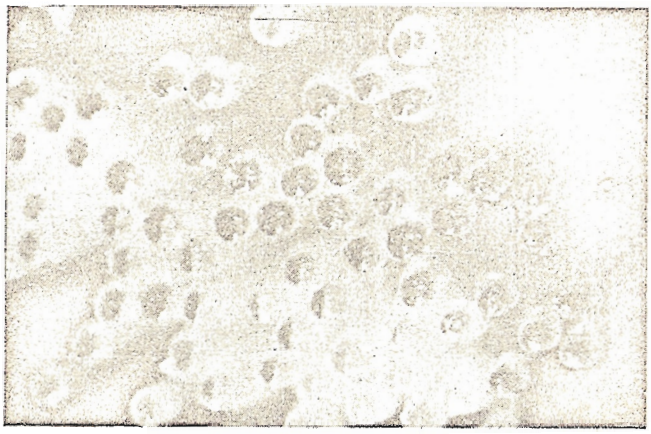

Fig. 15. Rounded ends of bristles in straight trim brush viewed from above

TABLE I

Stiffness of nylon toothbrush bristling material.

11/16 INCH BEAM

Diameter of Filament	*Wt. to Deflect Filament 1/8"*
.005"	0.136 grams
.006"	0.283 grams
.007"	0.417 grams

13/16 INCH BEAM

Diameter of Filament	*Wt. to Deflect Filament 1/8"*
.007"	0.236 grams
.012"	1.623 grams
.014"	3.785 grams

TABLE 2

Relative scratching and puncturing strength of high quality nylon toothbrush bristles, taking the smaller size as 1.

11/32 INCH BRISTLE

Diameter of Filament	*Scratching and Puncturing Strength*
.005"	1
.006"	2
.007"	3

13/32 INCH BRISTLE

Diameter of Filament	*Scratching and Puncturing Strength*
.007″	1
.012″	7
.014″	16

One-half this weight would be required to bend ⅛″, a bristle of corresponding size 13/32″ long, the length my experiments indicate toothbrush bristles should have for most effective use. Arbitrarily, I call this the "scratching strength." It provides a basis for a useful comparable numerical expression of the stiffness of different size bristles. It will be noted from Table 2 that the .014″ bristle has sixteen times the "scratching strength" of the .007″ size. Obviously it is desirable to select a bristle which does not have enough "scratching strength" to injure the gums when brushing the teeth. It should be clearly understood, however, that the purpose of brushing is to clean the teeth (not to, as so many imagine, "massage" the gums). The bristles of the brush strike the gums only to the extent this occurs during the necessary effort and manipulation to clean the areas on the teeth which can be reached by the bristles.

Injury to the border and surface of the gums by vigorous brushing with stiff, scratching brushes, at a given operation, is superficial and microscopic. The epithelial cells are torn away to a variable extent. Microscopic and sometimes macroscopic bleeding occurs. Healing or repair is very rapid and when it is time to brush again the gum is in about as good condition as previously. However, such injury, frequently repeated over a considerable period of time, gradually wears the border of the gum back away from its normal location on the enamel crown, exposing more and more of the crown and later an area of cementum.

EXPERIMENTAL INJURY OF DOG GUMS

An experiment was undertaken to try to learn something of the damaging effect upon the gums of dogs, of brushes with different size bristles such as are available on the market and represent what the average person would be likely to get (Figs. 5 and 6). Brushes of four different widely advertised makes were purchased from the open market, each having bristles of either .014″, .013″, or .012″ nylon. It was intended to compare the damaging effect of vigorous use of the different makes of brushes and size bristles upon the gums of the animals. This experiment was abandoned because it was found that there was so much damage produced by each of these brushes until no satisfactory comparison could be made between them. Also there would not seem to be any useful purpose in comparing implements, all of which are so damaging as to condemn their use. Under the dissecting microscope one could observe that the gums were badly

traumatized, much of the outer epithelial layer was torn away, microscpic bleeding was considerable and the traumatic inflammatory reaction, hyperemia, swelling and weeping which followed were noticeable.

Another attempt was made, using brushes with bristles ranging down by .001″ from .014″ to .006″.* These were all straight trimmed to approximately 7/16″ length and an attempt was made by the manufacturer to round the ends of the bristles. Due to limitations in the equipment available at the time, this was only partially successful. There were many side ground, chisel or other sharp shaped bristles, and imperfect rounding of the ends of many of them. However the sharp points and edges were more or less smoothed and the traumatizing effect greatly reduced thereby.

