

# Clinical Study on the Control of Dental Plaque Using a Photo Energy Conversion a Toothbrush Equipped with a TiO<sub>2</sub> Semiconductor

Motō NIWA and Masaomi FUKUDA

The Nippon Dental University, School of Dentistry at Tokyo,  
Department of Preventive and Community Dentistry  
(Chief : Prof. Motō NIWA)

**Abstract :** Adult female subjects used a toothbrush equipped with a cylindrical TiO<sub>2</sub> semiconductor for 3 weeks. The subjects were divided into two groups, one which used the semiconductor toothbrush and the other which used a conventional toothbrush. The pl-I of the experimental group was the same as that for the control group, but showed a tendency to decrease week by week during the experimental period. The PMA-I of the experimental group during the experimental period showed a tendency to decrease, with a significant difference being observed compared to the control group after the third week. CPITN in the experimental group showed no obvious tendency towards an improvement when compared with the PMA-I value. It is suggested that improvements in gingivitis and oral cleanliness can be expected through application of the present toothbrush which is equipped with a TiO<sub>2</sub> semiconductor.

**Key words :** Semiconductor, Toothbrush, Plaque control.

## Introduction

As a means of dental plaque removal, the toothbrush is the most effective. The proper use of the toothbrush has been advocated as the first and foremost method for preventing caries [1]. Of course, using the properties of dentifrice or toothpaste, chemical plaque removal and strengthening of the gingiva is also carried out, however, mostly through appropriate handling of the toothbrush itself is the removal of dental plaque from the surface of the teeth and the gingival sulcus accomplished.

Presently, it is said that there are several hundred varieties of toothbrushes on the market, making selection of an appropriate

toothbrush very difficult. When selecting a toothbrush, attention must be paid to the bristles portion of the toothbrush. To be more specific, the shape or form of the tuft portion, the condition of the bristles, the cut of the bundle of bristles, the material used for the tip of the bristles, etc., must all be considered. The shape and material of the handle portion of the brush are also extremely important with respect to the handling of a toothbrush.

The Japanese Ministry of Health and Welfare has determined several necessary requirements or conditions for toothbrushes as follows ; easy to use and effective in the oral cavity, the brush surface must be able to easily reach interdental areas, the handle and brush must be made from strong materials, and so

Received April 27, 1989

Recent, improvements made in toothbrushes have been remarkable, with many types of approaches being taken.

Toothbrushes with a semiconductor have been gaining a lot attention lately. The  $TiO_2$  semiconductor is buried in the neck region of the toothbrush. In theory, it converts light to electrochemical energy when light strikes the n-type semiconductor. It has already been reported that  $TiO_2$  powder decomposes lactic acid [2, 3], and  $TiO_2$  has received a lot attention since it was advocated that  $TiO_2$  has an effect against *Streptococcus mutans*, a microorganism which is particularly closely related to dental caries.

The present investigators report on the results of a comparison between conventional toothbrushes and the  $TiO_2$  semiconductor toothbrush by focussing on the condition of the dental plaque and gingival tissue in dental hygiene school students, subjects who are relatively knowledgeable with respect to oral hygiene.

## Materials and Methods

### 1. Experimental materials

The toothbrush used in the study was a photo energy conversion toothbrush equipped with a  $TiO_2$  semiconductor. The toothbrush was manufactured by Shiken Corporation (Osaka, Japan) and is shown in Figure 1. The conventional toothbrushes used by the control group were not equipped with a semiconductor but were of the same type as those used by the experimental group (Table 1). The composition of the toothpaste used in the present study is shown in Table 2.

### 2. Subjects

The subjects consisted of 60 dental hygiene

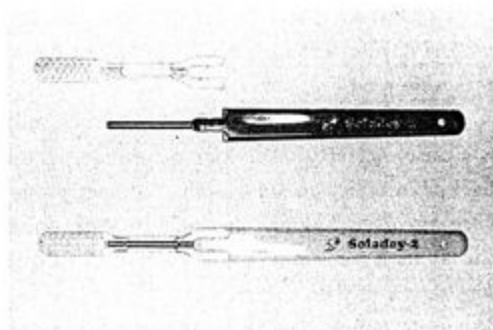


Fig. 1. Solar energy conversion toothbrush

Table 2. Toothpaste composition (%)

Precipitated Calcium Carbonate	35.0
Glycerin	36.0
CMC-Na	1.6
Flavor	0.7
Distilled water	36.7

school students aged 18-22 who had normal dentition and no clinical signs of any dental diseases.

