# 20
# Toothbrushes: benefits versus effects on hard and soft tissues

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## Introduction

Natural cleaning of the dentition is considered to be almost non-existent. The natural physiological forces that clean the oral cavity are insufficient to remove all dental plaque. Plaque, to be controlled, must be removed frequently by physical methods. Hence the dental community continues to encourage proper oral hygiene and more effective use of mechanical cleaning devices (Cancro and Fischman 1995). Maintenance of oral hygiene has been an objective of man since the dawn of civilization. The use of the chewing stick (Figure 20.1) to clean the dentition is an example of an ancient pre-Islamic custom that continues to be used today. Most historians trace the development of the first toothbrushes to 1498 AD in China. The Dutchman Cornelis van Solingen (1614–87) gave probably the oldest 'picture' of a toothbrush. In the 1698 edition of his book we find the picture of a toothbrush combined with a tongue-scraper (Figure 20.2). The bristle brush was reinvented in the late 18th century, and by the first part of the 20th century, in the USA a family toothbrush was


**Figure 20.1**

Primitive toothbrush (miswak or siwak).

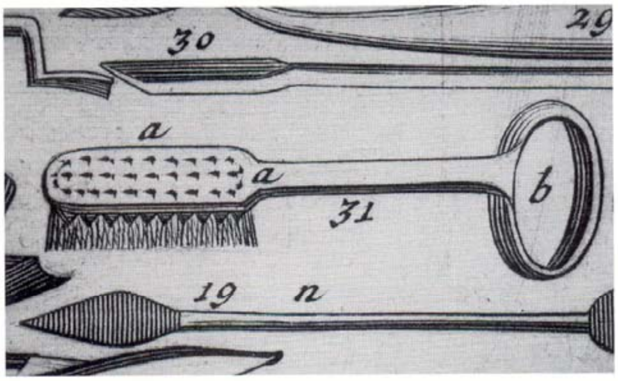



**Figure 20.2**

Toothbrush with tongue-scraper designed by Cornelis van Solingen (with thanks to Utrecht Universiteits Museum).

common even among the poor. In the late 1930s, nylon filaments began to replace natural bristles, and wood and plastic replaced bone handles. This made toothbrushes inexpensive enough for virtually everybody to own one. During the past 30 years oral hygiene has improved and in industrialized countries 80–90% of the population brush their teeth once or twice a day (Saxer and Yankell 1997) (see also Chapter 14).

## Benefit of oral hygiene

Bacterial plaque on teeth is considered the direct cause of periodontal diseases and caries. In the absence of plaque, disease will not occur. One practical approach to control both diseases simultaneously is to eliminate bacterial plaque at daily intervals (Löe 1979).

Oral hygiene will act as a non-specific suppressor of plaque mass. Such a therapeutic approach is based on the rationale that any decrease in plaque mass will benefit the inflamed tissues adjacent to bacterial deposits. This non-specific control of the periodontal microbiota is effective in the majority of cases where access to the plaque deposits is possible (Listgarten 1988). Diminishing the plaque mass, as a result of good oral hygiene, will reduce the injurious load on the tissues. Some residual inflammation may persist, but is unlikely to be of sufficient magnitude to contribute to progressive tissue destruction.

The significance of oral hygiene in the prevention of oral diseases has long been stressed in the dental literature. However, the impact of this message upon the prevalence of these diseases has been small and it is apparent that these diseases still constitute a serious problem today (Pilot and Miyazaki 1991). Proper mechanical cleansing of the teeth by brushing, flossing and/or the use of toothpicks can remove plaque thoroughly from the teeth, but correct oral hygiene techniques require an extended period of training for patient motivation and dexterity. One possible way to overcome the limitations associated with manual brushing is to develop a mechanical brushing device, and as early as 1855 the Swedish clockmaker Frederick Wilhelm Tornberg patented a mechanical toothbrush (Scutt and Swann 1975).

## Electric toothbrushes

The first electric toothbrushes came much later and were introduced in the 1960s. They provided a brush-head capable of a variety of motions driven by a power source. Over time such devices have become established as a valuable alternative to manual methods of toothbrushing. The first electric brushes mimicked the back-and-forth motion commonly used with a manual toothbrush. When first introduced there were many reports of the effectiveness of such devices. In 1986, an international workshop on oral hygiene concluded that up to that time neither powered nor manual toothbrushes removed more plaque, regardless of the brushing method (Löe and Kleinmann 1986). At that time, only what are now known as conventional electric toothbrushes were available. This first generation of electric toothbrushes had a brush-head designed as a manual toothbrush and a (combined) horizontal and vertical motion. Because of the lack of clear superiority and many problems of mechanical breakdown, powered toothbrushes fell out of favour, and during the late 1960s they gradually disappeared from the market. However, powered brushes continued to be recommended for the handicapped and for persons with reduced manual dexterity. Over the last decade a new generation of electric toothbrushes has become available and they can be conveniently categorized into two distinct types. Firstly, there has been a move towards more (oscillating) rotary action brushes, instead of the traditional side-to-side motion (Walmsley 1997). The rotary motion can be either the motion of the whole head, or of the individual tufts moving in a counter-clockwise direction. Secondly, there are brushes which operate with a brush-head motion at a higher frequency (Johnson and McInnes 1994). It has been shown that this new generation of brushes, featuring an oscillating or high frequency action, removes plaque significantly more effectively in the approximal area than do conventional manual toothbrushes (for review see van der Weijden *et al.* 1998a). This led (in the 1996 World Workshop in Periodontics) to the careful conclusion that limited evidence suggested that electric brushes provide additional benefit compared with manual brushes (Hancock 1996).

## Effects on hard and soft tissues

At the start of this century, toothbrushing was not common and was correlated with a degree of fear because of its newness. Many published papers focused on the side-effects of toothbrushes and even questioned the safety of regular use. Thompson, in 1927, described injuries to gingival margins from toothbrushing. He believed that it was better to have a diet that encouraged chewing coarse food than to brush teeth to gain tooth cleanliness (Gillette and van House 1980). In contrast, there were also many reports in support of the need for oral hygiene. Toothbrushing is now the most common means of oral prophylaxis and in the light of its potential benefits to oral health the adverse effects or damage caused by toothbrushing can be regarded as insignificant.

However, it would be an exaggeration to conclude that toothbrushing is totally harmless. It has been known for a long time that toothbrushing has some unwanted effects on the gingiva and hard tooth tissues. The simple act of cleaning away dental deposits from teeth requires that the toothbrush–dentifrice combination possesses some level of abrasivity. The filaments must have a degree of stiffness to create sufficient abrasion to dislodge plaque deposits. This stiffness has to be balanced against potential detrimental effects to dental hard and soft tissues. In the oral cavity, four tissues are at risk from the abrasive effect of toothbrushing. These are the enamel, dentine, gingival tissues and alveolar mucosa.

Three types of damage seem to predominate:

- Epithelial abrasion (Figure 20.3)
- Gingival recession with root surface exposure (Figure 20.4)
- Cervical abrasion of cementum and dentine (Figure 20.5).

