A study on the plaque removal efficiency of new and worn toothbrushes

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I. Introduction

Increased plaque accumulation is associated with gingivitis[1] and if not adequately removed may lead to periodontitis.[2] Poor oral hygiene status usually increases the poss- ibility of alveolar bone loss.[3] It is now widely accepted that thorough plaque control will prevent the development and recurrence of periodontitis .[4,5]

Toothbrushing is the most widespread mechanical means of personal plaque con- trol in the world[6] and is considered to be an important factor in the long-term maintenance of periodontal health.[7] The toothbrush is still the most common and often the only cleaning device people use. Therefore, its proper use is of importance in plaque control and prevention of periodontal disease.

Many factors can influence the ability of an individual to remove plaque with a manual toothbrush. Brushing duration, brushing force and brushing technique will all either increase or decrease the amount of plaque removed and therefore, in the long term, influence gingival health. Another factor that is thought to affect brushing efficacy is toothbrush wear.[8]

Dental professionals and toothbrush manufacturers generally recommend that a toothbrush be replaced every three months. This is based on the supposition that a worn toothbrush is likely to be less effective than a new one. The American Dental Association also makes this recommendation, stating that "worn brushes are not effective at removing plaque bacteria and broken bristles may injure gums."[9]

Evidence supporting the hypothesis that a worn brush is less effective at removing plaque than a new brush is, however, relatively scarce. Few studies have investi- gated the effect of toothbrush wear and those written on the subject have produc- ed conflicting results. Studies by Kreifeldt et al.,[10] Glaze and Wade[11] and Warren et al.[8] found that a worn toothbrush was significantly less effective at

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removing plaque than a new brush. They concluded that plaque removal decreased with increasing toothbrush wear and recomm- ended that toothbrushes be replaced freq- uently to ensure optimal plaque control. In contrast, McKendrick et al.,[12] Daly et al.[13] and Sforza et al.[14] have suggested that the wear status of a toothbrush may not be critical in ensuring optimal plaque control. Daly et al. (1996) found that the plaques cores actually improved as the initially new brushes became worn. Sforza et al. (2000) confirmed the findings of Daly et al. when they found that increased toothbrush wear was not associated with worsening plaque scores. Recently, Tan E et al.[15] reported that the percentage reductions in plaque scores achieved with new brushes were not significantly different from those achieved with 3-month-old brushes. No significant differences were found for plaque score reductions with 3-month- old brushes of minor, moderate or marked wear. They concluded that the 3-month-old toothbrushes were as effective as new brushes in plaque removal.

However, Conforti et al.[16] provided data in support of the hypothesis that a worn toothbrush is less efficient with respect to plaque removal than a new brush. Acco- rding to their conclusions, patients should therefore be encouraged to replace their toothbrush regularly before bristle wear becomes excessive.

Clearly, it is important that as much plaque be removed as is possible. To this purpose, manufacturers put significant effort into improving the efficiency of their toothbrushes. If the advantage gained from using new, more efficient brushes is counteracted by the effect of not replacing the toothbrush at an appropriate time, then it is suggested that worn brushes be replaced regularly.

However, patients do not always take this advice. It is very likely that they have little idea of when their toothbrush needs replacing. It was reported that the average age of a toothbrush at replacement ranges from 2.5 to 6 months.[12,17,18] Most people have been shown to base their decision as to when to replace their toothbrush on the degree of splaying and bending of the bristles.

As the rate of toothbrush wear is thought to be influenced by a number of factors, including duration of use, brushing force and brushing technique, this in part explains why the average age at replacement has been shown to vary so widely. In addition, assessment of when a toothbrush is "worn-out" will vary from person to person, which will also contribute to the wide variation in the age of a toothbrush at the time of replace- ment.

The purpose of this study was to determine the effect of toothbrush wear on plaque removal efficiency using a single-use design. This clinical investiga- tion was conducted to test the hypothesis that a 3-month-old toothbrush is less effective in removing plaque from a tooth surface than a new toothbrush.

II. Material and Methods

1. Subjects

A total of 42 healthy subjects were recruited. There were 27 males and 13 females with a mean age of 25.1 years (range 23-37). All participants were under- graduate students of Seoul National Univ- ersity's Dental College. They were selec- ted according to the following criteria :

1. Presence of all 6 Ramfjord teeth (16, 21, 24, 36, 41 and 44) and pocket depth $\leq$ 3mm on all tooth surfaces.
2. No crowns, fixed or removable prosth- eses or orthodontic appliances.
3. No restorations involving the surfaces of the

teeth to be scored.