### 3. Experimental procedure

The subjects were randomly divided into 2 groups, one group of 32 which used the semiconductor toothbrush (experimental group) and another group of 28 which used the conventional toothbrush (control group). Prior to commencing the study, the subjects practiced brushing until they had mastered the technique. The subjects' oral conditions were examined prior to the experiment. The toothbrushes were then distributed and the subjects' oral conditions were examined 1, 2 and 3 weeks later. The particular conditions were specified with respect to the intensity of illumination or light source for the normal daily brushing environment.

### 4. Evaluation criteria

Table 1. Toothbrush specifications

Total Length	Head Length	Width	Thickness	Tuft Design	Filament Length	Filament Diameter	Filaments Per Tuft
166	23	9	4.9	3×8	9.5	0.2	24 ± 1

## 1) Oral environment

The Snyder test and the saliva/occult blood test were used.

The Snyder test (S. T. media, simple method) is a caries activity test which determines lactobacillus activity in the saliva. The test procedure involves having the subject suck on a throat stick for 1 min in order to collect saliva. The saliva is then cultured at 37°C. After 24, 48 and 72 hours of culturing, the color changes in the medium are examined. An evaluation is made according to changes in color of medium which contains Bromocresol green (BCG) as a pH indicator. A value below 4.2 on the BCG color chart indicates a positive, while a value above 4.2 is negative. Cultures which were evaluated to be positive after 24, 48 and 72 hours were scored as (+++), (++) and (+), respectively, while those still negative after 72 were scored as (-).

The occult blood test (Salivaster-Bld) is a test which involves determining blood derived mainly from the gingival tissue which is released into the saliva. The test procedure involves dipping the test paper in the hematematic saliva for 2-3 seconds and then judging by comparing to the standard color change chart. The occult blood reaction is divided into 3 levels from low to high as follows, -, +, and ++.

## 2) Condition of the gingiva

Evaluation was carried out using 2 indices, PMA-1 and CPITN.

PMA-1 is a test in which the gingiva of the anterior teeth is divided into papillary, marginal and attached portions and the number of sites with gingivitis is determined to evaluate the severity of the gingivitis.

The Community Periodontal Index of Treatment Needs (CPITN) is an index that was proposed by WHO in 1982 for investigating the actual conditions of periodontal disorders and to determine the degree of therapy required in local or regional areas. In this study, the WHO

periodontal probe was used to score (0-4 points) the anterior teeth group for the upper and lower jaw and the left and right molar dentition group according to the following pattern,

76	1	67
76	1	67

The highest value obtained for each region was taken as a typical value.

## 3) Condition of dental plaque

The Quigley-Hein Plaque Index (PI-I) was used to evaluate the condition of the dental plaque. The teeth examined were based on OHI-S.

## Experimental Results

## 1. Snyder test

In the present study, the dental plaque condition was investigated after a semiconductor toothbrush was used over 3 weeks. The number of subjects for each evaluation for the experimental and control groups are shown in Table 3, while the changes in the Snyder test mean values of the two groups for each week are presented in Figure 2.