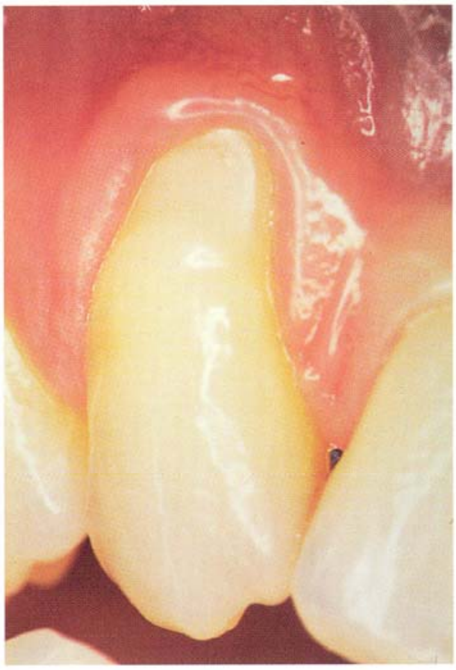


**Figure 20.4**

Gingival recession as a result of traumatic brushing.

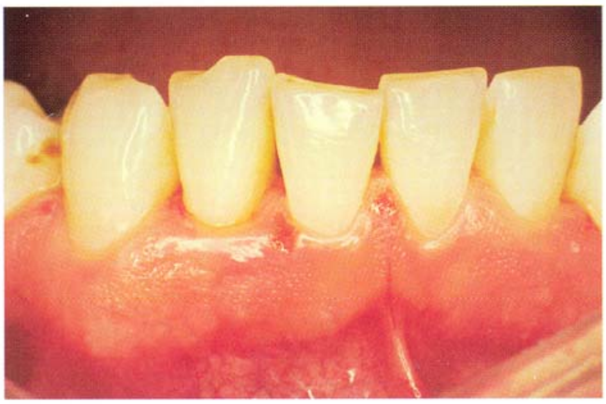


**Figure 20.3**

Gingival abrasion due to toothbrushing.

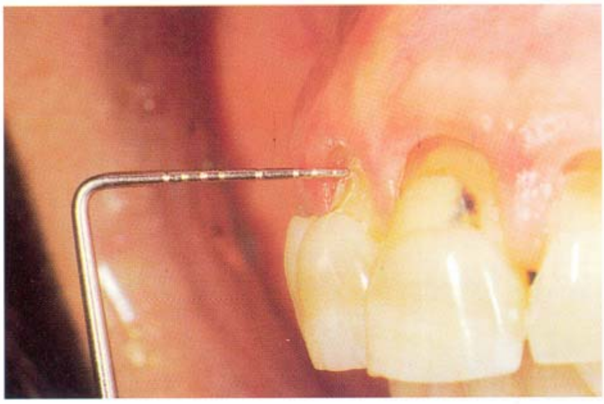


**Figure 20.5**

Cervical abrasion due to brushing.

To date, few scientific data have been available to help in understanding the risks associated with toothbrush abrasion. In particular, research into the abrasion of hard tissues is difficult. First of all the effect usually takes years to become visible. Secondly various factors have been regarded as responsible for the damage caused, namely: material-oriented factors such as dentifrice abrasivity and brush quality; and individual-oriented factors such as brushing habit, brushing frequency and the position of the teeth within the arch (Bergström and Lavstedt 1979).

Manly (1944) believed that the toothbrush causes little hard tissue abrasion compared with dentifrice. Radentz *et al.* 1976 reported cervical abrasion in exactly half their 80 subjects and they also thought that the type of dentifrice and brush had no effect on abrasion, nor did brushing technique or frequency. However, Reisstein *et al.* (1978) found that toothbrushing with dentifrice abraded cementum more than toothbrushing with a saline solution, but neither method abraded enamel.

## Effect on enamel and dentine – in vitro

Enamel is not as susceptible to toothbrush wear in vitro as less calcified structures (Bull *et al.* 1968, Stookey and Muhler 1968). Slop (1986) used an in-vitro model to investigate to what extent the enamel will wear down as a result of brushing. Although some wear was observed, there appeared to be no potential danger for extensive abrasion of enamel. The abrasivity of a modern dentifrice on enamel is such that after about 50 000 brush strokes an average layer of about 0.5 μm enamel is removed. Assuming in practice that a tooth is brushed with 25 strokes twice daily, the toothbrush/dentifrice abrasivity will remove in a life time about 10–15 μm of the 2-mm thick enamel. This suggests that toothbrushing with a dentifrice per se constitutes little risk to the integrity of the enamel. Kuroiwa *et al.* (1993) found some abrasion of enamel with a dentifrice containing abrasive; however, toothbrushing without dentifrice seemed to protect the enamel surface via the formation of a mineral protective membrane. The hardness of enamel may have some influence on the wear caused. Thus the presence of tooth erosion has been shown to increase the rate of enamel abrasion in an animal model (Attin *et al.* 1997). Dental erosion is usually attributed to such factors as the excessive drinking of fruit juices, the ingestion of medication with a low pH or working in an acid environment (Radentz *et al.* 1976). In such a case toothbrushing may increase the loss of enamel. In fact, tooth erosion can be observed even in young populations and should be considered a risk factor associated with tooth abrasion (Milosevic *et al.* 1997). A controversial theory of cervical loss enamel is that of Lee and Eakle (1984). They suggested that lateral forces can create tensile stresses that disrupt hydroxyapatite crystals in enamel, thereby allowing small molecules, such as those of water, to penetrate and render the crystals more susceptible to chemical attack and further mechanical deterioration.

As with enamel, little is known about the abrasion of dentine. This holds true for both manual and electric toothbrushes (Harrington and Terry 1964). One approach to evaluate dentine abrasion by toothbrushing has been to assess the relative dentine abrasion in vitro, using a model which has been developed at Indiana University (USA) and approved by the ADA. This method was developed primarily to assess the abrasiveness of dentifrices (Hefferren 1976, Schemehorn *et al.* 1993). To date no studies are available which specifically evaluated different manual toothbrushes with regard to dentine abrasivity; however, a number of studies have evaluated electric toothbrushes.

The results of several studies carried out in Indiana (Schemehorn *et al.* 1993, van der Velden *et al.* 1993, Schemehorn and Zwart 1996) indicate that oscillating/rotating electric toothbrushes are safe with respect to dentine abrasion. Recent studies carried out in Zurich (Imfeldt and Sener 1998a) apparently using the same model appear to contradict these findings. The origin of these differences could be the result of minor but trivial deviations from the original model and should be the object of future studies.

## Cervical abrasion – in vivo

Although the etiology of cervical abrasion is not fully understood as yet, it has become clear that

## Effect on gingiva – in vivo

Findings indicate that brushing increases the degree of keratinization of the gingiva (which in the past was considered to be protective) and that natural bristles are slightly more effective in this respect than synthetic bristles (Stahl *et al.* 1953). In an animal experiment, Plagmann *et al.* (1978) subjected guinea pigs to cleaning with two different manual toothbrushes three times weekly for 4 weeks. Depending on the brush type they found different epithelial lesions which differed in depth of the lesion. Abbas *et al.* (1990) showed that mechanical oral hygiene basically is a traumatic procedure for the periodontium. They observed increased bleeding upon probing scores shortly after oral hygiene procedures. Trauma to soft tissues can result in gingival recession (Gorman 1967, Paloheimo *et al.* 1987, Vekalahti 1989, Källestål and Uhlin 1992, Löe *et al.* 1992, Khocht *et al.* 1993, Serino *et al.* 1994) and gingival abrasion (Alexander *et al.* 1977, Breitenmoser *et al.* 1979, Sandholm *et al.* 1982). Gingival abrasion takes two forms: inflammation of the gingival margin, and inflammation of protruding areas on the gingiva away from the margin. Ulceration often accompanies both forms (Gillette and van House 1980).