There are four areas in the dog's mouth, all over the maxilla, which seem to be more accessible and better suited for testing the traumatizing effect of brushes, viz., an area on either side extending from the cuspid mesially over the two incisors and an area on either side extending distally from the cuspid over one or two teeth. Here again, in many tests, the injury produced by vigorous brushing was greater than anticipated but it was so much less, as the smaller size bristle brushes were used, that the difference was very striking. It was possible to severely injure the gums with the coarser bristle brushes. Visible injury consisting of scratches and hemorrhage could be produced with all sizes down to .009″ bristle brushes and sometimes with the .008″ size. No visible injury could be produced by either the .006″ or the .007″ bristles, except occasional hemorrhage from the gingival border where there was more or less gingivitis present.

Lack of any exact control of the amount and force of the brushing, plus the weaknesses of personal observations, limit the usefulness of the conclusions drawn from this experience largely to the individual observer. The author concludes from his observations that the gums of dogs can be injured by brushing them with toothbrushes with bristles larger than .007″, and that little or no injury can be produced by bristles of this size or smaller. There may be question as to how far this observation on dogs, for whatever it is worth, is applicable to the human.

SCRATCHING HUMAN GUMS

The author maintains his own teeth and gums free from active disease No hemorrhage (even microscopic) occurs from his gums. The high state of health is maintained by the proper use of a toothbrush with round end .007″ bristles, such as is specified herein, and 350 denier nylon dental floss as specified in the companion paper.[1] Although such an experiment would

*Large numbers of brushes have been supplied by the Prophylactic Brush Co., Florence, Mass., and made to conform to special specifications which were required as our experiments progressed. Cooperation and technical information were received from J. R. Brown, Jr., their Director of Chemical Research.

seem superfluous, the damaging or scratching effect of a .012" bristle brush on normally tough and resistant gums was tested as follows:

The teeth and alveolar ridge gingiva on the labial and buccal surfaces of all four quadrants were brushed with the .007" round end bristle brush. Long cross strokes were used and an effort was made to apply the brush to the gums as vigorously as would be done by the average individual in brushing his teeth improperly, as most people do. Washings were collected from the brushed gums by taking normal (85 per cent) saline into the mouth and moving it about gently over the teeth (but not forcing it between them) and gums. This was repeated ten times during a period of fifteen minutes. The washings were collected in a beaker together with washings of the brush and this was brought up to a total of 100 cc. by the addition of saline. This was strained through a pad of several thicknesses of surgical gauze to remove bubbles, transferred to large centrifuge tubes and centrifuged at 2300 r.p.m. so as to collect all cellular material. The clear supernatant fluid was poured off, the sediment was resuspended in saline, shaken thoroughly and then centrifuged again. The clear supernatant fluid was poured off, the sediment in the bottom was mixed by shaking and jarring the tube sideways. This concentrated suspension of the sediment was transferred to a slide, covered with a coverglass and examined for red blood cells. None was found present. This indicates that the friction on the gums with this .007" bristle brush did not damage the gums enough to cause escape of even microscopic amounts of blood cells, and also that the brushing did not cause the escape of any blood cells from periodontoclasia lesions between the teeth (there is none present, as a result of the proper use of the right kind of dental floss). Similar tests to this have been run previously, from time to time, repeatedly confirming the fact that this .007" round end bristle brush does not injure the gums sufficiently to cause even minute bleeding.

Thirty-five minutes after the above brushing the same areas were again brushed in the same way with a widely advertised brush which had .012" bristles, serrated trim, not rounded. There were many of the usual pointed, chisel shaped and rough ended bristles present (Figs. 7 and 8). Looking at this brush under the microscope one would believe it capable of tearing up almost any tissue except the toughest. However, the alveolar ridge of the gum is one of the most resistant mucous membrane surfaces to abrasion or trauma.