4. Healthy with no medical conditions requiring prophylactic antibiotic cove- rage for scaling and polishing.

2. Plaque scoring

Plaque was recorded using the patient hygiene performance (PHP) index.[19] Plaque was disclosed with erysthrosin solution (RED-COTE®, Butler, Chicago, USA) for 1 min and then plaque scores were assessed at the 6 Ramfjord teeth. The tooth surfaces, both facial and lingual, were divided into 5 sections as follows (Figure 1) :

(1) Mesial third
(2) Distal third
(3) Middle third : which was further subdivided horizontally into ging- ival, middle and occlusal sections ; a score of 1 or 0 was assigned to each subdivision depending on the presence or absence of plaque ; all questionable areas were scored zero.

3. Toothbrush

A manual toothbrush with soft bristles (Oral-B Advantage®, Oral-B Laboratories, Belmont, CA, USA) was selected for the present study. Subjects were instructed to use a commercial fluoridized toothpaste (e-fresh®, Bukwang Pharm Co., Ltd, Seoul, Korea) during the experimental periods.

4. Brushing surface area

The amount of wear for 3-month-old brushes was determined by measurement of the brushing surface area. To standardize measurements, each toothbrush was placed in the same position using prefabricated acrylic resin mounter. Digital camera (FinePix S2 Pro®, Fujifilm Co., Ltd, Tokyo, Japan) was used and all images were adjusted to focus on the outer row of bristles of each toothbrush head. Stand- ardized digital photographs of the outer row of bristles were then taken. The outline of outer row of bristles was marked and the brushing surface area was calculated (Figure 2) using image analysis software (TDI Scope Eye®, Techsan Co., Ltd., Seoul, Korea). Increases in the brushing surface area of 3-month-old brushes were then determined by compa- rison with the brushing surface area of new brush.

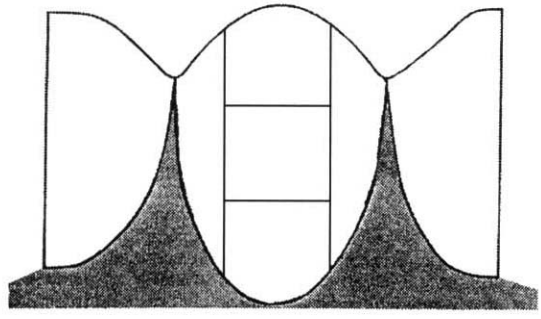


Figure 1. Sections of tooth surface for plaque scoring by the patient hygiene performance (PHP) index

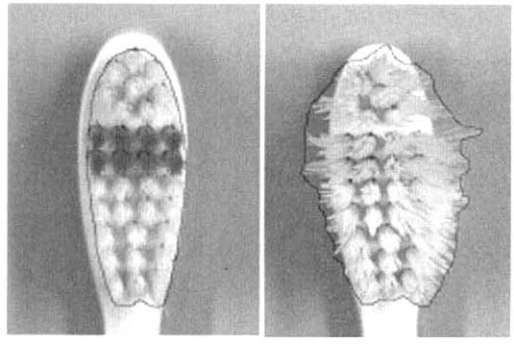


Figure 2. Brushing surface area : A new brush (left) and a 3-month-old brush (right). The outer row of bristles of brush head was marked and the area was calculated using image analysis software