Gingival recession has been related separately and collectively to alveolar bone dehiscences, inflammation, malalignment of teeth, toothbrushing, fastidious injuries, muscle pull, orthodontic tooth movement, dental trauma and iatrogenesis (Kållestal and Uhlin 1992). According to Gorman (1967) Miller stated in 1950 that gingival recession resulted from occlusal traumatism produced by overfunction and/or underfunction, improper toothbrushing and psychosomatic factors particularly associated with depression.

Gingival recession, predominantly on the vestibular tooth surfaces, is often attributed to incorrect toothbrushing technique (Sandholm *et al.* 1982). Findings that individuals with recession have lower mean plaque and mean gingival inflammation scores than individuals without recession support this hypothesis (Niemi 1987). Lesions are seldom seen on lingual and approximal surfaces; they tend to be more pronounced in the cervical regions of incisors, canines and premolars (Sangnes and Gjermo 1976). Furthermore, it has been observed that such defects are more prevalent in the maxilla than in the mandible.

In an adult population, subjects with thin gingival tissues may be more susceptible to gingival recession than subjects with thick gingival tissues (Olsson and Lindhe 1991). In older individuals, gingival recession is more prevalent and tends to show a generalized pattern, perhaps as the combined consequence of loss of attachment due to periodontal disease and the presence of calculus and toothbrushing trauma (Serino *et al.* 1994, van Palenstein Helderman *et al.* 1998). Kalsbeek *et al.* (1996), in a study on oral health in Dutch adults, found a positive relationship between age and mean number of roots exposed to the oral cavity. In the age category 45–54 years this number (8.6 surfaces) was approximately 2.5 times higher than for those 25–34 years of age (3.4 surfaces). In a study among a group of subjects aged 18–65 years Khocht *et al.* (1993) also observed that the proportion of subjects with recession increased with age. Recession was also found to be more pronounced for subjects with a history of hard toothbrush use. The association with age does not necessarily suggest a physiological effect of ageing on recession. It may just reflect the fact that older people have been subject to the force of brushing and irritant effects of plaque for a longer period (Joshipura *et al.* 1994). Paloheimo *et al.* (1987) observed in a Finnish adolescent population that recession was associated with the length of service life of the toothbrush and with the toothbrushing technique.

Predictions that the increase in recession due to toothbrushing would result in an increase in the incidence of root caries in countries such as Finland, Switzerland and the Netherlands have not come true (König 1990, Mierau 1992). The problem seems to be replaced by another problem, that of cervical and V-shaped abrasions (König 1990).

## Electric toothbrushes and gingival abrasion

As most of the previously published studies regarding gingival abrasion due to toothbrushing and the resultant gingival lesions predate the introduction of electric toothbrushes, less is toothbrushing plays an important part. Only a few studies concerning cervical lesions due to toothbrushing have been reported in the dental literature. The lack of control of the frequency and force of brushing and also the exact criteria for the observations do not permit definite conclusions to be drawn. In a large epidemiological study Bergström and Lavstedt (1979) investigated the prevalence and severity of abrasive lesions in the light of individual toothbrushing technique and toothbrushing frequency and also of the stiffness of the toothbrush and abrasivity of the dentifrice. They differentiated between superficial and deep cervical lesions. Of the sample taken from a population in Sweden (aged 18–65 years) 31% of the subjects exhibited either superficial or deep lesions, of whom 12% had deep lesions. There appeared to be a slight predominance for the left side in both jaws. A strong correlation to abrasion was found for the variable brushing techniques (horizontal, vertical, roll, or combination) and brushing frequency (number of times per day), whereas the influence exerted by bristle stiffness (soft, medium, hard) and dentifrice abrasivity (low, medium and high) were rather weak. The age of the subject exhibited the strongest correlation to abrasion, where age may be interpreted as an expression for the toothbrushing consumption of the individual.

Toothbrush abrasion is usually located at the cervical area on the facial surfaces of teeth prominent in the arch. Premolars and canines are most commonly affected, second and third molars are least affected. The notch-shaped lesion usually begins at the cemento–enamel junction and extends a short distance apically. Extensive lesions can involve the pulp. Lesions are initiated by horizontal brushing with a brush with firm bristles. Although not all studies agree, contributory factors seem to be time, force of application, dentifrice and prominence of the tooth in the arch. Abrasion occurs only in the presence of gingival recession, also probably caused by the brushing technique where the cemento–enamel junction becomes exposed. Occasionally, multiple parallel grooves are present rather than just one groove. Cervical hypersensitivity may accompany the lesion (Gillette and van House 1980) (see Chapter 21).

Sangnes and Gjermo (1976) observed concomitant gingival and dental lesions in the same individual in more than half of the cases studied, indicating a common etiology. However, some cases with hard tissue lesions but no retraction of the gingiva were also observed. This suggests that individual factors in the oral environment may influence the development of the lesions.

## Effect on soft tissue – in vitro

To date there have been few if any in-vitro models to assess the possible damaging effects of toothbrushes on soft tissues and certainly none that could be reliably extrapolated to clinical outcome. Human skin, mucosa or gingiva can be obtained, but tissue from animals is more readily available in in-vitro studies (Addy 1998). Alexander *et al.* (1977) studied the effect of toothbrushing on soft tissue abrasion by assessing the amount of protein removed during brushing of hamster cheek pouch tissue. They found that with increasing brushing pressure and number of strokes, there was a corresponding rise in the amount of tissue protein removed. They concluded that their method was sensitive in detecting the effects of brush load, number of strokes applied and the texture of the brush.

More recently a model was introduced by Imfeldt and Sener (1998b) in which a dead pig jaw is brushed for a specified amount of time with different brushing forces. Several concerns have to be expressed about such a model. Firstly, the reproducibility of the system has not been addressed as yet, and standardization problems can be envisaged. Secondly, it is difficult to translate this model back to the situation in vivo, as brushing at a specific spot for >30 s would implicate a brushing time of at least 14 min, which is not common daily practice (for review see van der Weijden *et al.* 1993). Thirdly, because the model employs non-vital tissue, it does not have natural defence systems nor the normal potential for repair. Therefore the relevance to the clinical situation in vivo must be questioned. The same criticisms also apply to the model introduced by Alexander *et al.* (1977). Therefore both models offer only the possibility of evaluating the relative gingival abrasive potential of brushes, which may be useful while developing new designs. True in vivo studies are needed to assess the effect in the clinical situation.

known about the abrasive potential of automated brushing. From related studies, however, it would appear that electric toothbrushes should be at least as safe as a manual toothbrush. Indeed it has been shown that the brushing force applied by users of an electric toothbrush is lower than that applied with a manual toothbrush (van der Weijden *et al.* 1996b, Boyd *et al.* 1997).

The old generation of powered toothbrushes was effective and generally did not cause gingival abrasion because of low power exerted on the handle and because of the stop mechanism when excessive force was applied. However, these brushes functioned for relatively short time periods and were generally not used after the initial 'novelty' had worn off. Studies have looked at the number of gingival abrasions that have occurred with the use of a conventional electric toothbrush and compared their occurrence to the potential damage caused by manual toothbrushing by means of visual scoring (Niemi *et al.* 1986). Results demonstrated a greater number of abrasions following use of the manual brush. Walsh *et al.* (1989) found no differences between electric and manual toothbrushes with respect to gingival abrasion. However, in their study, subjects brushed at home; therefore the brushing time, the brushing pressure and the brushing method may have differed.