Washings were collected in exactly the same way as previously, so far as possible. The material was prepared by centrifuging and the sediment was prepared for examination as before. There were many blood cells present. These can be differentiated readily from all other cellular and other material. There are an abundance of epithelial cells derived from

the surfaces of the mouth and tongue which are constantly shedding hornified pavement cells, in addition to cells torn, by the bristles of the brush, from deeper layers of gum tissue. Although there was an abundance of red cells present, they were not as numerous as would be expected from the force applied and the apparent potential traumatic capacity of the weapon used.

Three or four weeks later, on May 3, the above experiment was repeated, using this time a currently popular so-called "professional." two-row brush, serrated trim, .014", unrounded bristles. The preliminary brushing with the .007" round end bristle brush was carried out as described above. No blood cells were found present in the washings. Two hours afterward the teeth and gums were brushed vigorously with the stiff brush. The fact that the gums were being torn up and injured could be felt. Washings were collected over a period of thirty minutes, centrifuged and prepared as before. This time there were many red blood cells present.

The implications of these two experiments have to be accepted by others with reservations on account of the personal factor involved and the lack of absolute controls and quantitative determinations. They prove satisfactorily to the author that sufficient damage to the tissues is done by vigorous brushing with these brushes to permit escape of blood cells through the gums. Greater significance attaches to this observation in consideration of the structure of the gum tissue. There are no blood vessels in the epithelium. The connective tissue papillae which project into the epithelial tissue contain a network of capillaries. To cause even minute bleeding, it is necessary for the injury to extend through the epithelium to the underlying tips at least, of some of the papillae, and for some of the capillaries there to be broken. In this case the rough, sharp pointed, stiff bristles tear through the epithelial tissue and into some of the papillae, opening some of the capillaries. The .007" bristles, having only 1/16 the scratching strength of the .014" bristles, do not appreciably injure the thick tough gingival epithelial tissue in the same way (see Table 2).

PUNCTURING STRENGTH OF BRISTLES

Obviously the ability of a sharp pointed bristle to puncture a tissue depends upon its stiffness which, in turn, is governed by size—all other things being equal. A sharp pointed object, when forced against a tissue, either penetrates the tissue or it bends. The values in Table 1 indicate that the .007" bristle would withstand only 1/16 as much force before bending* as the .014" size. In the same way as we have arbitrarily interpreted this information as indicating the different size bristles, we may also

*Mcfarlane[9] has shown that the force required to bend or buckle a filament varies inversely with the square of the length, instead of the cube, as in deflection.

interpret it as indicating their "puncturing strength." The relative "puncturing strength" of the .014" bristles is therefore about 16 times that of the .007" size (see Table 2).

Numerous experiments have been carried out in an effort to ascertain the ability of sharp pointed toothbrush bristles to puncture the gums. The most satisfactory and conclusive evidence was obtained by tattooing the gums of dogs with brushes dipped in tattoo ink (powdered graphite from an ordinary indelible lead pencil was used) and applied vigorously so as to press the sharp pointed bristles firmly against the gums.

Permanent tattooing of skin or mucous membrane requires that the pigment be carried to, and in fact through, the basal layer of epithelial cells. Thus, the points carrying the pigment must penetrate to this depth. The epithelial tissue of the alveolar ridge gingiva is many cells thick and the tips of the papillae, where the basal layer lies nearest to the surface, are relatively deep. To permanently tattoo this part of the gum requires deep penetration by the points. It was found that the gums could be tattooed heavily, showing that the points of the bristles do penetrate the epithelial tissue. However, the pigment gradually faded (probably grew out) and usually disappeared within from a few days to about three weeks. This is interpreted as indicating that the points of the bristles do not penetrate the basal epithelial layer.

It was quite different when the thinner mucous membrane over the maxilla within the buccal or labial sulci and just above the alveolar ridge gingiva, was tattooed. Not only was it easy to tattoo but the pigment was permanently retained in the tissue. These results have been obtained repeatedly using .014" sharp pointed bristles (Figs. 5, 6 and 7). On the other hand it has not been possible to tattoo dog gums in the same way with the .007" bristles. In addition to the rough cut bristles similar to those of commercial toothbrushes, bristles of this same .007" size were ground on an abrasive belt in a way to produce long keen sharp points (Fig. 9). In repeated tests it was not possible to tattoo the dog's gums with these sharpened .007" bristles. When pressed against the gums these sharpened bristles bend before they penetrate enough to tattoo even superficially and temporarily. We can conclude that the "puncturing strength" of the .007" bristles is not sufficient to permit harmful puncture damage to the gums.