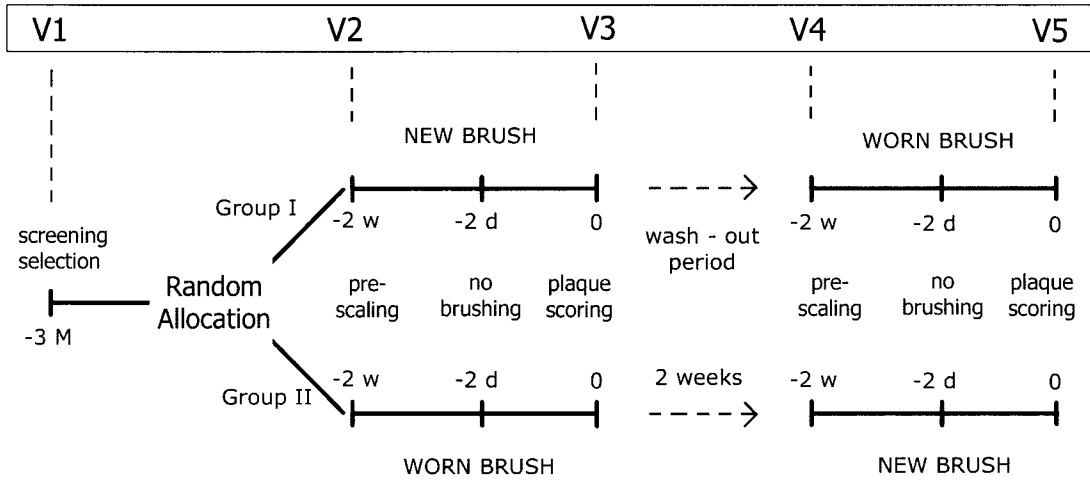


Figure 3. Experimental design and procedures. (V = Visit, M = months, w = weeks, d = days, Group I = New/Worn, Group II = Worn/New)

5. Experimental design

This study was a single-center, single- examiner blind, randomized, cross-over controlled clinical trial to compare the clinical efficacy of new and worn tooth- brushes. There were a total of 5 visits and 2 experimental periods. The study design is summarized in Figure 3.

At the first visit, selected subjects answered a questionnaire about their den- tal behaviors (frequency, duration and methods of daily brushing, replacement interval of toothbrush, smoking, drinking, right/left handedness). They were given the same toothbrush and instructed to use it for 3 months. This 3-month-old toothbrush was used as the 'worn' brush for later experimental periods.

At the second visit (3 months later), all subjects were randomly assigned to one of two experimental groups (I, II). Group I subjects used a new brush at the third visit and worn brush at the fifth visit. Group II subjects used a worn brush at the third visit and new brush at the fifth visit. All plaque and calculus were professionally removed to obtain a plaque score of 0 for each subject. All subjects were then instructed not to brush their teeth 48 hours before the next visit so that plaque could accumulate.

At the third visit (2 weeks later), an examiner confirmed the 48h-periods of no oral hygiene. Following plaque scoring by the PHP index, group I subjects brushed with new brush and group II subjects brushed with a worn brush using their familiar brushing techniques. After brush- ing, plaque was re-scored (Figure 4). Wear extent of the 3-month-old brushes was determined by measurement of brushing surface areas.

The two experimental periods were separated by a 2-week washout period, which was designed to prevent signifi- cant carry-over effects of using respective toothbrushes at the third and fifth visits.

After this period, at the forth visit, all subjects were recruited for professional plaque control. At the final visit (2 weeks later), groups I and II brushed with

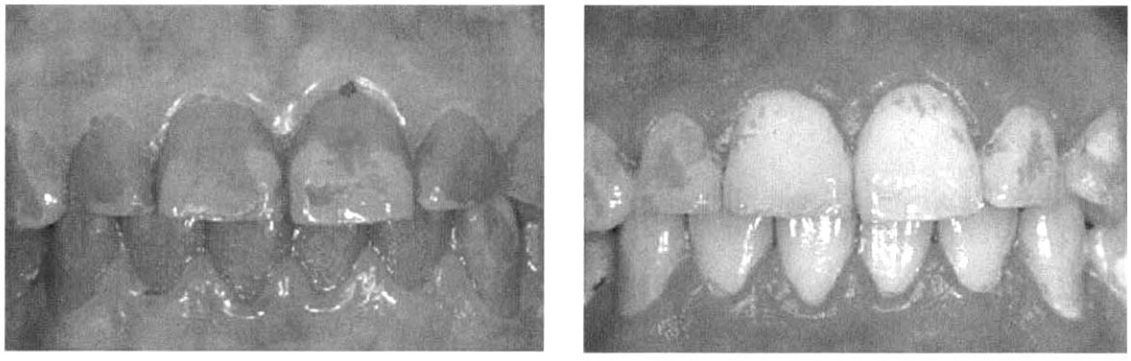
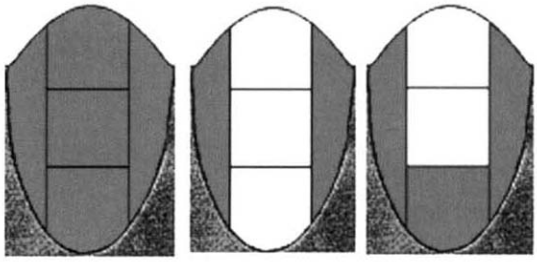


Figure 4. Plaque was disclosed with erysthrosin solution before (left) and after (right) brushing

the opposite toothbrush. Plaque score was recorded before and after brushing, as performed at the third visit. All plaque scoring was carried out by a single calibrated examiner who was blinded to the type of toothbrush used in both groups.