In most studies, plaque removal by the new generation of powered toothbrushes is greater than that by manual brushes (Walmsley 1997). Some studies have found a reduction in gingival inflammation and most have found that gingival abrasion is usually not present or minimal. Nevertheless, long-term outcomes regarding gingival abrasion with modern electric toothbrushes require further investigation (Saxer and Yankell 1997).

A sonic brush, which has a high frequency action, has been subjected to safety testing in dogs (Engel *et al.* 1993). It appeared that after brushing for 7.5 min daily for 2 months, no damage was evident on clinical or histological examination.

Recently Danser *et al.* (1998a) conducted a study to establish the incidence of gingival abrasion as a result of toothbrushing, using a manual toothbrush and an oscillating/rotating electric toothbrush. In agreement with Walsh *et al.* (1989) the results showed no differences in the amount of gingival abrasion caused by either the electric or manual brushes using standardized brushing time and procedures.

Grossman *et al.* (1996), in a comparative clinical study of stain removal with two oscillating/rotating electric toothbrushes, also found no evidence of soft or hard tissue abrasion in either group. Similarly, Cronin *et al.* (1998), reporting on a 3-month clinical study with an oscillating/rotating reciprocating electric toothbrush and a manual toothbrush, found that soft tissue abrasion was negligible and clinically insignificant in both groups. In a study testing another oscillating electric toothbrush, none of the brushes – including a manual – exhibited any propensity for injury or harm to the subjects' oral tissues beyond that transiently associated with the use of new toothbrush filaments (Khocht *et al.* 1992).

In two longitudinal investigations using two different oscillating/rotating toothbrushes, the indirect effect on the gingival tissues was studied. Neither brush caused more gingival abrasion than was observed with a manual toothbrush (Wilson *et al.* 1993, van der Weijden *et al.* 1994). Wilson *et al.* (1993) also measured gingival recession. They observed that neither the manual nor electric toothbrush group developed significant changes in the level of gingival recession over the 1-year study period.

In a 1-year study with a rotating action electric toothbrush the participants lost 0.12 mm attachment level on the buccal sides, whereas the manual toothbrush lost only about 0.05 mm (Boyd *et al.* 1989). These differences were not statistically significant, although 0.1 mm attachment loss in 1 year was higher than the epidemiological average in patients in a prophylactic programme (Saxer and Yankell 1997).

## Morphology and histology of gingival lesions

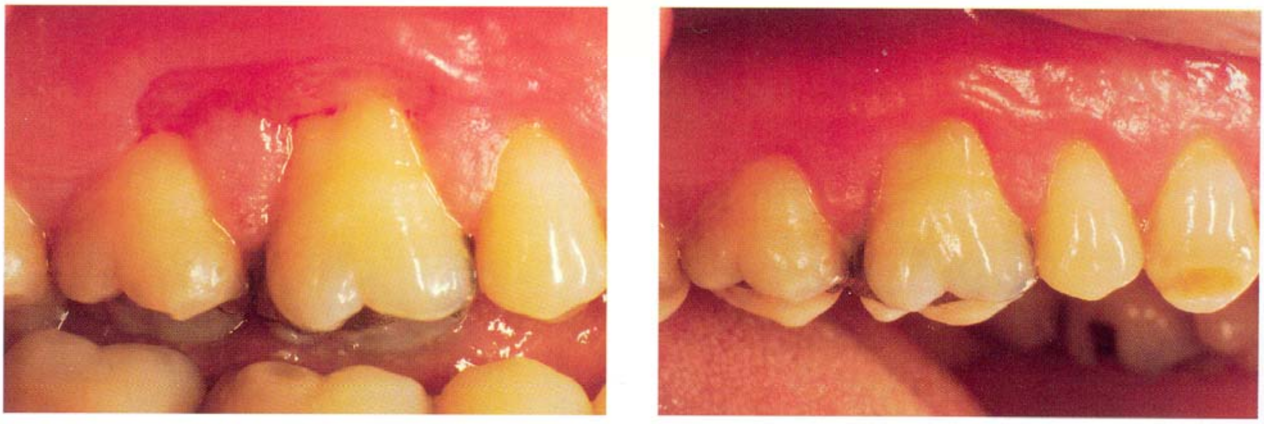
Baker and Seymour (1976) suggested a localized inflammatory process as an etiological factor for gingival recessions. They speculated that the inflammatory reaction causes breakdown of the connective tissue leading to proliferation of the epithelium into the site of connective tissue destruction. This process would involve tissue remodelling, leading to gingival recession. This remodelling process is particularly likely to occur where the tissue is thin. The histological evidence from sections taken from broad recession areas tends to confirm the hypothesis that destruction of the intervening connective tissue cores more easily permits penetration of a proliferating dento-gingival epithelium until such time as the dento-gingival and oral epithelia coalesce. Loss of proper nutrition to the enlarged epithelial layer enhances loss of adhesiveness and/or physical removal (Smuckler and Landsberg 1984).

Not all damage is found in one form. Puncture wounds are observed as microhemorrhagic lesions, usually localized on the buccal aspect of the free gingiva or the interdental papilla. Generally only the superficial epithelial cell layers are damaged. Scratches are erosive lesions, generally extending along the marginal gingiva, with no involvement of the subepithelial connective tissue. The abrasion lesion is superficial; sometimes only the most superficial layers of the keratin are torn from the underlying cellular layer. Ulceration is described as tissue damage extending beyond the superficial epithelium and involving the subepithelial connective tissue. When the total thickness of the gingiva is destroyed and the root is evident, the lesion is a fenestration. These lesions are significant clinically because of their esthetic component. The traumatic toothbrushing lesions that are superimposed on a pre-existing gingival recession may act as an exacerbating factor in the extension of tissue damage (Figure 20.6). Impacted foreign materials such as toothbrush bristles (Agudio *et al.* 1987) may cause acute abscesses in gingival tissues.

Gingival lesions can be restricted to the superficial epithelium, thus damaging only the keratinized superficial layer of the epithelium, or they may proceed more deeply to involve the basal layer and the underlying connective tissue (Figure 20.7).

## Diagnosis of gingival abrasion

Systems for classification of lesions related to mechanical tooth cleansing procedures, with proper consideration of differential diagnostic problems, are scarce. Sangnes and Gjermo (1976) pointed out that pockets generally associated with gingival recession are shallow. Recessions in areas with pocket depths of ≤ 1 mm are considered to be related to habitual toothbrushing (Sangnes and Gjermo 1976).



