Efficacy of using 3D motion tracking toothbrush in dental plaque control

Jin-Sun Jeong

Department of Dental Science
The Graduate School, Yonsei University

Efficacy of using 3D motion tracking toothbrush in dental plaque control

Directed by Professor Kee-Deog Kim

The Doctoral Dissertation
Submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the requirements for the degree of
Ph.D. in Dental Science

Jin-Sun Jeong

December 2015

This certifies that the dissertation thesis of Jin-Sun Jeong is approved.

____

Thesis Supervisor: Kee-Deog Kim

____

Thesis Committee Member: Jae-Ho Lee

____

Thesis Committee Member: Baek-Il Kim

____

Thesis Committee Member: Bock-Young Jung

____

Thesis Committee Member: Nan-Sim Pang

The Graduate School
Yonsei University

December 2015

감사의 글

모든일에 처음과 끝을 주관해 주신 하나님께 감사드립니다.

2009년 3월 부터 지금까지 연세대학교 치과대학병원 통합진료과 연구원으로 일하면서 정말 많은 것을 배우며 성장할 수 있었습니다.

특히, 김기덕 교수님과 김희진 교수님의 도움으로 대학원을 시작할 수 있었고, 이렇게 졸업할 수 있게 되었습니다. 두 분 교수님께 진심으로 감사드립니다.

이 논문이 완성되기까지 격려와 조언을 아낌없이 해주신 지도교수님이신 김기덕 교수님, 심사위원이신 이제호 교수님, 김백일 교수님, 정복영 교수님, 방난심 교수님과 통계에 조언을 주신 김기열 교수님께도 감사드립니다.

그리고, 통합진료과에서 다양한 치의학 분야의 연구를 배울 수 있게 기회를 주시고, 지도해 주신 박원서 교수님께도 감사드립니다. 기쁨과 어려움을 함께 나눌 수 있었던 통합진료과 친구이자 동료인 박경미 연구원과 한기희 선생님께도 감사드립니다.

또한, 구강병리학 분야를 연구 할 수 있게 기회를 주시고 가르침을 주신 장향란 교수님과 여러 도움을 주신 즐거운 실험실 친구들 감사합니다.

저의 본보기가 되어주신 아버지와 아낌없는 사랑을 주신 어머니께도 감사드립니다. 두 분의 기도로 제가 여기까지 왔습니다.

그리고, 곁에서 항상 따뜻한 말과 기도로 격려해 주신 언니, 형부, 둥이 조카, 상윤이, 친인척, 친구, 집사님, 권사님들께도 감사드립니다.

또한, 먼 중국에서도 공부하는 며느리를 이해해 주시고, 지원과 격려를 해주신 시부모님과 시댁 식구들에게도 감사 드립니다.

누구보다 이 논문을 위해 많이 노력해 주신 사랑하는 신랑 구유에게 진심으로 감사하고 존경합니다. 엄마가 많이 보살펴 주지 못했지만 밝고 예쁘게 자라준 사랑하는 딸 구슬기에게도 감사의 마음을 전합니다.

공부하면서 어렵고 힘든 일이 많았지만 포기하지 않고 좋은 맺음을 할 수 있게 도와주신 모든 분들께 감사드리며, 박사가 끝이 아닌 앞으로 새로 시작하는 마음으로 치의학 분야에 도움이 되는 한 사람이 되도록 노력하겠습니다.

2015년 12월

정진선 씀

Table of Contents

List of Figures

List of Tables

Abstract

Efficacy of using 3D motion tracking toothbrush in dental plaque control

Jin-Sun Jeong

Department of Dental Science,
The Graduate School, Yonsei University

(Directed by Professor Kee-Deog Kim, D.D.S., M.S.D., Ph.D.)

The objective of this study was to compare the efficacy of a smart mirror toothbrush instruction (TBI) system and a smartphone-based remote toothbrushing monitoring system to conventional TBI in plaque control.

The smart mirror system was tested by analyzing the reductions of the modified Quigley-Hein plaque index in two experiments, either in 60 adults or in 42 children. These volunteers were assigned randomly into two groups, in which the volunteers received TBI using smart mirror system or traditional TBI. The changes in the plaque indexes were recorded at baseline, immediately after TBI, 1 week later, 1 month later, and 10 months (adults only) later.

The smartphone system was evaluated at home in 80 days in 92 children. The Patient Hygiene Performance Simplified Index (PHPsI) and a survey were completed by all of the children regarding their toothbrushing pattern at baseline and at the 80-days. Children who spent less than two minutes on toothbrushing or brushed their teeth less than two times a day were assigned into group one, the rest were assigned into group two. Changes in mean PHPsI score for all participants between baseline and 80 days were analyzed, and changes of plaque indices were compared between different sites of the dentition.