6. Data analysis

The hypothesis was that a worn toothbrush is less effective for reducing plaque than a new brush. Plaque scores in 10 sections of each tooth were recorded and calculated for regions of interest. In this investigation, 3 sites were selected : whole, proximal and marginal. The marginal site represents proximal plus gingival section (Figure 5).



A. whole B. proximal C. marginal

Figure 5. Plaque scoring of 3 sites (whole, proximal, marginal sites, from left to right)

For each of the 2 phases of the study, changes in plaque scores of the 3 sites were computed before and after brushing. Percentage reductions in plaque scores were then calculated and compared. Individual index scores at each phase were compared using paired t-tests.

Pearson's correlation analysis was done to find the relation among the plaque scores and toothbrush wear. For all statistical analyses, two-sided values of $p<0.05$ were accepted as statistically significant.

III. Results

1. Dental behaviors

42 subjects initially volunteered to take part in the study. Since 2 subjects dropped out at the second visit, 40 subjects went to completion. All sugjects answered a questionnaire about their dental behavio- rs (frequency, duration and methods of daily brushing, replacement interval of toothbrush, smoking, drinking, right/left handedness) as shown in Table 1.

2. Plaque scores

The results of the plaque scores are summarized in

Table 1. Dental behaviors of the subjects (n=40)

Questions	No.of subjects	Questions	No.of subjects
Brushing Frequency		Drinking	
1 time/day	1	No	23
2 times/day	16	Yes	17
3 times/day	23	Smoking	
Brushing Duration		No	32
0-30 s	0	Yes 1-10	5
30-60 s	7	10-20	2
1-2 mins	16	20-30	1
2-3 mins	9	Brushing Method	
3- mins	8	Rolling technique	17
Brush Replacement Interval		Bass technique	5
1 month	2	Modified Bass	10
2 months	6	Miscellaneous	8
3 months	19		
4 months	4	Right-handed	36
5 months	2	Left-handed	4
6 months	7		

Table 2. Plaque Scores of Pre- and Post-Brushing, Mean Reduction (Standard Deviations) and Percentage Difference Between Groups

Brush sites	Pre-Brushing	Post-Brushing	Mean Reduction	% Plaque Reduction	Difference Between Groups[a]	Group Comparison (p-value)
Whole-sites						
New	42.23 (3.97)	17.75 (6.40)	24.48 (6.83)*	57.96	15.1%	0.0001
Worn	41.55 (3.94)	23.73 (6.72)	17.83 (6.81)*	42.90		
Proximal						
New	24.00 (0.00)	13.15 (4.26)	10.85 (4.26)*	45.21	20.6%	0.0001
Worn	23.95 (0.22)	18.05 (4.41)	5.90 (4.45)*	24.69		
Non-Proximal						
New	18.23 (3.97)	4.60 (2.86)	13.63 (3.98)*	74.76	7.0%	0.071
Worn	17.60 (3.91)	5.68 (3.08)	11.93 (4.12)*	67.76		
Marginal						
New	35.90 (0.63)	16.50 (6.01)	19.40 (6.04)*	54.04	16.3%	0.0001
Worn	35.75 (0.54)	22.50 (6.30)	13.50 (6.42)*	37.76		
Non-Marginal						
New	6.33 (3.86)	1.25 (1.21)	5.08 (3.28)*	80.24	5.7%	0.317
Worn	5.80 (3.97)	1.48 (1.20)	4.33 (3.53)*	74.57		

* Statistically significant difference between pre- to post-brushing, $p < 0.05$

[a] % difference calculated from mean % plaque reduction pre- to post-brushing(% reduction for new - % reduction for worn)

Table 2. Nineteen subjects (group I) followed the New/Worn sequence, while 21 subjects (group II) performed the Worn/New sequence. Both types of tooth- brushes demonstrated statistically signifi- cant reductions in whole mouth, proximal and marginal plaque from pre- to post-brushing for each experi-

