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Current concepts in toothbrushing and interdental cleaning

NICHOLAS C. CLAYDON

The benefits of optimal home-use plaque-control measures include the opportunity to maintain a functional dentition throughout life, a reduction in the risk of loss of periodontal attatchment, optimization of esthetic values such as appearance and breath freshness, and also a reduced risk of complex, uncomfortable and expensive dental care. Broadly speaking, the self-care or home-use activities that contribute to the oral health status of an individual include toothbrushing by manual or electric means combined with interdental cleaning. Self-care has been defined by the World Health Organization as 'all the activities that the individual takes to prevent, diagnose and treat personal ill health by self-support activities or by referral to a healthcare professional for diagnosis and care'.

The importance of plaque-control measures is emphasized in all workshops on periodontology. However, it is worth noting that reviews on mechanical plaque control (10) consider standard toothbrushing first, electric toothbrushing second and interdental cleaning last of all. This, despite the fact that in terms of risk analysis for the development of periodontal disease and caries, the interproximal areas carry most risk. Indeed, the importance of interproximal plaque control, and its effectiveness at reducing inflammation, are well documented (44, 45). It is appreciated that the toothbrush alone is capable of removing up to 1 mm of subgingival plaque, but is ineffective in the interproximal region. Hence, the development of a variety of mechanical and electrical devices have been sanctioned, with the aim of enabling the user to achieve higher standards of interdental cleaning. Frandsen (32), in his seminal article on oral hygiene practices, states that no interdental cleaning agent showed greater efficacy than any other in relation to plaque control or for establishing and maintaining gingival health. He further suggested that cleaning devices should be recommended according to individual dexterity, preference and interdental anatomy.

Toothbrushing remains the mainstay of oral health measures in the western world, but despite the widespread use of both toothbrush and fluoride toothpaste, the majority of the population do not clean their teeth thoroughly enough to prevent plaque accumulation. This is attributed (78) to be a result of a lack of understanding of the disease process.

Periodontal diseases are the result of interactions between plaque bacteria and the immune response developed by the host. The prevalence of such diseases, as investigated by epidemiological survey, is particularly difficult to define. The current best estimate of the prevalence of periodontal disease (12) involves extrapolation of data and suggests that around 90% of the population are affected by inflammation and by periodontal pockets of ≥ 4 mm, and that this representation increases with age. This value, however, needs to be interpreted with caution because it represents a composite figure of periodontal diseases that may range from simple (such as gingival inflammation) to complex (such as aggressive periodontitis) conditions. One of the implications of considering collective data is that inappropriate (i.e. increased) levels of care may be recommended from a young age. This is, in some respects, unavoidable because susceptibility to periodontal disease cannot be predicted from a young age (1). Similarly, it has also been difficult to determine the prevalence of gingival inflammation, with estimates in the adult population varying from 40 to 90% (16, 17). More recent surveys (12) indicate a pattern of decreasing prevalence of periodontal disease that, it is suggested, can be explained by increasing consumer awareness and a transition to a more prevention-orientated approach to caries control, resulting in fewer restorations. Notwithstanding, the current evidence suggests that the accumulation of microbial plaque on the tooth surface is a direct cause of gingivitis (70) and that gingivitis may precede periodontitis (46, 47, 63, 64). The inflammatory signs were shown to resolve once plaque-control measures were re-instated (53), and studies since (11, 51) have re-affirmed that self-performed plaque-control measures may be essential in the prevention of periodontal disease. However, even now, it is unclear from the evidence derived from systematic review (1, 39) whether chronic periodontitis can be entirely prevented by self-care or professional care measures alone. There are currently no methods of safely influencing the host response, and therefore the prevention and treatment of periodontal diseases are routinely approached by inhibiting plaque formation and instituting mechanical plaque-removal measures.

Dental plaque

Dental plaque may be defined as 'the soft tenacious material found on tooth surfaces that is not readily removed by rinsing with water' (25), but more specifically it is an organized matrix derived from salivary glycoproteins and extracellular microbial products in the form of a biofilm that forms on the hard, nonshedding surfaces in the mouth (3).

The unhindered deposition of plaque occurs on all surfaces of the teeth and is recognizable clinically within 24 hours (19). At this stage the predilection is for accumulation in the interproximal areas of the molars and premolars followed by accumulation in the interproximal surfaces of the anterior teeth and the facial surfaces of the molars and premolars (44). Other sites of predilection include the gingival margin, together with pits and fissures, whilst the oral surfaces accumulate the least amount of plaque. Beyond the initial 24 hours, the temporal accumulation of plaque increases in thickness and in a coronal direction until such time as the pattern of extension reaches a maximum. At this stage, the plaque dimensions stabilize and do not increase with time, but vary and reflect such factors as tooth group, position in the mouth and surface affected. The rate and pattern of plaque formation can be assessed using the Plaque Formation Rate Index (7, 8) (Fig. 1).