From these results, it was observed that caries activity in both groups determined by the

Table 3. Comparison of Snyder test scores at each observation week

Group		Before	1 W	2 W	3 W
Experimental	- (N)	10	15	14	19
	(%)	31.3	48.4	48.3	70.4
	± (N)	7	8	11	8
	(%)	21.9	25.8	37.9	27.6
	+ (N)	15	8	4	2
	(%)	46.8	25.8	13.8	2.0
	⊕ (N)	0	0	0	0
	(%)	0	0	0	0
Control	- (N)	10	6	10	14
	(%)	35.7	21.4	37.0	51.9
	± (N)	10	14	9	4
	(%)	35.7	50.0	33.4	14.8
	+ (N)	6	8	8	9
	(%)	21.4	28.6	29.6	33.3
	⊕ (N)	2	0	0	0
	(%)	7.2	0	0	0

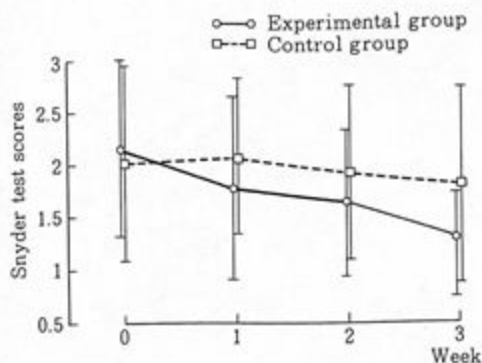


Fig. 2. Changes in Snyder test scores in the experimental and control groups

Snyder test showed a tendency to decrease, however, the degree of decrease was greater in the experimental, i.e., semiconductor toothbrush, group than in the control group. However, there was no significant differences between the 2 groups for any week.

### 2. Saliva/occult blood test

The results of bleeding tendency determined using Salivaster-Bld are shown in Table 4. Both groups exhibited a tendency towards a gentle decrease with respect to the mean value, although there was no significant difference between the 2 groups.

### 3. PMA-I

The results of PMA-I with respect to the investigation of the improvement in gingival tissue through the use of the semiconductor toothbrush are presented in Table 5 and Figure 4. Even though the PMA-I mean value of the experimental group prior to the study was higher than that of the control group, the PMA-I value showed a clear tendency to decrease with use of the semiconductor toothbrush. A significant difference compared to the control group was

Table 4. Comparison of Salivaster Bld test scores at each observation week

Group	Before	1 W	2 W	3 W	
Experimental	- (N)	17	30	28	29
	(%)	53.1	96.8	96.6	93.5
	± (N)	13	1	1	2
	(%)	40.6	3.2	3.4	6.5
Control	- (N)	20	26	19	26
	(%)	74.1	92.9	67.9	96.3
	± (N)	7	2	9	1
	(%)	25.9	7.1	32.1	3.7
+	(N)	0	0	0	0
	(%)	0	0	0	0

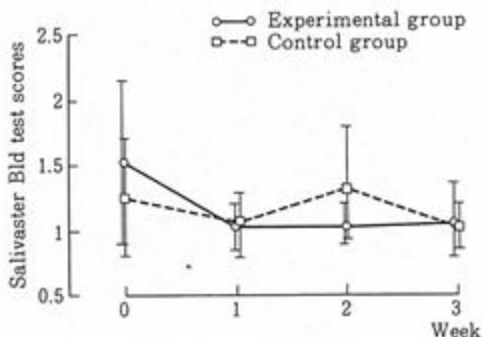


Fig. 3. Changes in Salivaster Bld scores in the experimental and control groups

observed at 3 weeks. In Figures 5 and 6, the PMA-I values for the upper and lower jaws showing P and M separately are presented. It was found that for P (Papilla) the weekly changes in the value for the upper jaw were more of a straight line in nature compared to that for the lower jaw for the experimental group. No effect was observed in the control group with the conventional toothbrush.

On the other hand, there was a slight change

Table 5. PMA-I scores

Group	Week			
	0	1	2	3
Experimental	4.48 ± 2.75	2.93 ± 2.00	2.06 ± 0.75	1.58 ± 1.40
Control	3.39 ± 2.75	2.79 ± 2.14	2.39 ± 1.50	3.44 ± 1.38**