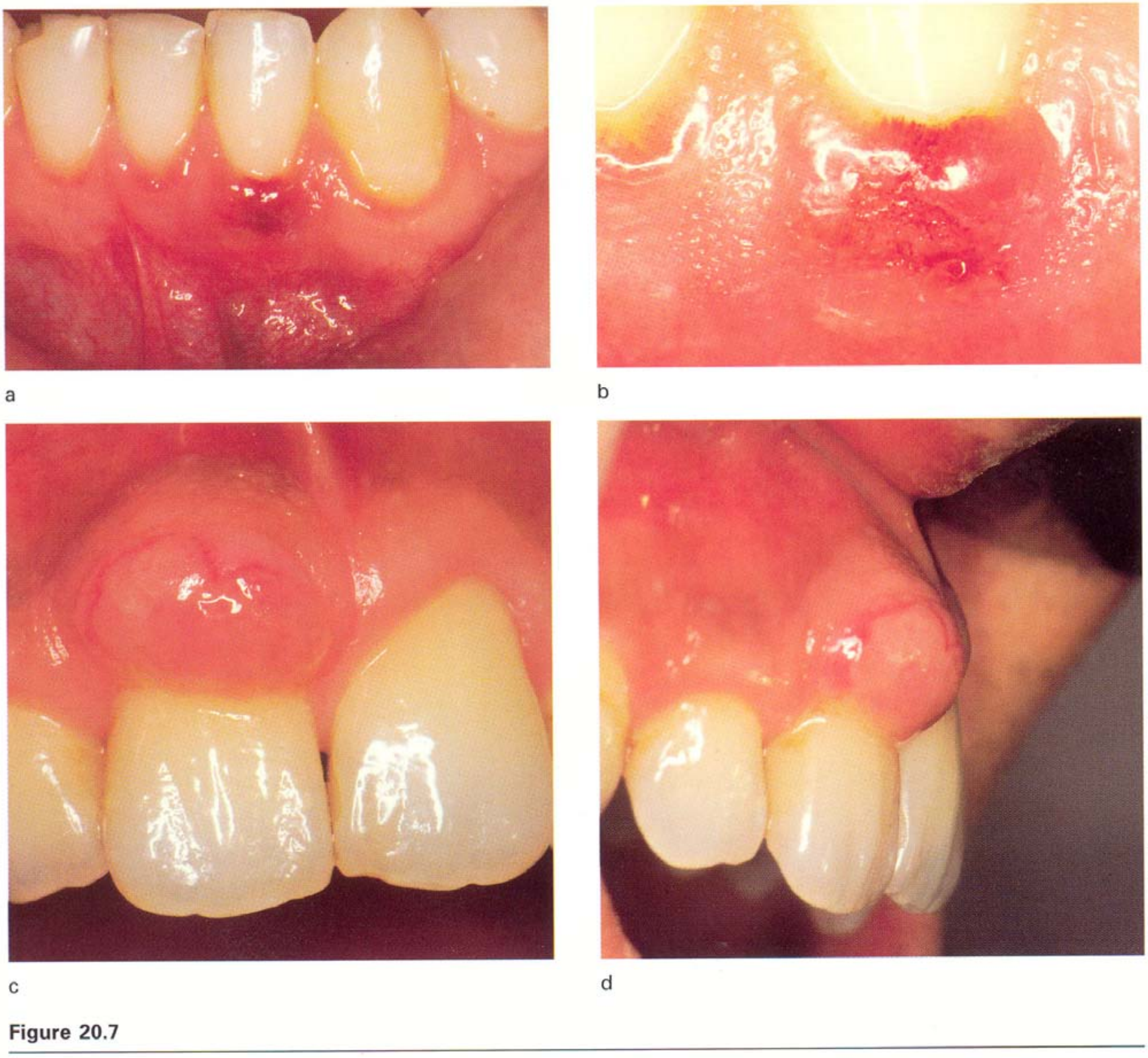
a b

**Figure 20.6**

*a* An example of traumatic ulcerative gingival lesions.
*b* The same site shown after a period of 2 weeks of non-brushing but rinsing with chlorhexidine.

Diagnosis of toothbrushing recession is based on the localized nature. Usually on the facial surface and frequently V-shaped, recession often occurs in association with toothbrush abrasion of the tooth surface.

Gillette and van House (1980) have described a dental classification for injuries of this type which result from improper oral hygiene measures. Their classification is based upon source of injury, site of occurrence and potential side-effects. Gingival lesions, possibly caused by toothbrushing, may be classified in terms of three groups: laceration, gingival recession and hyperplasia, especially hyperkeratinization. Laceration



a b c d

**Figure 20.7**

*a* and *b* Hematoma as a result of traumatic brushing. The patient presented as shown the morning after he had started brushing with a new toothbrush.
*c* and *d* Irritation fibroma as a result of traumatic brushing. The patient had a site with toothbrush trauma and continued brushing this site vigorously for 3 months to get rid of the irritation, which resulted in the situation illustrated here.

or ulceration of gingival tissues is usually recognized as an acute mechanical trauma, whereas gingival recession and hyperplasia are thought to be characteristics of chronic lesions.

Compared with clinical classification of gingival trauma, scanning electron microscopic (SEM) evaluation has been shown to be a more reliable method for further studying these lesions (Sandholm *et al.* 1982). A study by Sandholm *et al.* (1982) revealed that brushing may in many cases result in moderate to severe abrasion of the gingiva. All subjects participating in their study were brushed by one dental hygienist using hard and soft manual toothbrushes. Clinical evaluation (visual) and SEM findings were found to correlate significantly, although discrepancies between the two classification systems were observed. Niemi *et al.* (1986) investigated gingival injury caused by standardized brushing. One examiner scored the visible gingival abrasion and the consistency of this examiner was ascertained to be 90% compared with SEM analysis. For SEM assessment of gingival abrasion, replicas based on silicon rubber-based impressions are taken.

Three types of gingival lesions have been described using SEM and categorized as follows (Sandholm *et al.* 1982) (Figure 20.8):

- Type 1. Erosion of the epithelial surface at the gingival margin, with the appearance of a ribbon or a patch-like surface defect, or a diffuse border at the gingiva–tooth interface caused by bleeding or oozing of tissue fluid from the eroded area.
- Type 2. Epithelial; surface 'flap' turned or rolled up leaving the underlying tissue uncovered.
- Type 3. Rupture or fenestration of the surface epithelium in the middle of a prominent but otherwise healthy gingival area.

Breitenmoser *et al.* (1979) investigated the use of a disclosing agent for the identification of gingival abrasions. They found that a commercially obtained plaque disclosing solution could give excellent staining of the lesions and they could be distinguished easily from normal gingiva (Figure 20.9). In a recent study, it was found that before staining the gingiva small sites of abrasion were not visible with clinical evaluation (Danser *et al.* 1998b). A background incidence of toothbrush abrasion, which can be observed with a disclosing agent, is a normal response to brushing.

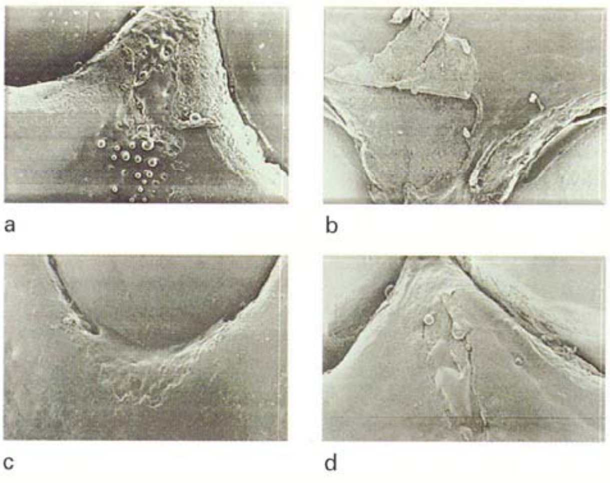


**Figure 20.8**

Gingival lesions (taken from Sandholm *et al.* 1982).

*a* Type 1 lesion.
*b* and *c* Type 2 lesions.
*d* Type 3 lesion.