Plaque accumulation was found to be greatest on the distolingual and mesiolingual surfaces of the mandibular molars and premolars, followed by the distobuccal and mesiobuccal surfaces of the maxillary and mandibular molars. Almost no plaque accumulated on the lingual surfaces of the maxillary teeth. It is widely recognized (51) that this pattern reflects individual masticatory patterns, together with the physical influence of the tongue and cheeks. The masticatory forces on food are believed to create frictional forces that are physically able to prevent the accumulation of, and can assist in the removal of, plaque from the occlusal and incisal areas of teeth, although these same forces are less effective interproximally and at the gingival margin. Ingestion of high-fibre food might be anticipated to reduce plaque accumulation, but in fact has no significant preventive effect. Indeed, the conclusions (28) following studies with tube feeding were that the presence or absence of cervical plaque is independent of the passage of food through the mouth.

The unhindered accumulation of plaque is such that the natural cleaning of the human dentition by the anatomical structures and masticatory force is limited to the regions less 'at risk' (incisal

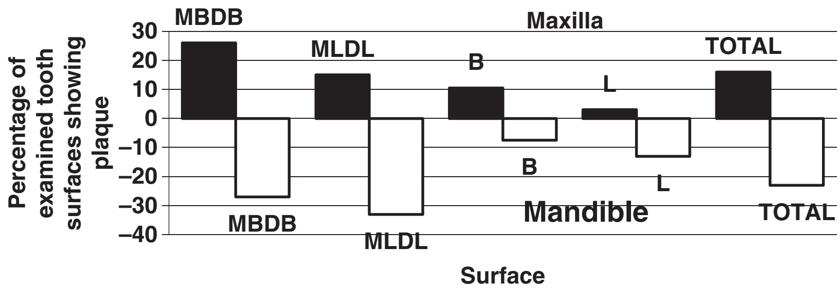

Fig. 1. Plaque-formation rate. B, buccal; L, lingual; MBDB, mesio-buccal, disto-buccal; MLDL, mesio-lingual, disto-lingual.

and occlusal areas) for periodontal disease. This underlies the precept that the only way to exert control is to remove plaque in an active manner (49).

The role of mechanical plaque control in the prevention of periodontal diseases

Periodontal diseases are complex processes, with strong cause–effect relationships proven between the accumulation of supragingival plaque and the development of gingivitis (53). This study, by Löe et al., instructed students with clinically healthy gingivae to abstain from all oral hygiene procedures, whereupon measurable levels of gingivitis developed within 2–3 weeks, which resolved within 1 week on the resumption of mechanical tooth cleaning. Therefore, mechanical plaque control remains the best approach for the prevention and treatment of gingivitis. Periodontitis is characterized by the loss of attachment and is often, if not always, preceded by gingivitis (10). Because the progression of periodontal diseases is advanced by subgingival bacteria, which are, in turn, derived from the supragingival dental plaque, it necessarily follows that meticulous mechanical supragingival plaque control can reduce the risk for the development or recurrence of periodontal disease.

If dentogingival plaque is allowed to accumulate freely, subclinical symptoms of gingival inflammation, in the form of an exudate from the gingival sulcus, appear within 4 days (3, 44). Students who thoroughly removed plaque every second day did not develop clinical signs of gingivitis, whereas those who cleaned their teeth every 3 or 4 days all developed gingivitis. In untreated gingivitis a gradual increase in gingival edema results in a higher proportion of plaque in the subgingival area. As a consequence, the subgingival microflora gradually shifts to predominately gram-negative anaerobic rods (i.e. straight, curved and motile) (10).

Epidemiological studies (56) have demonstrated a strong correlation between the localization of gingival plaque and gingivitis, with the highest plaque and gingivitis scores in the molar regions. As a consequence, in populations with poor oral hygiene and a lack of periodontal treatment, the most significant loss of periodontal attachment is in the maxillary molars followed by the mandibular molars. Several site-related changes can be noted with increasing age (10).

- 35-year-old subjects: loss of periodontal attachment is twice as severe on the distal surface of maxillary first molars as the mesial aspect.
- 50-year-old subjects: the distal surface of maxillary molars has the highest incidence of furcational involvement.
- 65-year-old subjects: the molars represent the lowest percentage of remaining teeth.

In all adult age groups, the highest Community Periodontal Index of Treatment Needs (CPITN) scores are found on the approximal surfaces of the molars and, in addition, subjects with the highest Plaque Formation Rate Indices develop more gingivitis than those with low Plaque Formation Rate Indices. The progression of gingivitis to periodontitis, however, has not been shown, except in animal models (47).