Plaque score changes for whole-sites

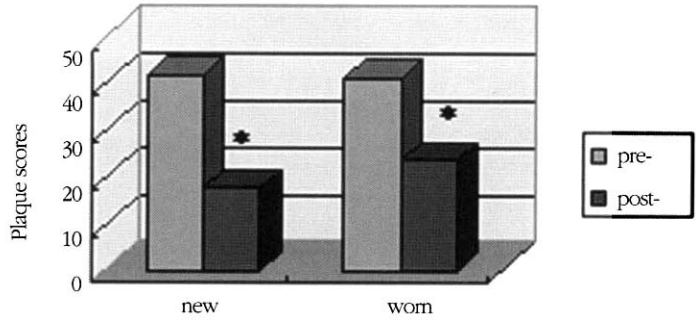


Figure 6. Plaque score changes for whole-sites

*Statistically significant difference between pre-to post-brushing, p〈0.05

Plaque score changes for proximal & non-proximal

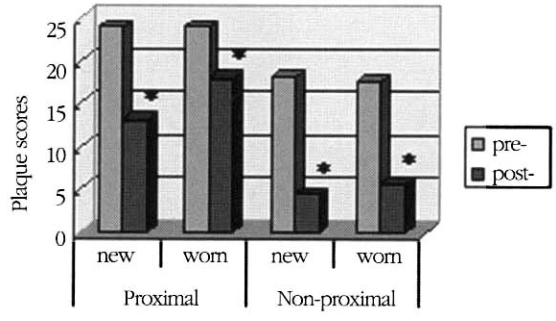


Figure 7. Plaque score changes for proximal & non-proximal sites

*Statistically significant difference between pre-to post-brushing, p〈0.05

mental period (p=0.0001, Figure 6-8). Plaque reductions for the new brush were 58.0%, 45.2% and 54.0% for whole, proximal, and marginal sites, res- pectively. Plaque reductions for the worn brush were 42.9%, 24.6%, and 37.8% for whole, proximal, and marginal sites, respectively. Therefore, the new toothbrush demonstrated 15.1%, 20.6%, and 16.3% greater mean plaque reduction than the worn brush for whole, proximal, and marginal sites, respectively, which was statistically significant (p=0.0001, Figure 9).

In non-proximal and non-marginal sites, both the new and worn tooth- brushes also demonstrated statistically significant plaque reductions (p=0.0001, Figure 8). However, there was no statistically significant reduction between the two toothbrushes. (p=0.071 for non-proximal sites, and p=0.371 for non-marginal sites).

3. Brushing surface area

The 3-month-old toothbrushes showed a wide variation in bristle wear (Figure 10). Compared with the brushing surface areas of the new brushes used by each subject, their 3-month-old brushes exhibited increased brushing surface areas ranging from 0.2 % to 112.1%. The overall mean increase (±SD) in the

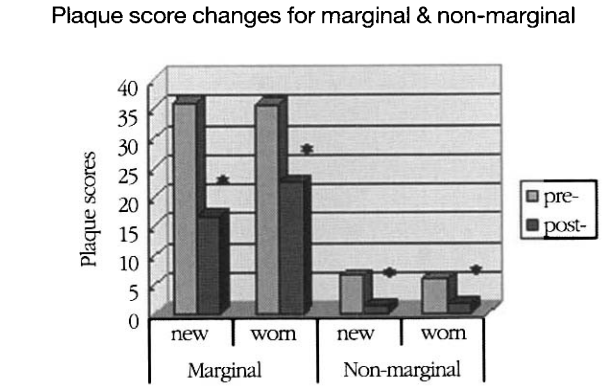


Figure 8. Plaque score changes for marginal & non-marginal sites

*Statistically significant difference between pre- to post-brushing, $p<0.05$

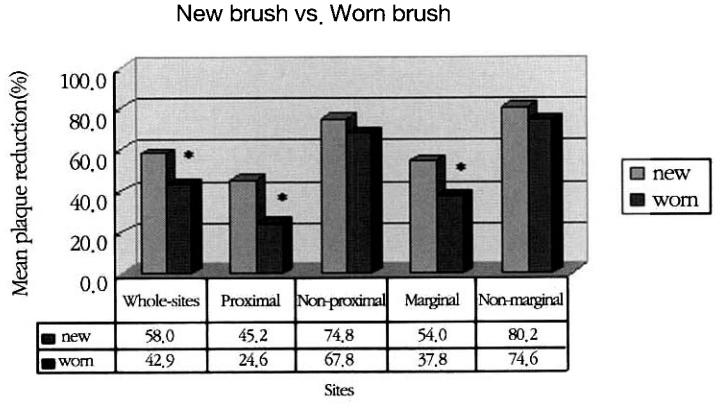


Figure 9. Mean plaque reduction (%) of new and worn toothbrush types for different sites