Values are mean ± S. D. \*\* P < 0.01

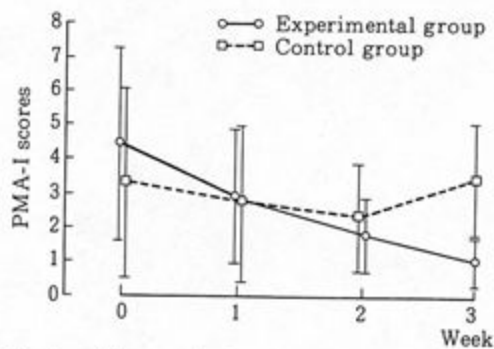


Fig. 4. Changes in PMA-I scores in the experimental and control groups

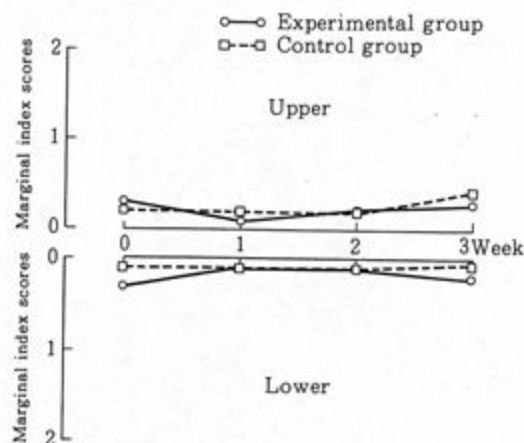


Fig. 6. Changes in Marginal index for PMA-I in the experimental and control groups

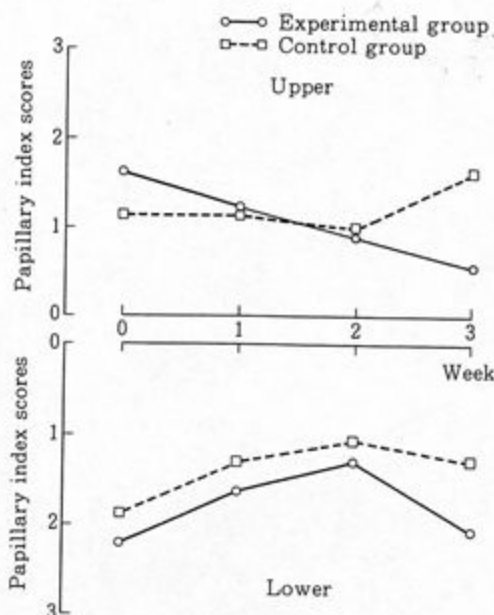


Fig. 5. Changes in Papillary index for PMA-I in the experimental and control groups

in both groups during the experimental period were poor.

#### 4. CPITN

The CPITN of the experimental group was the same as the control group until 2 weeks,

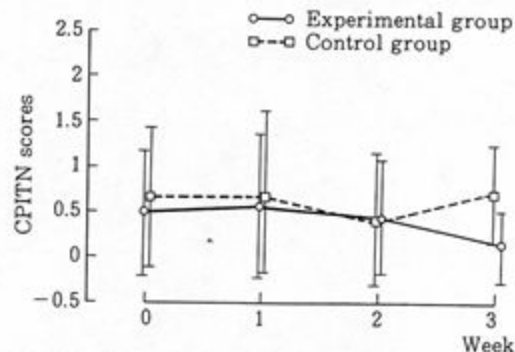


Fig. 7. Changes in CPITN scores in the experimental and control groups

with no changes being observed. However, after the 3 week time point, the CPITN value of the experimental group exhibited a tendency to decrease (Table 6, Figure 7), although a significant difference compared to the control group was not seen.

#### 5. PI-I

Changes in dental plaque condition were using PI-I. The results are shown in Table 7 and

Table 6. CPITN scores

Group	Week			
	0	1	2	3
Experimental	0.50 ± 0.72	0.57 ± 0.83	0.45 ± 0.74	0.36 ± 0.87
Control	0.67 ± 0.74	0.70 ± 0.87	0.44 ± 0.64	0.73 ± 0.82

Values are mean ± S. D.

Table 7. PI-I scores

Group	Week			
	0	1	2	3
Experimental	1.58 ± 0.42	1.27 ± 0.60	1.16 ± 0.51	0.93 ± 0.43
Control	1.80 ± 0.64	1.45 ± 0.71	1.20 ± 0.70	1.05 ± 0.51

Values are mean ± S. D.