A successful strategy for primary as well as secondary prevention of periodontal disease therefore depends on an understanding of the consequences, as well as of the etiology. Furthermore, despite the tenuous link between the progression of gingivitis to periodontal disease there is overwhelming evidence that the complete removal of bacterial plaque from the dentogingival region is the most effective method of preventing gingivitis and periodontitis.

Appropriate frequency of mechanical plaque control to maintain dental and gingival health

Having established a direct link between plaque and gingivitis and having determined that the best way of preventing periodontal disease is by implementing optimal plaque-control measures, it is appropriate to consider the temporal influences. The clinical and subclinical effects of unhindered plaque accumulation over a time line from a healthy baseline show that it takes 48 h to produce signs of gingival inflammation (48). Gingival health was maintained when plaque-removal intervals were more frequent than every 48 h (49) but where the time was extended, gingival inflammation ensued (44). The conclusion that can be drawn from this finding is that in order to prevent gingivitis from developing, an individual need only meticulously remove the plaque from their teeth every 2 days.

The neat dichotomy between the scientific evidence for the frequency of toothbrushing and the traditional recommendation to clean the teeth twice a day is widened by the further appreciation that the pattern of toothbrushing for patients is habitual and does not vary (54, 60). Furthermore, no more than 60% of the overall plaque is removed (26) at each episode of cleaning (i.e. individuals will clean the same areas each time they brush their teeth, no matter how many times they repeat the exercise). What does justify the increased brushing frequency is that in addition to mechanical plaque removal the toothbrush is a delivery device for chemical adjuncts contained in toothpaste; moreover, there is the (vain) hope that toothbrushing efficacy may increase with frequency. Therefore, the overall benefit of twice-daily cleaning is derived from the summary of benefit of mechanical plaque removal as well as the adjunctive chemical benefit derived from delivering toothpaste (2, 10).

As a point of principle, it is reasonable to state that meticulous mechanical removal of plaque by toothbrushing, combined with the removal of interdental plaque once every 24 h, is adequate to prevent the onset of gingivitis as well as of interdental caries (10). It is generally understood that the population does not practise meticulous plaque removal, and more frequent tooth cleaning (up to twice daily) has been shown to improve gingival health significantly (50). Furthermore, epidemiological studies and reviews of data indicate that gingival health improves with up to twice-daily brushing but not with more frequent toothbrushing (32, 67). Relevant to this, correlation coefficients show a weakly positive, but significant, relationship between the frequency of tooth brushing, and oral hygiene and gingival health (2).

Most efficacious toothbrushing method to maintain gingival health

Enthusiastic use of the toothbrush is not necessarily synonymous with a high standard of oral hygiene as a result of the fact that there is limited access to the wide approximal surfaces of the molars and premolars. Furthermore, visual assessment of plaque removal does not mean that all the bacteria have been removed. The most common technique used by uninstructed individuals is a horizontal scrubbing motion that engages the occlusal and buccal ⁄ lingual surfaces (51). Instruction of patients was deemed to have been achieved by introducing more ‘advanced techniques’, such as rolling, circular or vibratory movements. In order to systemise the toothbrushing procedure, various techniques have been suggested, including: horizontal scrubbing, the roll technique, and Charters’ and Bass’ methods. There are no recent studies that compare toothbrushing methods, and the original studies conducted were typically short-term, did not evaluate gingival health and did not demonstrate one method as being consistently superior (32, 33).

The Bass technique (13) was first described in 1954 and in the past decade has become the method most frequently recommended. It has been shown that proper use of the Bass technique three times a week will prevent the formation of subgingival plaque on buccal surfaces accessible to the toothbrush (40). It was also shown that plaque can be removed from at least 1 mm subgingivally. Similar studies (33) of the roll, horizontal scrub and Charters’ techniques all had limited effect on the approximal tooth surfaces, although the Charters’ technique did at least attempt to address the presence of proximal plaque because the method involves holding the head of the brush so that the filaments are at 45° to the tooth surface and pointing in an occlusal direction, whilst using a gentle vibratory motion.

Studies (26, 54, 60) into the patterns of toothbrush use indicate that most right handers begin brushing the buccal surfaces of the anterior teeth or left side. The mean brushing time was 50 s and only 10% of the time was spent on the lingual surfaces. Accordingly, most severe gingival recession and abrasion defects are localized to the buccal surfaces on the left side (the potential for harm from oral health devices is considered separately). Where studies are standardized for brushing time, frequency and pressure on the buccal surfaces, it has been shown that by using a medium-abrasive dentifrice the plaque-removal effect was increased to approximately 50%.