*Statistically significant difference between the two brush types, $p<0.05$

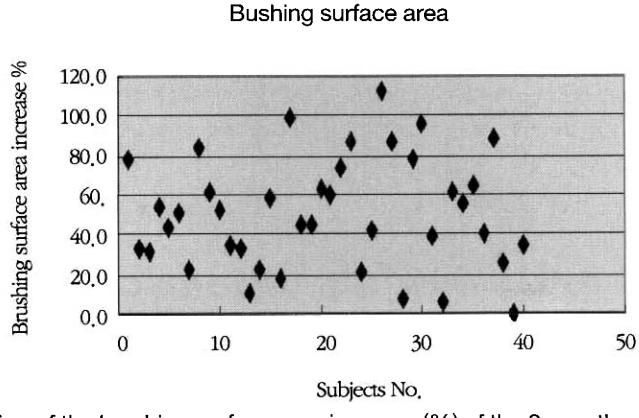


Figure 10. The distribution of the brushing surface area increase (%) of the 3-month-old toothbrushes (n=40)

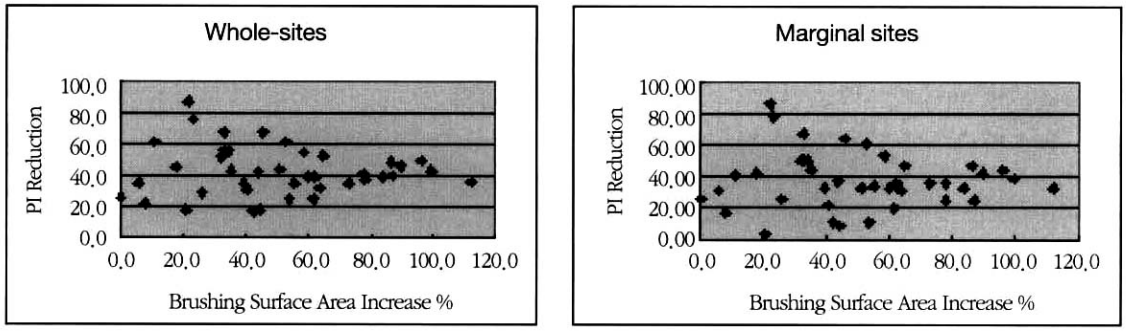


Figure 11. The percentile plaque score reductions achieved for whole-sites (left) and marginal (right) with each of the 3-month-old toothbrushes are shown in relation to the increase in the brushing surface area of each brush (n=40)

brushing surface area of the 3-month-old brushes was 50.6% (±27.8%).

4. Correlation analysis

The effect of toothbrush wear on plaque removal was investigated by assessing percentile plaque score reductions achieved with brushes exhibiting varying degrees of wear. There were linear correlations betwe- en the progressive wear of a toothbrush and plaque score reductions (r=-0.58 for whole-sites and r=-0.50 for marginal sites). However, there was no statistical signi- ficance for whole-sites (p=0.72) or marginal sites (p=0.76, Figure 11).

IV. Discussion

The aim of this study was to compare the effectiveness of new and 3-month-old toothbrushes in the removal of dental plaque. Bergstrom (1973) reported a signifi- cant correlation between the age of a brush and its wear.[17] He revealed that the wear condition of the toothbrush deteriorated with its length of use. The relationship between the "state-of-wear" of a toothbrush and its plaque-removing effectiveness has been studied for a long time. However, these studies have yielded conflicting results.

Our present study supports the previous findings of Kreifeldt et al.[10] (1980), Glaze and Wade[11] (1986) and Warren et al.[8] (2002) namely that a worn toothbrush is less effective than a new brush. This single-use study found that the new brush achieved 15.1% greater plaque reduction than the worn brush for the whole mouth, 20.6% for proximal sites and 16.3% for marginal sites.