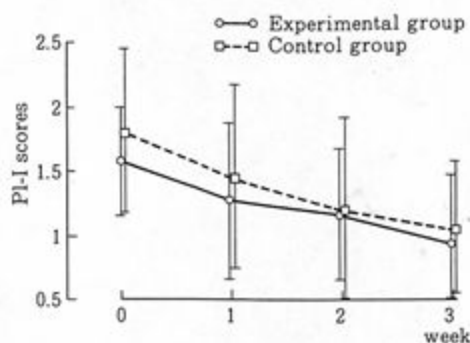


Fig. 8. Changes in PI-I scores in the experimental and control groups

Figure 8. A clear decrease was found in both groups, however, there was no significant difference between the 2 groups.

### Discussion

When examining the efficacy of a toothbrush, *in vitro* as well as *in vivo* research methods can be used. Due to the differences with respect to knowledge concerning of toothbrushes, brushing customs, age, gender etc., a rather difficult and complicated experimental plan is usually required for a clinical study. In order to overcome these difficulties in the present research, dental hygiene school students, a group with a significant degree of knowledge concerning oral hygiene, were used as subjects. The TiO<sub>2</sub> semiconductor of the toothbrush used in this experiment has been shown in *in vitro* research to have an anti-bacterial effect against the cariogenic *Streptococcus mutans* [1]. The decomposition of lactic acid by the photocatalytic reaction of semiconductor TiO<sub>2</sub> fine powder has also been reported [2].

The semiconductor toothbrush used in this

study was equipped with a cylindrical shaped TiO<sub>2</sub> semiconductor located in the neck of the toothbrush. *In vitro*, the TiO<sub>2</sub> photocatalytic reaction is known to readily occur, however, the effects during actual use of the toothbrush must also be investigated.

In Japan, a clinical report on semiconductor TiO<sub>2</sub> toothbrushes has been conducted by Kusunoki et al [4]. They reported that in 24-39 year-old adults with normal gingival tissue who used the TiO<sub>2</sub> semiconductor toothbrush, the dental plaque removal effect was large during the early phase of dental plaque formation. In their report, plaque adhesion amount was evaluated with the plaque scoring system, a different method to the one used here. However, the plaque removal effect during the early phase of plaque formation in the present study was quite large, and somewhat resembled that of Kusunoki et al. The reason for this may be mainly related to the brushing effect. Weiger [5] investigated the dental plaque cleaning effect of a TiO<sub>2</sub> semiconductor toothbrush over 4 weeks in 20 dental university students. The evaluation method used, PI-I, was the same as this study. It was found that the toothbrush had an obvious dental plaque cleaning effect. The results obtained were thought to be due to the improvement in the subjects' brushing habits, as well as to the inhibitory effect of the light current on dental plaque adhesion.

Oral bacteria, saliva and plaque can be used as caries activity indices, however, in this study lactobacilli acid production in the oral cavity was focused upon. Various points of debate remain concerning the predictability of the caries activity test. Yoshikawa et al [6] examined



and evaluated all types of caries activity tests by screening methods and reported that the Snyder test exhibited the best predictability.

The Snyder test was used in the present study. It was observed that the activity in the experimental group showed a gradual decrease. Therefore, it is thought that the semiconductor  $TiO_2$  had some degree of anti-bacterial action against lactobacilli.

When changes in oral cavity bleeding were investigated using Salivaster-Bld, it was found that there were slight changes in the experimental and control groups after one week. Weiger [5] examined the improvement in gingival bleeding with a toothbrush equipped with a  $TiO_2$  semiconductor in 20 subjects over 4 weeks and observed an improvement in the initial period of use. However, it was reported that no improvements were seen after this period. Weiger's results are similar to those of the present research.

The effects of the  $TiO_2$  semiconductor on the gingiva were investigated using PMA-I and CPITN. The PMA-I showed a tendency to decrease on a weekly basis in the experimental group. This is thought to be indicative of the remarkable effect of the  $TiO_2$  semiconductor on gingivitis of the anterior teeth. It is of particular interest that a significant difference between the experimental group and the control group was observed at the 3 week time point. In addition, when the PMA-I changes according to region were investigated, it was observed that there was brushing effect on the gingiva of the papillary region of the anterior teeth of the upper jaw. This is why the  $TiO_2$  semiconductor converts light mainly in the anterior region mainly.