Toothbrush design

The ideal toothbrush design is specified as being user-friendly, removes plaque effectively and has no deleterious soft tissue or hard tissue effects. The current patterns were introduced about 100 years ago and are based on the natural materials available at the time – hog bristles and a wooden or ivory handle (31). Whilst acceptable at the time, and no doubt efficacous in terms of plaque removal, natural products are inherently unhygienic as the bristle fibres and wooden grain allow for the accumulation and proliferation of orally derived bacteria. Furthermore, the expense of manufacturing such devices in that era precluded their widespread use. The advent of nylon filaments and plastic handles in the 1930s addressed the issue of hygiene and made toothbrushes more affordable, thereby increasing acceptability to the point where, within industrial societies, the majority of the population own one and claim to use it to brush their teeth at least once a day (6).

Since then, considerable effort and resources have been invested in the design and detail of toothbrushes (62), all of which have failed to produce a single product that has a statistically superior plaque-removing performance. Indeed, Frandsen (32) concluded that modern toothbrushes are satisfactory aids to personal oral hygiene practices, provided that the person using them is properly motivated and instructed in their use. In terms of efficacy, the inference here is that the skill of the user is a more important factor than the design of the toothbrush.

Nevertheless, the European Workshop on Mechanical Plaque Control in 1998 specified the following attributes for an acceptable toothbrush.

- handle size appropriate to user age and dexterity – handle design has been investigated in many studies (24, 40, 42) to determine the effect on plaque removal. The consensus was that a long contoured handle performed better than short uncontoured handles and that the shape of the handle could be tailored to suit a particular style of toothbrush use (Bass toothbrushing technique) for improved plaque removal.
- head size appropriate to the size of the user's mouth – the appropriate choice of head size is very much one of the application of common sense, although it is interesting to note that the standard comparator for toothbrush studies continues to be the Oral-B P35® (®Proctor and Gamble UK, Weybridge, Surrey) and the majority of toothbrushes in development have smaller heads. The boundaries of design were extended with the introduction of novel concepts such as toothbrushes characterized by double (4) or triple (79) heads, which aimed to clean all bar the interproximal surfaces simultaneously and to a greater degree of efficacy than the standard comparator. Further interesting products utilized designs where the filaments were arranged so that they were angled away from the head and these were shown to be significantly more effective than the standard comparator (27, 61, 66, 68). However, none of the results and conclusions here have been substantiated by independent studies. Indeed, independent investigators (20, 21) were unable to demonstrate any statistically significant superiority when they used the same products and protocols despite the fact that the outcome measures such as plaque removed (approximately 60%) were very much in line with other investigators (26).
- the use of round-ended nylon or polyester filaments not larger than 0.23 mm in diameter – the properties of toothbrush filaments may vary according to thickness, stiffness, pattern of arrangement and density. As a result of the myriad of potential combinations, there are no single studies that investigate the impact of each characteristic independently. Those researchers who do look at filament variation produce (as one may predict!) a spectrum of varying results (41). On the one hand, studies (15) were unable to discern any clinically statistical difference between four test toothbrushes when examining stiffness, density and pattern (14) of arrangement (straight multi-tufted and V-shaped). However, on the other hand, superior plaque removal was demonstrated (57) with higher-filament-density toothbrushes. One of the conclusions of such studies is that design features other than filament texture are responsible for differences in mechanical plaque-removal efficiency (30), a perception not altogether remote from Frandsen's conclusions regarding oral health-efficacy measures (32).
- the use of soft filament configurations, as defined by the acceptable industry standards (ISO). The criteria for acceptance and accreditation of toothbrushes are not stringent; rather, they are straightforward to meet, particulary when compared with those for chemotherapeutic agents. The 1996 Council on Scientific Affairs (22) demands one 30-day clinical study that demonstrates clinical safety and a 15% statistically significant reduction in plaque and gingivitis when compared with baseline.

Overall, available short-term studies (40) indicate that many brush designs can potentially fulfil these broad specifications. However, in terms of perspective, it is worth appreciating that many such short-term studies are often used to assert definitive conclusions of toothbrush efficacy and to support claims of plaque-removing superiority when they are, in fact, merely screening experiments that do not consider the clinical impact on oral health (21).

Automated toothbrushes

Phrases similar to 'mechanical plaque control with a manual toothbrush remains the mainstay of oral hygiene measures for the majority of the population' are commonly found in the introduction to many review and research articles on the subject and this perfectly summarizes the importance of manual toothbrushes in achieving oral health. It is well recognized, from the results of behavioural toothbrush studies (54, 60), that the average person spends approximately 1 min brushing their teeth and in doing so removes approximately 60% of the plaque present around the teeth. Consequently, the scope for improving this leads to the adjunctive use of chemicals (a topic that is outside the scope of this review) and/or improvements in the design of toothbrushes. Bizarrely, the habitual element of toothbrushing means that improvements in toothbrush efficacy rarely come from improvement in technique alone! The majority of improvements in design for the manual toothbrush yield very little statistically significant improvement in plaque-removal efficacy (32). This contrasts with the developments in powered toothbrushes (51, 72), where improvements in design have led not only to improvements in plaque-removal efficacy for a given standard of toothbrushing, but have also resulted in high compliance levels, with one study reporting 62% of people continuing to use their powered toothbrushes on a daily basis 36 months after purchase (69). This is neatly reflected in sales figures for powered toothbrushes that virtually doubled every year between 1999 and 2001 for one of the markets in the western world (59).