**Figure 20.9**

Example of sites with gingival abrasion after brushing by panellists, made visible after disclosing with Mira-2-Tone®. Small and large sites of abrasion can be seen.

In another study (Danser *et al.* 1998b), the incidence of abrasion after brushing with a manual and an electric brush and with two electric brushes with different bristle end-roundings was evaluated. In these two tests the incidence of sites of abrasion post-brushing was larger in the first phase (manual and electric brush) of the study than in the second phase (two electric brushes). However the pre-brushing scores in both parts were comparable. This indicates that the way the subject brushes is probably important and influences the observed effect.

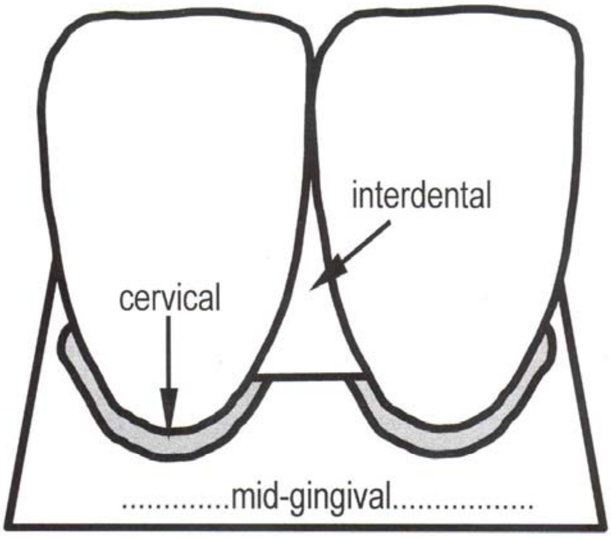



**Figure 20.10**

Diagram showing the division of the tooth-related soft tissues into three areas for the assessment of gingival abrasion: cervical, interdental and mid-gingival.

## Clinical investigations using staining

One of our first studies with a two-tone disclosing solution compared the number of gingival abrasions with oscillating/rotating and sonic electric toothbrushes (van der Weijden *et al.* 1996a).

The results with regard to abrasion are presented in Table 20.1. No difference in either large or small gingival abrasion sites was observed between the two brushes. Based on the results of this experiment two main questions arose:

- Is there a baseline level of abrasion after 24–48 h of non-brushing?
- What is the level of abrasion when brushing with a manual toothbrush?

To investigate these questions another study was carried out. One of the objectives was to establish the potential of manual and electric toothbrushes to cause gingival abrasion. Plaque and gingival abrasion were assessed by means of a two-tone solution. The tooth-related soft tissues were divided into three areas: cervical, interdental and mid-gingival, as shown in Figure 20.10. The subjects brushed their teeth in a random split-mouth order with two electric brushes, using brush-heads of the same design. The gums were redisclosed and gingival abrasions were recorded. The mean gingival abrasion scores for the electric toothbrush and the manual brush at baseline for sites ≤5 mm were 2.67 and 2.43 respectively and for sites >5 mm it was 0.82 for the electric and 0.49 for the manual brush (Table 20.2). The difference between the brushes was not significant. No

**Table 20.1** Gingival abrasion was scored as small ≤5 mm or large sites >5 mm.

| *Site* | *Oscillating/rotating brush* | *Significance* | *Sonic brush* |
|---|---|---|---|
| Small sites | 1.71 (2.86) | NS | 2.00 (2.60) |
| Large sites | 0.09 (0.37) | NS | 0.06 (0.34) |

Standard deviation in parentheses.

**Table 20.2** Gingival abrasion was scored as small ≤5 mm or large sites >5 mm (Danser *et al.* 1998a).

| *Sites* | *Manual brush* | *Significance* | *Electric brush* |
|---|---|---|---|
| Small sites | | | |
| pre-brushing | 2.43 (3.00) | NS | 2.67 (2.69) |
| post-brushing | 3.45 (3.10) | NS | 3.55 (2.99) |
| Large sites | | | |
| pre-brushing | 0.49 (0.94) | NS | 0.82 (1.51) |
| post-brushing | 0.20 (0.57) | NS | 0.35 (0.80) |

Standard deviation in parentheses.

relationship between efficacy and the incidence of gingival abrasion was observed for both the manual versus electric brush. This suggests that within this study design, effective brushers are not more prone to gingival abrasion.

In a single-use study gingival abrasion with the oscillating/rotating was compared with the oscillating/rotating/reciprocating electric toothbrush. The mean number of small traumas increased from 2.57 at baseline to 4.04 after brushing with the oscillating/rotating brush and from 1.98 to 4.14 after brushing with the oscillating/rotating/reciprocating brush. There was no statistically significant difference between the two groups. For both toothbrushes, more small traumas were found in the upper jaw compared with the lower jaw. No increase in the number of large traumas was observed (Table 20.3).

## Toothbrushing force

Several experimental and clinical studies support the assumption that excessive force in brushing is partly responsible for the origin of toothbrush trauma (Arnim and Blackburn 1961, Alexander *et al.* 1977, Niemi *et al.* 1987). Mierau and Spindler (1984) observed that in a group of subjects without recession the mean brushing force with a manual toothbrush was 2.12 N (± 0.31) whereas a group with multiple recession had a mean force of 3.75 N (± 0.47).

In the past a number of studies have assessed toothbrushing force and shown a significant variation in the magnitude of forces (e.g. Phaneuf *et al.* 1962, Fraleigh *et al.* 1967). Some of the differences appear to be related to the research method, brushing technique and variation in brushes. The 'average brushing force' has been reported to range from 92 to 175 g for electric toothbrushes and 318 to 471 g for manual brushes (Phaneuf *et al.* 1962, Fraleigh *et al.* 1967). Fraleigh *et al.* (1967) reported a mean force of 167 g with an electric toothbrush in the age group 16–25 years. More recently McLey and Zahradnik (1994) investigated brushing force with electric and manual brushes. They showed that less force was used with the electric brushes as compared with a manual toothbrush (N = 296 g). When a comparison was made between the habitual brushing force with two different oscillating/rotating toothbrushes (van der Weijden *et al.* 1995), the brushing forces were 173 g and 175 g respectively.

Burgett and Ash (1974) argued that the potential detrimental effect of brushing is related to the force applied at a particular point, which is actually pressure. As the forces are given as a total of the force over the entire brush, the unit pressure is less for smaller brush-heads.

Another study evaluated the habitual brushing force which individuals use with various toothbrushes (van der Weijden *et al.* 1996b). Besides a manual toothbrush, three electric toothbrushes were examined. The results showed that considerably more force is used with a manual brush than with the electric brushes, the difference being >100 g. Considering all these findings, there appears to be a range of forces used (e.g. 95–173 g), but they also show a specific trend that less force is used with electric toothbrushes as compared with manual toothbrushes. These results may have significance for the long-term integrity of oral hard and soft tissue exposed to various brushing devices.

**Table 20.3** Gingival abrasion was scored as small ≤5 mm or large sites >5 mm. (Danser *et al.* 1998b).

| *Sites* | *Oscillating/rotating reciprocating brush* | *Significance* | *Oscillating/rotating brush* |
|---|---|---|---|
| Small sites | | | |
| pre-brushing | 1.98 (2.06) | NS | 2.57 (2.59) |
| post-brushing | 4.14 (3.24) | NS | 4.04 (3.10) |
| Large sites | | | |
| pre-brushing | 0.37 (0.81) | NS | 0.43 (0.68) |
| post-brushing | 0.39 (0.81) | NS | 0.47 (0.77) |

Standard deviation in parentheses.