TRIM

Years ago many of the toothbrushes were straight trimmed, making all bristles about the same length. Later serrated trim became more and more popular until now practically all brushes are trimmed in this way (Figs. 5 and 6). The outside bristles of each tuft are trimmed considerably shorter than those in the center. This gives more or less of an angular cut to nearly

all of the bristles. Many of them have sharp pin- or chisel-shaped points (Fig. 7). These are the points which puncture the tissue when used with sufficient force against the mucous membrane. They also scratch and tear the gum when used vigorously with long strokes.

The idea is well founded that the serrated trim, with bristles in the center of each tuft considerably longer than those around the periphery, permits the longest bristles of current coarse bristle brushes to enter deeper into pits, grooves, depressions and narrow spaces on and between the teeth. These are the most important areas to be cleaned by the toothbrush. However, in the case of the usual size stiff bristles, the relatively small number of long bristles hold off and prevent effective application of the shorter bristles, thus greatly reducing the number of potentially effective bristles in the brush.

On the other hand when a straight trimmed brush, wherein all bristles are of about equal length (Fig. 10), is applied properly, every bristle is potentially effective in cleaning any area to which they are applied, provided the bristles are small enough .007". Pressed against the irregular surfaces of the teeth, bristles that come, for the moment, against high places are deflected or bent allowing others to enter the depressions. This can be observed most satisfactorily by pressing and manipulating the brush against the occlusal surface of extracted molar teeth held in the field of a dissecting microscope and under incident light. With the proper short back and forth "vibratory" movement of the brush held firmly against the surface being cleaned, many bristles are applied effectively to the most important areas. This is made possible by the low bending resistance of the .007" bristle. Therefore, it is apparent that the total number of potentially effective bristles in a straight trim .007" bristle brush is several times greater than the number in a serrated trim coarse bristle brush.

SIZE OF BRISTLE IN RELATION TO THE SPACES TO BE CLEANED

The dimensions of pits, grooves and spaces on or about teeth vary greatly. However, the smaller the diameter of the bristle the smaller spaces it can enter. A .007" bristle can enter a space which is only one-half the width that can be entered by a .014" bristle (Fig. 4). Likewise the smaller size bristle can go deeper into a cone or wedge shaped space, such as the pits and fissures on teeth and sulci between them.

The smaller size .007" bristle is of still greater importance in cleaning the teeth at the gingival crevice. This size bristle not only is applicable to the tooth at the exposed gingival margin but it also enters the crevice (Fig. 3) to considerable depth, thus mechanically dislodging, and promoting removal of bacterial and other soft material on the tooth within the crevice. Ideally, we would like to clean the tooth down to the zdeac. This line is at the inner border of the bacterial film pad and

the concretion on the surface of the tooth within the gingival crevice. The depth to which this material on the tooth extends within the crevice varies greatly on different teeth and at different locations around a given tooth.

When the brush is properly manipulated so as to direct and apply the ends of the bristles to the entrance to the gingival crevice, some of the small .007" bristles enter the crevice and go as far as they may, until they meet with sufficient resistance to deflect or bend them. Bristles of this size bend without injuring the tissues of the gingival crevice. However, they do have enough strength, before bending, to break up and dislodge much of the soft material there.

There is usually some hemorrhage from gingival crevices brushed in this way for the first time, due to the presence of more of less gingivitis. Subsidence of the inflammation and healing of the tissue within the crevice is often so rapid, following brushing with this size bristles (and cleaning the interproximal crevices with the right kind of dental floss) at night before retiring, until little or no bleeding occurs at the next cleaning, or subsequently. Only where there are deep, extensive periodontoclasia lesions and under especially unfavorable conditions may bleeding occur again, indicating active disease at the particular location where effective cleaning had not been accomplished.

NUMBER OF BRISTLES PER TUFT

The total number of bristles in each tuft may vary slightly. About 80 to 86 of the .007" bristles per tuft make them of proper size and allow sufficient space between the bristles of different tufts to favor effective application in cleaning the teeth. This much spacing also favors cleaning and drying of the brush after it has been used.