Furthermore, the manual toothbrush was consistently shown to remove less plaque in a given time when compared with the powered toothbrush; it takes 6 min to remove the same percentage of plaque using a manual toothbrush that is removed in 1 min using a powered tootbrush in the hands of a professional operator. Furthermore, using a manual toothbrush, plaque removal is increased with time up to 6 min, whereas, for a powered toothbrush, optimum levels (84% plaque removal) are reached at about 2 min and at 6 min this only rises to 93% (i.e. the extra time does not yield large increases in plaque removal.

The origins of powered toothbrushes date back to the 18th century, with such designs as a mechanical toothbrush (65) by a Swedish clockmaker and Dr Scott's electric toothbrush (26), but it was not until the 1960s that electrically powered toothbrushes were introduced (18, 23, 29, 38) and became established as a preferred alternative to manual methods of toothbrushing.These initially produced a 'back and forth' motion in an effort to simulate the motion of a manual toothbrush, but claims for plaque-removing superiority were not substantiated (6, 32) for the 'average' user, although they were still recommended for persons with reduced dexterity or mental impairment. Further and more recent developments of powered toothbrushes resulted in the filaments being moved in a rotating or oscillating motion (76), and/or with very much higher frequency of motion (41). The rationale behind the improvement was that, potentially, such toothbrushes were able to remove more plaque than a manual toothbrush for a comparable period of time; the implication being that the 'average ' person who brushes for 50 s (54) would be able to achieve more by way of plaque removal. Indeed, several studies have demonstrated (71, 73–75) the relationship between time and plaque removal for both manual and powered toothbrushes.

Such is the extent of development that modern automated toothbushes present with various different design principles that may be classified according to action (Table 1).

The nature and complexity of clinical trials, together with that of interpreting and standardizing information, amply illustrates the difficulty of determining the efficacy of automated toothbrushes. This is particularly highlighted in various systematic reviews that compare manual and powered toothbrushes (37, 59). Such systematic reviews carry the advantage of offering the best quantitative results based on international standards, reduce the risk of author bias and because the data are processed using meta analysis represent the best method of refining the information and identifying the more obscure trends or patterns as well as reducing the risk of statistical anomalies that may surface occasionally (37, 55, 59). A limiting characteristic of such meta analyses, however, is the source data or the clinical trials themselves. In the original review, a total of 354 studies that compared manual toothbrushes with powered toothbrushes were reviewed from the literature by the Cochrane Collaboration Oral Health Group (37). Of these, only 29 studies (13%) met the inclusion criteria for consideration, whereas 186 (87%) did not. This represents a significant loss of data and inevitably leads to a level of confusion within the profession and for the consumers (which may or may not be the desired effect). The data were updated in 2008, and 42 studies were deemed appropriate for inclusion. The main outcome measures of plaque and gingivitis were grouped for each of the types of toothbrush and are outlined in Tables 2 and 3.

The data synthesis of a systematic review needs to contend with information that is collated and aggregated from different sources which have used different indices for both plaque and gingivitis. As it is not possible to combine or compare the results from different indices, the effects from each study were expressed as standardized values, which have no units, before combining them in the analysis. This is presented as the standard mean difference, with appropriate 95% confidence intervals, for use as the effect measure for each meta analysis. As such, the standard mean difference values carry no inherent clinical meaning but can be applied selectively to

Table 1. Classification of powered toothbrushes according to mode of action

Design	Mode of action	Range example
Lateral motion	Brush head action that moves laterally from side to side	Philips Sonicare http://www.philips.com
Counter oscillation	Adjacent tufts, containing between 6 and 10 filaments, rotate in one direction and then counter-rotate with adjacent tufts moving in opposite directions	Interplak brush http://www.conair.com
Rotation oscillation	The whole brush head rotates in one direction followed by the other	Braun Oral B http://www.oralb.com Philips Jordan http://www.philips.com Colgate Actibrush http://www.colgate.com
Circular	The whole brush head rotates in one direction	Rowenta Dentiphant http://www.rowenta.com Teledyne AquaTech Brushes http://www.waterpik.com
Ultrasonic	The toothbrush filaments vibrate at ultrasonic frequencies (> 20 kHz)	Ultrasonex Brush http://www.saltoninc.com
Ionic	An electric current is applied to the filaments during tootbrushing that alters the charge polarity of the tooth and results in the attraction of dental plaque towards the filaments and away from the tooth. No automated action is provided	Hukuba Ionic http://ionicbrush.com