Furthermore, our study overcomes some of the potential criticism that can be leveled at previous studies. Kreifeldt et al. and Warren et al. used mechanically worn brushes, but we used naturally worn brushes by each subject. Sforza et al.[14] concluded the use of artificially worn toothbrush may not be considered an objective method, since it only approxima- tes the characteristics of naturally worn toothbrushes. Even if artificially obtained bending and splaying of the bristles closely resemble the characteristics of naturally worn bristles, other factors may influence and modify the intrinsic characteristics of the bristles, such as the rubbing against the tooth surface, its interaction with food particles and bacterial plaque, abrasive characteristics of

toothpastes and natural aging of the bristles. Furthermore, if the bristles were naturally worn, the wear patterns would be varied with indivi- duals according to the different brush- ing methods.

Toothbrush wear was assessed in the present study by measuring the increase in the brushing surface area for each tooth- brush. Glaze & Wade[11] first described this technique but, in their study, the brushing surface area was calculated by multiplying the greatest length by the greatest breadth of the brushing surface. However, this method has been regarded as inappropriate because the brushing surf- aces of worn toothbrushes are generally irregular in outline.[13] Our study utilized the developed method of determining and calculating toothbrush wear by using standardized digital photographs and measuring the brushing surface area with image analysis computer software.

The results from this investigation confirmed that a worn brush also removed plaque effectively after brushing and this was statistically significant. But, a worn brush was less effective than a new brush. This result differs from the conclusions reached by McKendrick et al.[12] (1971), Daly et al.[13] (1996), Sforza et al.[14] (2000) and Tan E et al.[15] (2002) and the difference may be due to a number of factors associated with the respective study design. Method of toothbrush wear, the type of toothbrush tested, and the experimental designs are all factors that may have influenced the clinical outcome of the studies. For example, Daly (1996), in his 9-week period of study design, reported the "Hawthorne effect" that sub- jects improved their oral hygiene perform- ance during a clinical trial as a result of anticipation of oral examinations.

In this study, we asked subjects to brush as they would normally. Sforza et al. (2000) and Tan E et al. (2002), however, controlled brushing method and duration. They instructed subjects to brush by the modified Bass method for 60 seconds. Snedector et al.[20] and Dean[21] commented that brushing force, duration, and method may all have the potential to influence efficacy to a greater extent than toothbrush wear, thus masking the effect of wear on plaque removal. However, we thought that brushing method and duration could vary with each subject because factors such as force, intensity, frequency of strokes and manual skill could not be controlled in clinical trials.

Although, the most important factor for the conflicting results may be the plaque scoring index system. This study used the patient hygiene performance (PHP) index by Podshadley & Haley[19] (1968) for plaque scoring. The tooth surfaces, both facial and lingual, were divided into 5 sections : mesial, distal, gingival, middle, and occlusal. Since additional plaque scores were given to proximal and gingival sites separately before brushing and a new brush could remove more plaque on the proximal and gingival sites (called together, "marginal" sites) after brushing, the significant difference of plaque reduction between new and worn brushes could be found. Glaze & Wade (1986) also used the PHP index in their study which showed similar results. Since Kreifeldt et al. (1980) focused on the gingival margin for the plaque scoring[22-23] and Conforti et al (2003) used the Proximal Marginal Plaque index,[24] a new brush also revealed more plaque reduction than worn brush.

However, Daly et al. (1996) and Tan E et al. (2002) used the Turesky (1970) modification[25] of the Quigley & Hein (1962) index in which plaque scores were recorded for the facial, lingual- palatal and total. Sforza et al. (2000) used the Sillness & Löe(1964) index[26] in which proximal and gingival sites of lingual-palatal surface were not recorded. Therefore, new brushes could not obtain additional plaque score reduction and there was no statistical

significance.

In our study, non-marginal sites revealed no statistical difference of plaque reduction between new and worn brushes while there was statistical significance in marginal sites. Therefore, we need to use a different plaque index system that gives more significance on proximal and gingival sites. Among the previous studies, the Modified Navy Plaque Index by Elliott et al.[27] (1972) could be an appropriate example which gives double scores to the marginal gingival area. Rustogi et al.[28] (1992) developed a new index based on the original Modified Navy Plaque Index, so-called the Rustogi Modified Navy Plaque Index (RMNPI). They reported that plaque removal efficiency was increased in the gumline and interproximal tooth areas using RMNPI. There are some reports using this new index system to compare plaque removal efficacy of different toothbruses.[29-31] Although, there is no study that compares the plaque removal efficacy of new and worn brushes using the RMNPI system. If the RMNPI had been used for this study, we would have obtained more significant data of plaque score reduction between new and worn brushes.