LENGTH OF BRISTLES

Considerable experimenting with bristles of different lengths has been carried out. The length finally decided upon for brushes for use by adults is 13/32". The author has found that this is the right length of .007" bristles for the most effective use in cleaning the most important locations on the teeth which can be cleaned with the brush. Bristles longer than this tend to bend easier and are less effective and less applicable to some of the areas of the teeth which we desire to clean with the brush. Shorter bristles tend to be less effective in penetrating spaces on and between the teeth, and those within gingival crevices. The 13/32" bristle brush is manipulated with greater ease within the mouth in brushing the teeth than brushes with either longer or shorter bristles.

ROUNDING THE ENDS OF THE BRISTLES

It is only necessary to see the ends of bristles of current types of toothbrushes under the microscope (Figs. 4, 5 and 6) and to recall the damage

that almost all who have used them consistently have sustained, to realize that there is urgent need for improvement in this regard. The sharp pointed, chisel shaped, rough ended (Fig. 11) bristles must be corrected. This can be accomplished readily by grinding and finishing the ends of the bristles so as to eliminate all sharp, rough-cut points and edges, and to make the ends smooth and as nearly hemispherical in shape as possible (Fig. 12).

Since the "scratching strength" and the "puncturing strength" of the .007" bristles is so much less than that of coarser bristles, it is obvious that the need for rounding and smoothing them, to prevent injury to the gums, is very much less (Fig. 13). However, the rounded and smooth end bristles are also more appropriate for entrance and penetration of narrow spaces, such as gingival crevices, and for effective application within the crevices. Also the total potential area of such a bristle for dislodging and removing soft bacterial material there is much greater than that of a sharp pointed and rough cut bristle (Fig. 14).

The rounding and finishing* of the bristles can be accomplished by holding and revolving the brush endwise against a rapidly moving abrasive surface such as the flat side of a grinding wheel or a "sander belt." By regulating the pressure and the duration of the grinding, it is possible to finish the ends of the bristles so that most of them are almost perfect hemispheres (Figs. 10, 15). There is usually more or less angular grinding of some of the outside bristles due to the flexibility of the .007" size, but all objectionable sharp edges and points are eliminated from them.

Holding and manipulating the brush by hand against the grinding surface, the author has been able to round and finish the bristles entirely satisfactorily. When the demand justifies, it can be done better and on a large scale by mechanical means. But this is a simple problem for the manufacturer to work out and need not be discussed here.

REDUCED SIZE BRUSH FOR CHILDREN

There is need for a similar brush of reduced size for the use of young children before they are old and large enough to use the regular size. Although the author's most intensive and thorough studies and experiments have applied especially to the diseases and conditions to be met in older people, he has carried out sufficient additional studies and tests relative to the problem in young children to permit laying down specifications for the most suitable toothbrush for their use.

The child's brush should correspond to the regular brush in every way except it should be of a reduced size. It should conform approximately to the following dimensions:

*One manufacturer claims a patent on rounding the ends of the bristles of serrated trim brushes. The process, as I understand it, is not intended for, or adapted to, rounding and finishing the bristles of straight trim brushes. It probably can be modified for this purpose.

Over-all length 5", width 6/16"; bristles .005" high quality nylon, straight trim, finished to 11/32" length; ends smooth and rounded. (For stiffness and relative scratching and puncturing strength of this size bristles see Tables 1 and 2).

COMMENT

Every person who has teeth to save and who wishes to maintain oral cleanliness must have the right kind of toothbrush and must know how to use it correctly. The brush herein specified meets the needs adequately for all purposes and should replace current inappropriate and harmful makes.

The manufacturer should be able to supply brushes conforming to the requirements indicated, whenever there is demand for them. Teaching effective use of the toothbrush should be done by dentists, dental hygienists, public health nurses, parents, teachers and others who are interested in promoting oral health.

SUMMARY

The following optimum characteristics for toothbrushes for personal oral hygiene, and reasons therefore, have been presented:

1. Plain straight-handle design; over-all length about 6", width about 7/16"; 3 rows of bristles, 6 tufts to the row, evenly spaced.
2. High quality nylon bristles, about 80 per tuft, .007" diameter, straight trim, finished to 13/32" length.
3. Ends of bristles ground and finished to hemispherical shape or at least enough to eliminate all sharp points and rough edges.
4. A similar brush of reduced size for the use of young children should have an over-all length of about 5", .005" bristles, finished to 11/32" length.

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