Table 2. Plaque reduction for powered toothbrushes vs. manual toothbrushes at (1–3 months) > 3 months

Toothbrush type	Number of studies	Number of participants	Statistical method	Effect size
Side to side	(6) 2	(402) 220	Standardized mean difference (random) 95% CI	(−0.42 [−0.91, 0.07]) 0.03 [−0.23, 0.29]
Counter oscillation	(4) 2	(184) 69	Standardized mean difference (random) 95% CI	(−0.07 [−0.36, 0.22]) −0.63 [−1.11, 0.14]
Rotation oscillation	(15) 3	(1181) 266	Standardized mean difference (random) 95% CI	(−0.43 [−0.72, −0.14]) −1.29 [−2.67, 0.08]
Circular	(3) 1	(168) 40	Standardized mean difference (random) 95% CI	(−0.06 [−0.36, 0.25]) 0.04 [−0.58, 0.66]
Ultrasonic	(3) 1	(171) 46	Standardized mean difference (random) 95% CI	(−1.13 [−2.42, 0.15]) 0.20 [−0.38, 0.78]
Ionic	(3) 1	(179) 64	Standardized mean difference (random) 95% CI	(−0.28 [−0.58, 0.01]) −1.01 [−1.53, −0.49]

The effect measure for each meta-analysis was the standardized mean difference with 95% confidence intervals (CI) using random-effects models. It is not possible to combine the results from different indices. Therefore, the effects are expressed as standardized values, which have no units, before combining. The standardized mean difference was therefore calculated together with the appropriate 95% CI and was used for each meta-analysis.

appropriate clinical indices included in the study to indicate clinical value.

When comparing the plaque-removal efficacy and gingivitis-reduction efficacy, the side-to-side, circular motion and ultrasonic versions were statistically no different from their manual counterparts, both up to and beyond 3 months. This provides clear evidence that these particular powered toothbrushes are no more effective than manual toothbrushes.

The toothbrushes with a counter oscillatory motion likewise did not produce statistically significant differences over a manual comparator for plaque or gingivitis up to 3 months but are linked with a moderate reduction in plaque levels over 3 months

Table 3. Gingivitis reduction for powered toothbrushes vs. manual toothbrushes at (1–3 months) > 3 months

Toothbrush type	Number of studies	Number of participants	Statistical method	Effect size
Side to side	(8) 2	(627) 220	Standardized mean difference (random) 95% CI	(−0.44 [−0.91, 0.02]) 0.12 [−0.14, 0.39]
Counter oscillation	(4) 2	(172) 69	Standardized mean difference (random) 95% CI	(−0.04 [−0.52, 0.45]) −0.19 [−0.66, 0.29]
Rotation oscillation	(16) 4	(1256) 423	Standardized mean difference (random) 95% CI	(−0.62 [−0.90, −0.34]) −0.51 [−0.76, −0.25]
Circular	(3) 1	(168) 40	Standardized mean difference (random) 95% CI	(−0.39 [−0.95, 0.18]) −0.30 [−0.92, 0.33]
Ultrasonic	(3) 1	(171) 46	Standardized mean difference (random) 95% CI	(−0.64 [−1.04, −0.24]) 0.00 [−0.58, 0.58]
Ionic	(2) 1	(116) 64	Standardized mean difference (random) 95% CI	(−0.14 [−0.51, 0.22]) −0.78 [−1.29, −0.27]

The effect measure for each meta-analysis was the standardized mean difference with 95% confidence intervals (CI) using random-effects models. It is not possible to combine the results from different indices. Therefore, the effects are expressed as standardized values, which have no units, before combining. The standardized mean difference was therefore calculated together with the appropriate 95% CI and was used for each meta-analysis.

(standard mean difference, −0.63; 95% confidence interval: −1.11 to −0.14). There was no similar effect on gingivitis beyond 3 months.

The ionic styled toothbrushes showed no statistical difference for either plaque or gingivitis up to 3 months but demonstrated benefit for plaque (standard mean difference, −1.01; 95% confidence interval: −1.53 to −0.49) and gingivitis (standard mean difference, −0.78; 95% confidence interval: −1.29 to −0.27) in the longer term.

The most significant results were attained from studies investigating the rotational oscillating powered toothbrushes in their comparison with manual counterparts. This style of toothbrushe carries the advantage of having the highest number of appropriate research studies conducted and as such the data are unequivocal. Toothbrushes of this design removed more plaque and reduced gingivitis in the short-term and long-term studies. For studies up to 3 months the differences amount to a reduction of 0.27 or 11% of the Quigley & Hein plaque index (58) and 0.06 or 6% for the Löe & Silness gingival index (52). The improvement over 3 months was greater, with an equivalent reduction of 17% on the Ainamo-Bay bleeding on probing index (5).