## Force and efficacy

A recent survey investigated the association between the efficacy of plaque removal and toothbrushing forces during a normal brushing regime (van der Weijden *et al.* 1998b). Brushing force has been measured using a computer set-up. A double strain gauge was glued to the handle of the toothbrush (Figure 20.11). The mean plaque reduction was 39% and the mean brushing force was 330 g. No correlation was observed between efficacy and brushing force. Multiple regression analysis entering squared values of force as an independent variable into the equation indicated that the relationship between efficacy and force was not linear. A curve could be fitted to the plot, demonstrating that up to a certain level of force an increase of force is associated with an increase in efficacy. Beyond this point, application of higher forces resulted in reduced efficacy. As was calculated in this particular test, this 'transition' level of force was 407.4 g.

Another study examined the relationship between brushing force and plaque removal efficacy comparing a regular manual toothbrush with an electric toothbrush. Different brushing forces were evaluated (100, 150, 200, 250 and 300 g). The results showed that when brushing force is increased, more plaque is removed with both of the two brushes (van der Weijden *et al.* 1996b).

Hasegawa *et al.* (1992) evaluated the effect of different toothbrushing forces on plaque reduction by brushing with 100 g intervals on a scale from 100 to 500 g. The results of their study corroborate the findings of the above study (van der Weijden *et al.* 1996b) and earlier studies (White 1983), that with increasing force more plaque is removed. In addition they observed that 300 g seems, for both children and adults, the most effective brushing force when using a manual toothbrush. Forces exceeding this 300 g caused pain and gingival bleeding.

Another investigation evaluated the habitual brushing force which individuals use with various toothbrushes (van der Weijden *et al.* 1996b). A manual toothbrush and three electric toothbrushes were examined. The results showed that considerably more force (273 g) is used with a manual brush than with the electric brushes (96–146 g). No significant relationship between brushing force and plaque removal was demonstrated for any of the brushes. This indicates that brushing force is not the sole factor in determining efficacy.

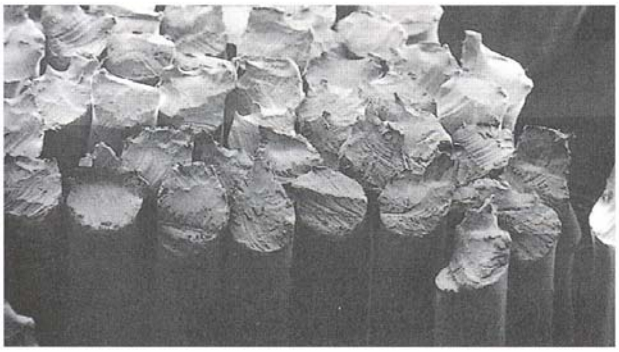


**Figure 20.11**

Non-end-rounded bristles (taken from Silverstone and Featherstone 1988).

## Force and gingival abrasion

Danser *et al.* (1998a) conducted a study in order to assess whether the brushing force used is correlated to the incidence of gingival abrasion. The mean force of brushing was 169 g. The mean maximum scores ranged between 54 and 304 g. Multiple regression analysis showed no correlations between toothbrushing force and the incidence of gingival abrasion. This indicates that other factors (e.g. brushing itself, tooth anatomy, bristle form, brush-head, brushing time and manual dexterity) appear to be more important than the force used with an electric brush. The results disagree with several experimental and clinical studies which support the assumption that excessive brushing force is partly responsible for the origin of toothbrush trauma (Arnim and Blackburn 1961, Alexander *et al.* 1977, Niemi *et al.* 1987). The average force used with the electric brush in this study was 169 g. There seems to be a specific trend that the average brushing force for powered brushing is significantly less than the force usually used in manual brushing (Phaneuf *et al.* 1962, Niemi *et al.* 1986, 1987, van der Weijden *et al.* 1996b).

## Force control

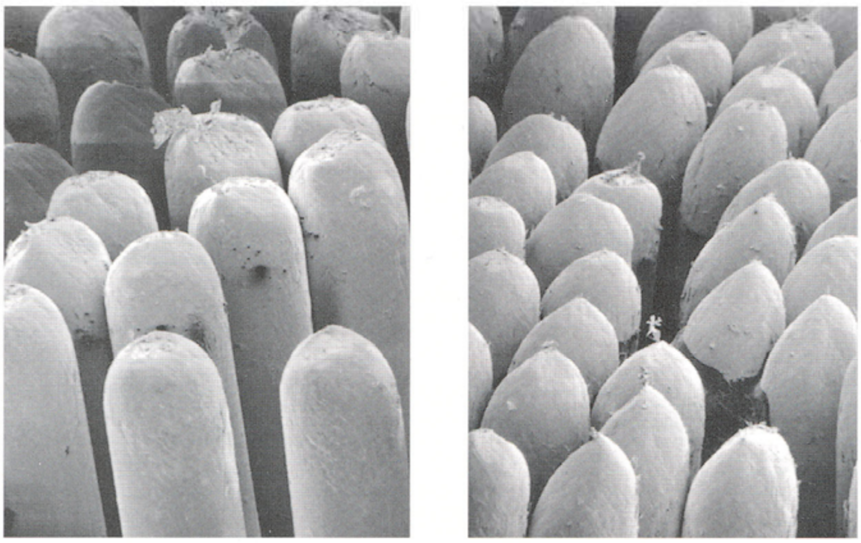
Manual and electric toothbrush manufacturers have introduced toothbrush designs which would limit the amount of force used in order to reduce the chance of damage to soft and hard tissues (e.g. Soparker *et al.* 1991, van der Weijden *et al.* 1995). With the electric toothbrush, the level of force at which the feedback system should work has been debated. One brush manufacturer has set the level at 350 g (van der Weijden *et al.* 1995), which apparently did not reduce the mean force used while brushing. The results of a recent study (van der Weijden *et al.* 1998b) indicate that with the tested manual brush approximately 400 g was the optimal level. Applying more force would result, on average, in less effective brushing. A force indicator could therefore be set at such a level.

## Filament stiffness and end-rounding

Tests in vitro using a variety of substrates including dentine suggest that the use of a toothbrush alone would have insignificant abrasive influences on dental hard tissues. Concerns over filament stiffness have therefore concentrated on potential damage to adjacent soft tissues, namely the attached gingiva and alveolar mucosa.

Toothbrushes are primarily designed to remove plaque from accessible tooth surfaces. To achieve this the filaments must have a degree of stiffness to create sufficient abrasion to dislodge plaque deposits. This stiffness has to be balanced against potential detrimental effects on dental hard and soft tissues. The determination of filament stiffness can be obtained mathematically using filament diameter and length, together with the modulus of elasticity of the filament material. Alternatively, an instrument has been designed to provide the grading of stiffness for brushes (Addy 1998).

Despite wide acceptance of the need for end-rounded bristles and the fact that grinding and polishing bristle tips is common practice, studies have found many differences in the bristle shapes (Adriaens *et al.* 1985, Silverstone and Featherstone 1988, Dellerman *et al.* 1994). Breitenmoser *et al.* (1979) evaluated the effect of bristle end form on the gingival surface. They found that manual toothbrushes with cut bristle ends (Figure 20.12) resulted in significantly greater gingival lesions than rounded ends using an average brushing force of 500 g. This is in agreement with other observations (Lange 1977).



a b

**Figure 20.12**

*a* 'Roman'-shaped end-rounding of toothbrush bristles.
*b* 'Gothic'-shaped end-rounding of toothbrush bristles.