There were linear correlations between the progressive wear of a toothbrush and plaque score reduction, which means that the brushing efficiency of the 3-month-old brushes tends to decrease with progressive wear increase. However, these correlations were not statistically significant. This is because plaque reduction may be influe- nced and changed by several factors such as different frequency, duration, force, and method of daily brushing of each subject as well as toothbrush wear differences. To determine the effect of increased toothbrush wear on plaque reductions, other factors stated above should be excluded. If toothbrushing with all different worn brush were performed by one subject, better results could be obtained.

This study was performed on the gingivitis model. If subjects suffered periodontitis, the study design should be changed. A new index system may be used in order to record plaque on the root surface area near the marginal gingiva. Furthermore, some variables such as brushing method and duration may influence the results, since root surface is a more three-dimensional structure. Therefore, a more careful design of plaque index may be needed to evaluate the patient hygiene performance. The impor- tance of regular oral hygiene monitoring and professional cleaning has been well documented in maintaining low plaque scores.[4,32,33]

V. Conclusions

Within the limits of the present study, it is concluded as follows ;

1. The single-use clinical study shows that a worn toothbrush is less effective than a new brush for plaque removal.
2. Since toothbrush wear is a potentially important factor in personal oral hygiene, it is obviously recommended that worn brushes be replaced regularly.
3. Further study regarding the plaque index system that focuses on proximal and gingival sites is needed for more careful evaluation of the patients' hygiene perf- ormance.

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-국문초록-

새 칫솔과 마모된 칫솔의 치태제거효율에 관한 비교연구

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3개월 동안 사용한 마모된 칫솔의 마모 정도와 양상을 관찰하고, 새 칫솔과 마모된 칫솔의 잇솔질 전 · 후 치태제거효율을 single-use design으로 비교 · 평가하여 3개월 주기의 칫솔 교체 주기의 근거를 임상적으로 확인해보고자 하였다.

치주적으로 건강한 치과 대학생 42명을 대상으로 설문지를 통해 잇솔질 습관을 조사하고, 3개월간 동일한 칫솔과 치약을 사용하게 하였다. 3개월 후 피시험자를 무작위로 두 군(I, II)으로 나누고, 치석제거술을 시행한 뒤 2주후에 내원하도록 하였으며 내원 전 48시간동안은 잇솔질을 하지 않도록 지시하였다. 2주후 I군은 새 칫솔을, II군은 마모된 칫솔을 사용하도록 하였으며 잇솔질 전 · 후에 각각 구강 내를 erythrosin으로 염색한 후 6개의 Ramfjord 치아의 plaque score를 Patient Hygiene Performance (PHP) index로 측정하였다. 2주간의 wash-out period 후에 다시 치석제거술을 시행한 뒤, I군이 마모된 칫솔을, II군은 새 칫솔을 사용하게 하여 동일한 방법으로 PHP index를 각각 측정하였다. 마모된 칫솔은 수거하여 brushing surface area의 면적으로 마모도를 평가하였다. 결과는 paired t-test와 Pearson's correlation analysis로 통계처리 하였다.

2명이 탈락하였고 잇솔질 전 · 후에 대한 전체 부위, 치간 부위, 변연치은 부위의 plaque score는 두 칫솔 모두 통계학적으로 유의성 있게 감소하였으며 ($p<0.0001$), 두 칫솔을 비교한 경우에는 새 칫솔이 마모된 칫솔보다 치태 감소량이 통계학적으로 유의성 있게 많았다 ($p<0.0001$). 칫솔의 마모도는 평균 50.6% 증가하였으며, 마모도 증가에 따른 치태 감소량에는 직선적인 상관관계가 있었으나 통계학적인 유의성은 없었다. (전체 부위 $r=-0.58$, $p=0.72$ / 변연치은 부위 $r=-0.50$, $p=0.76$).

Single-use design에서 3개월 동안 마모된 칫솔은 치태제거 능력에 있어서 새 칫솔보다 덜 효율적이었다. 칫솔의 마모도는 구강 위생 관리에 영향을 미치는 중요한 요인이며, 마모된 칫솔은 정기적인 교체가 요구된다. 또한, 치간 부위를 포함한 변연치은 부위의 치태를 정확하게 평가할 수 있는 치태지수에 대한 연구가 필요하겠다.

주요어 : 새 칫솔, 마모된 칫솔, 마모도, 치태제거효율, 구강 위생, 치태지수