Further secondary outcomes were also evaluated in the systemic analysis that may be of interest to consumers should further convincing be required as to the benefit of (rotational oscillation) powered toothbrushes over manual alternatives. The devices were found to be of good reliability and although no cost–benefit evaluations were made, they have become relatively inexpensive of late.

Recent literature reviews (37, 59, 62, 76,) concur and conclude that powered toothbrushes show benefit with respect to plaque removal and gingival condition over the standard manual comparitor. It would appear that these benefits are derived primarily from the fact that plaque removal is comparable on the flat surfaces of the teeth, but that it is superior for the approximal area. This carries an additional benefit in that the disease activities of concern to most patients and, by implication, dentists (caries and periodontal disease) most commonly originate in the interproximal area (51) (i.e. immediately adjacent to the area of improved cleaning). Consequently, these developments culminated in the carefully worded endorsement from the 1996 World Workshop in Periodontics that electric brushes carry an 'additional benefit compared to manual brushes' (36) and that the use of 'an electric brush with its standard movements may result in more frequent and better cleansing of the teeth' for 'nondentally orientated persons', 'persons not motivated to oral health care' and 'those who have difficulty in mastering a suitable handbrushing technique' (34).

Interdental cleaning

The rationale for considering interdental cleaning as a separate subheading is related to the fact that toothbrushing alone is considered to be optimally capable of thoroughly cleaning the 'flat' surfaces of the teeth only (43). That is to say, the buccal, lingual and occlusal surfaces, with the exception of pits and fissures, have the potential for maximum plaque removal, leaving the proximal and interdental areas 'essentially untouched' (51). The implications are that these particular areas have a high risk of developing periodontal lesions in particular (and caries also) as the accumulation of microbial plaque is one of the prerequisites for periodontitis (43).

An appreciation of the importance of this area has permitted a strategic evaluation of plaque-control priorities, leading to modern programs that emphasize the proximal and interdental areas – hence the added value of powered toothbrushes that have been shown to be more effective at cleaning the proximal regions (72). Systematic review evidence exists for toothbrushing methods; however, as yet these have not been undertaken for interdental cleaning.

The starting point therefore is an evaluation of existing products (43). An ideal interdental cleaning device should be user-friendly, remove plaque effectively and have no deleterious soft-tissue or hard-tissue effects. Short-term studies (43) indicate that many devices can potentially fulfil the broad specifications where the (now familiar) consensus is that each of the variety of intercleaning devices may have been shown to be useful.

The range is overwhelming, from simple dental floss or tape, through woodsticks and brushes (single or multi-tufted), to mechanical or electrical devices. However, what is apparent is that the choice of interdental cleaning method should be tailored to the size and shape of each interdental and proximal space. In addition, it should be borne in mind that the advice offered may need to change as the effectiveness of treatment and improved oral hygiene changes the shape of the interproximal region. Furthermore, in order to gain maximum effectiveness, the level of oral hygiene advice delivered to the patient must contain enough information to enable the patient to be able to identify each site in turn, select a device and effectively clean the whole interdental surface.

Bearing in mind that the average patient manages to remove approximately 60% (26) of the plaque present in their mouth, it soon becomes apparent that the general population do not carry the requisite knowledge, motivation and skill required to establish interproximal cleaning as part of their daily oral hygiene care. One method of approach is to make use of colour-coded interdental brushes (for example Tepe®; ®Tepe Munhygienprodukter AB, Malmö, Sweden), which allows a health educator to help the patient to identify each area, allocate a colour-coded brush according to the size of the space and instruct an appropriate technique for use. It is worth bearing in mind that as for the manual toothbrush, the interdental brush has a primary role of mechanically debriding a surface, but may also serve as a delivery mechanism for chemical adjuncts, such as chlorhexidine gluconate or toothpaste. Further aide memoirs along the lines of the 'linking method' (9) of developing new skills include printing a dental chart of a patient's arch with the colour-coded detail for each site included so that it can be meticulously followed at the time of cleaning.

Approximal tooth cleaning

For adults with normal interdental spaces, the tufted interdental brush (Tepe®) is the most appropriate cleaning tool in these areas because the resilience of the gingivae allows cleaning apical to the contact points (i.e. risk areas for periodontal disease). Furthermore, when considering restoration of the approximal surfaces, the shape guarantees a correctly shaped embrasure that is readily accessible to the interdental cleaning aids.