A clinical trial that attempted to investigate the relative merits of cut-end and round-end bristles found no advantage in the round-end over the cut-end either in terms of keratinization or in the production of gingival abrasion and hyperemia (Breitenmoser *et al.* 1979). More recently, the end-rounding of the nylon bristles of widely used toothbrushes was compared and significant differences between the brands were reported (Mulry *et al.* 1992, Dellerman *et al.* 1994). The clinical relevance of these findings has yet to be substantiated.

In a recent study different levels of end-rounding were compared (Danser *et al.* 1998a). Both bristle types used in this study, had different styles of end-rounding (Figure 20.13). The 'roman'-shaped and the 'gothic'-shaped end-rounding are the two extreme end-roundings that can be produced. The gothic-shaped end-rounding resulted in more small sites of gingival abrasion than the roman-shaped end-rounding. For the toothbrushing exercise in this study a new brush-head was used every time. This implies that for the experiment a maximum possible abrasive effect was scored. However, it is questionable whether these types of end-rounding will remain when the brush is used daily. It has been found that sharp-edged bristle ends become rounded and less sharp with prolonged use. The results of a study by Kreifeldt *et al.* (1980) suggest that usage of a brush will change the original end-rounding due to wear. They observed that bristles of used toothbrushes in many instances show a tapering, proceeding from the insertion to the free end. Massassati and Frank (1982) observed that new synthetic bristles with some minor manufacturing defects improved with use, producing smooth rounded bristles. It appeared that bristle ends were in a better state of preservation for hard nylon as a function of use.

**Figure 20.13**

Brush-head equipped with a strain gauge.

## Dentifrice abrasiveness

It is generally agreed that the toothbrush alone does not have an abrasive effect on the tooth surfaces (Massassati and Frank 1982), but that abrasiveness depends mainly on the properties of the dentifrice. A large variety of dentifrices are available to the general public. These products contain a number of ingredients, but common to most are two ingredients which could cause tooth substance loss, namely detergents and abrasives. Dentine abrasion (RDA) and enamel abrasion (REA) values for commercial dentifrices vary widely from dentifrice to dentifrice (Barbakow *et al.* 1989). Adequate tooth cleansing can be achieved by brushing with a toothbrush only (Mooser 1959, Beyeler and Mooser 1960), but this does not prevent brown stain formation (Kitchin and Robinson 1948). A dentifrice containing adequate abrasives is needed to ensure faster removal of bacterial plaque and prevention of stain formation (Lobene 1968). Use of a dentifrice can also reduce the brushing time by 20–40% (Beyeler and Mooser 1960).

In assessing the safety of toothbrushes for hard tissues it would not seem unreasonable to consider this in the context of the interaction with dentifrice. For example, it might be expected that a hard brush tested with a standard paste would cause more abrasion of the substrate than a soft brush. Preliminary data, however, do not support this contention and filament stiffness appears not to be directly related to abrasion by a standard dentifrice. Consideration of this apparent anomaly in the light of polishing and abrasion of other surfaces makes the finding less surprising. Thus, polishing and/or abrasion of surfaces either employs materials of similar or greater hardness than the surface or a vehicle to carry a polishing agent.

One of the areas of concern has been the abrasiveness of the dentifrice. Miller conducted the earliest known study in 1907. His pioneer in-vitro work on the abrasive effect of dentifrices demonstrated the damage that dentifrices could cause to the enamel and dentine. By 'cross-brushing' the labial surfaces of extracted teeth with different dentifrices, he demonstrated an abrasive action on both enamel and dentine. Abrasives in dentifrice should preserve the tooth structure as much as possible (Baxter *et al.* 1981).

In studying dentifrices, it must be noted that the material is diluted to about 33% concentration by saliva (Manly 1944), and such allowance has to be made when evaluating abrasiveness of dentifrices in vivo. The amount of dentifrice applied to a particular brush may also contribute to the abrasion potential (Harte and Manly 1976). Beyeler and Mooser (1960), in a study of subjects with 'perfect' oral hygiene, showed that tooth abrasion and gingival injuries can be caused by the abrasive components of dentifrices.

Niemi *et al.* (1984) showed that a modest increase in plaque removing efficacy could be obtained with increasing stiffness of the toothbrush bristles and with increasing abrasiveness of the dentifrice. However, this increase in efficacy is accompanied by increased damage caused to the gingival tissues. Especially highly abrasive tooth powder seemed to cause more abrasion.

Radentz *et al.* (1976) observed that cervical abrasion is related in some way to a factor or factors associated with the initial stages of the toothbrushing procedure. The evidence, furthermore, demonstrates that an excessive use of undiluted dentifrice, habitually placed in the same area of the mouth, may produce abrasion. In view of this, it would seem prudent to advise patients to use decreased quantities of dentifrice and to initiate the brushing procedure on the occlusal surfaces of the teeth to effect a dilution of the dentifrice. The same effect might be accomplished by alternating the initial placement of the brush between the quadrants to distribute the abrasive effect more evenly.

## Systemic effects

Bacteria may enter the bloodstream during certain oral hygiene measures, especially in patients with advanced chronic gingival disease. The rate of occurrence is unknown because conflicting results have been found in different studies. These bacteremias are of concern to patients who have rheumatic heart disease, prosthetic heart valves, prosthetic joints and renal dialysis shunts, or fistulas used in renal disease. The ability to predict bacteremia after toothbrushing, flossing, gingival stimulation and oral irrigation remains elusive (Gillette and van House 1980).

## Final statements

There are numerous oral hygiene products, including toothbrushes, which reasonably should be evaluated for safety. However, the safety of brushes for hard and soft tissue in vivo is difficult to assess for many reasons. Firstly, tooth wear and gingival recession have multifactorial etiologies and are further complicated, almost certainly, by a variety of predisposing factors which may be anatomical, physiological or pathological. In addition, both conditions are slow to develop, and measurement techniques that could be applied in the mouth are in the main too imprecise to detect minor changes. This obviates short-term evaluations, where some attempt to control for other variables might be attempted.

Superficial cervical abrasion is so common in dentally aware subjects that it may be an inevitable minor side-effect of practising oral hygiene as recommended by the dental profession. Deep lesions or wedge-like defects, however, are undesirable. They probably reflect faulty toothbrushing habits, which may be not only ineffective for preventing disease, but also may cause damage to oral tissues. It seems fair to conclude that the possibility of developing such lesions on the teeth or the gingiva should not prevent dental professionals from recommending meticulous mechanical oral hygiene in the prevention of dental diseases. However, research on the specific aetiological factors involved in the development of the various lesions is desirable in order to reduce their frequency and severity.

If the unwanted effect of toothbrushing is unavoidable and concomitant with the efforts of maintaining oral health it may be regarded as acceptable. But, on the other hand, if abrasion lesions are the result of inadequate brushing habits, which also have unsatisfactory cleansing effects, this cannot be accepted and must be considered when recommending toothbrushing technique, so that people may be furnished with appropriate prophylactic measures that are effective for oral cleanliness but still harmless to oral tissues.

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