It is thought that a similar tendency to that shown by PMA-I was not observed for CPITN due to the fact that in CPITN the molar dentition is also included in the gingiva tested.

The anti-bacterial effect of  $TiO_2$  semicon-

ductors has been reported *in vitro* [7], however, an important problem is whether or not a sufficient photo electrochemical effect is exhibited in the clinical situation. From the results of the present investigation, it is thought that photo decomposition of lactic acid can be expected with normal brushing.

Future studies should be carried out in order to attain even more effective oral hygienic conditions.

## Conclusions

Adult female subjects used a toothbrush equipped with a cylindrical  $TiO_2$  semiconductor for 3 weeks and the improvement in the condition of the gingiva as well as the effect on dental plaque were investigated. The following conclusions were obtained when the subjects were divided into two groups, one which used the semiconductor toothbrush (the experimental group, 32 subjects) and the other which used a conventional toothbrush (the control group, 28 subjects).

1) The PI-I of the experimental group was the same as that of the control group, showing a tendency to decrease week by week during the experimental period. However, no significant differences were observed between the 2 groups in any week.

2) As a result of investigation using the Snyder test, a caries activity test, it was found that the value for the experimental group during the experimental period exhibited a tendency to decrease, although a significant difference compared to the control group was not seen.

3) Examination of the effect on gingival bleeding tendency with the saliva/occult blood test revealed a slight improvement in both groups, however, a significant difference between the 2 groups was not observed.

4) The PMA-I of the experimental group during the experimental period showed a tendency to decrease, with a significant difference

being observed compared with the control group after the third week. Further analysis of PMA-I revealed an improvement in the gingivitis symptoms of the gingival papillary of the anterior teeth in the experimental group.

5) CPITN in the experimental group showed no obvious tendency towards an improvement when compared with the PMA-I value.

6) From the overall findings listed above, it is suggested that improvements in gingivitis and oral cleanliness can be expected through application of the present toothbrush equipped with a TiO<sub>2</sub> semiconductor.

#### Acknowledgments

The authors would like to express their gratitude toward Shiken Corporation (Osaka) for kindly supplying the toothbrushes and toothpaste used in this study, and to Mr. Stephen McKay for translating the manuscript.

#### References

- 1) Caldwell, R. C. and Stallard, R. E : A textbook of preventive dentistry, W. B. Saunders, 1977.
- 2) Harada, H., Sakata, T. and Ueda, T. : Ef-

fect of semiconductor on photocatalytic decomposition of lactic acid, *J Am Chem Soc*, **107** : 1773-1774, 1985.

- 3) Saito, T., Nara, Y., Morioka, T. and Onoda, K. : Antibacterial effect of powdered TiO<sub>2</sub> with photocatalytic reaction on *Streptococcus mutans* strain AHT, *J Dent Hlth*, **36** : 490-491, 1986.
- 4) Kusunoki, K., Oku, T., Koni, H., Nakaya, K., Mori, T., Hiratuka, Y., Taguchi, M., Watanabe, Y. and Miyake, T. : A study on the effect of the solar energy toothbrush on the control of dental plaque, *J Osaka Odont Soc*, **49** : 550-559, 1986.
- 5) Weiger, R. : Klinisch-experimentelle Untersuchung über die Wirksamkeit der Denta-Solar mit integriertem Halbleiter aus TiO<sub>2</sub>, Inaugural-Dissertation zur Erlangung des Doktorgrades der Zahnheilkunde, Eberhard-Karls-Universität, 1987.
- 6) Furukawa, K. and Fukuda, M. : Relationship between caries activity test in school children —with special evaluation to the screening method—, *J Dent Hlth*, **39** : 27-58, 1989.
- 7) Onoda, K., Matsushita, K., Nakagawa, Y. and Izumi, I. : Photoassisted decomposition of lactic acid on polycrystalline TiO<sub>2</sub> films, *Denki Kagaku*, **55** : 946-947, 1987.