Approximal plaque distal to the canines is often undetected despite the use of disclosing agents because the gingival papillae completely fill the interproximal spaces and obscure the disclosed plaque. Naturally, the exception to this is in patients whose approximal surfaces have been exposed by advanced periodontitis. As the posterior approximal spaces have wider lingual embrasures, the most effective means of plaque removal is by approaching from the lingual side. Access and efficiency may be improved if a handle is used. Further supplementary aids include the use of interspace brushes to clean furcational areas or tipped or rotated molars, super-floss for cleaning around bridge pontics, and scrapers for cleaning the back of the tongue.

Needs-related oral hygiene

A fundamental principle of prevention is that the effect is greatest where the risk of disease is greatest (9). Patients will therefore see positive results if they concentrate on at-risk surfaces or teeth. The results of oral hygiene surveys show that few of the population perform interdental cleaning on a daily basis, as amply illustrated by the results from a Swedish national dental survey (35), which show that toothpicks are used four times more frequently than dental floss (Table 4).

In addition, a fluoride dentifrice should be introduced interdentally in the molar and premolar regions. As the practice of interdental cleaning is not widespread, it can be concluded that habitual tooth cleaning is not needs related, and that adult patients

Table 4. Frequency of daily interdental cleaning carried out by children and adults[1]

	Children	Adults
Dental floss	10%	12%
Toothpicks	–	46%

[1]Data obtained from a Swedish national dental survey (35).

mainly brush tooth surfaces with the least disease activity.

It is a priority, therefore, to establish a needs-related cleaning habit for each patient by ensuring that they are well motivated, informed and instructed. New habits should be introduced alongside established habits, but should be performed before the entrenched habits because the risk of neglecting an ingrained habit is minimal. In behavioural science this is known as a 'linking method' (77). An example of this would be to improve the regularity (for example) of an irregular toothbrusher by scheduling the oral hygiene sessions prior to a regular event, such as showering.

Therefore, according to the linking method, needs-related tooth cleaning for adults (10) should begin with interdental cleaning from the lingual aspect of the mandibular molars ⁄ premolars, using a toothpick with a handle and an abrasive dentifrice, and progress to the maxillary molars and then to the premolars. The toothbrush should then be applied to the lingual surfaces of the lower right quadrant (for right handers), which is the least effectively cleaned region. Furthermore, from the studies regarding plaque development (3, 7, 8), it is apparent that lingual plaque re-accumulates most rapidly and is particularly adhesive. Therefore, toothbrushing should commence here while most toothpaste is on the brush, the bristles are most rigid and the focus of attention is at its greatest. The mandibular buccal and occlusal surfaces should then be cleaned before moving on to the maxillary teeth, beginning with the palatal surfaces of the molars and premolars followed by the labial surfaces. The order is, in effect, a reversal of the 'normal' routine recommended to patients, and the early establishment of the habit of interdental cleaning using dental tape and toothpaste can prevent interdental caries and loss of periodontal support.

The principles of the linking method are also applicable to clinical dentistry (i.e. to apply prevention towards a needs-related *modus operandi*). For most professionals the prophylaxis of the buccal surfaces with a rubber cup and polishing paste is not needs related and is habitual. Needs-related professional tooth cleaning should mirror the self-care procedure but differ by substituting toothpicks and toothbrushes for mechanically powered interdental cleaners and prophy handpieces.

Conclusions

It is certain that for a motivated, well-instructed person with the time and skill, mechanical plaque-control measures are sufficient to attain complete dental health. The combination of toothbrushing plus interproximal oral hygiene aids proves the optimal method of controlling plaque accumulation, whilst gingivitis can be prevented by daily toothbrushing. Indeed, by extending the period between brushing in experimental gingivitis studies it has been shown that the symptoms of gingival inflammation persist in those who brush every 2–3 days, whereas gingival inflammation resolved within a week in those who brushed every other day.

It can be concluded that there are no scientific studies to indicate that one specific manual toothbrush design is superior to another in the maintenance of gingival health, although some manual toothbrushes show benefit. Powered toothbrushes are superior to their manual counterparts in their ability to remove plaque from the approximal areas but show equality on the flat or facial surfaces of the teeth. Powered toothbrushes that are described as having a rotation oscillation movement have been shown by systematic review to reduce plaque and gingivitis by 11% and 6% respectively. There are currently no systematic review data to provide concrete 'best practice' recommendations for interproximal cleaning. The greatest improvement in personal oral hygiene can be derived from the development of motivation and aptitude. There is little evidence regarding guidelines for frequency of toothbrushing save that the minimum requirement is every 2 days to maintain health and that the common recommendation is twice per day. An oral hygiene training program has to be based on risk analysis and tailored to the individual's needs by diagnosis, education and training, and needs-related oral hygiene. High-quality mechanical plaque control can efficiently prevent initiation, as well as the recurrence, of plaque formation. Toothbrushing is one of the (many) etiological factors in hard and soft tissue abrasion, and these effects are minimized with the use of powered toothbrushes.

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