The patterns of decrease in the modified Quigley- Hein plaque indexes were similar in the two groups in both adults and children when using the smart mirror system. Reductions of the plaque indexes of both groups in each test time period were observed for both adults (P<0.0001) and children (P<0.0001), and the effects of TBI did not differ between the two groups in both adults (P=0.9035) and children (P=0.424). Non- inferiority was validated in a limited time after TBI for both experiments.

As the smartphone system was used by children, the mean PHPsI decreased from the baseline to the second visit (P<0.0001) in both groups, the highest reduction rate was at the buccal surfaces of tooth numbers 16 and 26, and the least was at the labial surfaces of tooth numbers 11 and 31 for both groups.

The smart mirror system showed similar effect in dental plaque control in both adults and children when comparing with conventional TBI. The smartphone exhibited efficacy in plaque control for children in both groups, and could be a potential alternative to the traditional TBI.

Key words: Toothbrushing instruction, Computer, Oral hygiene, Smart toothbrush, Habit control, Dental plaque, Teledentistry, Smartphone

Efficacy of using 3D motion tracking toothbrush in dental plaque control

Jin-Sun Jeong

Department of Dental Science,
The Graduate School, Yonsei University
(Directed by Professor Kee-Deog Kim, D.D.S., M.S.D., Ph.D.)

I. Introduction

Controlling dental plaque is the most important way of preventing dental disease, especially periodontal disease, which makes plaque control the main target during the maintenance period of periodontal treatment (Taylor *et al.*, 1995; Axelsson *et al.*, 2004). One of the most important and effective methods of plaque control is toothbrushing (Finkelstein and Grossman, 1984), which makes toothbrushing instruction (TBI) the most important process in a dental clinic for enhancing oral hygiene (Axelsson *et al.*, 1991; Engelmayer and Lang, 1979). The goal of TBI is to change or improve the brushing habit or pattern of individual patients, but it is impractical to provide professional instruction to every patient in a dental clinic. The problem of "compliance" is always a major issue of TBI, especially for children (Zanin *et al.*, 2007), since people are prone to brush as they have done previously, rather than how they were instructed in the dental clinic.

The duration and frequency of toothbrushing, as well as the manipulative skill and motivation of the individual are the most important determinants regarding the effective removal of dental plaque (Sharma *et al.*, 2012; Grossman and Proskin, 1997).

Previous research regarding TBI using verbal, written, or videotaped methods yielded unsatisfactory results due to a lack of repetition and reinforcement (Yazdani *et al.*, 2009). Some investigators have attempted to overcome this problem using special toothbrushes, such as a data-logger toothbrush (McCracken *et al.*, 2005). Other research reports electric toothbrushes also improve motivation by enhancing the patient's interest in oral hygiene and thereby improving their brushing technique (Hellstadius *et al.*, 1993).

The development of contemporary electronic and information technology (IT) and advancement of biosensors has enabled the use of three-dimensional (3D) motion-capture devices in both medical and dental fields. These devices capture the position and movement of the target, so that they are used for movement analyses such as gait analyses, rehabilitation treatments, and telemedicine (Gebruers *et al.*, 2010; Jehn *et al.*, 2009; Kim *et al.*, 2009; Kishimoto *et al.*, 2009; Lee *et al.*, 2009; Walters *et al.*, 2010).

The smart toothbrush and smart mirror system (XiuSolution, Seoul, Korea) are recent products that contain a 3D accelerometer and magnetic sensor (Kim *et al.*, 2009; Lee *et al.*, 2009; Lee *et al.*, 2006). The smartphone system (XiuSolution, Seoul, Korea), another TBI system based on a smartphone, comprises a three-dimensional (3D) motion-capture device, which can hold a toothbrush, and a smartphone application (APP). When using the smartphone system, toothbrushing is practiced by following the animation displayed through the smartphone APP.

The sensors embedded inside the holder will detect the toothbrush motions, and the data will be sent to the server and saved for analysis. Health managers can then inspect the data and send feedback to the users. Comparing with conventional TBI by verbal, written, or videotaped methods, the computer assisted TBI can offer individual education, and comparing with conventional TBI by dentist or dental hygienist, the computer assisted TBI may save some consulting hours.

The aim of the present study was to determine the effectiveness of the smartphone system and smart mirror system in reducing dental plaque and improving toothbrushing skills in both children and adults. Non-inferiority test of experimental group using the smart mirror system was also performed at different sites and time points, since the use of the smart mirror system should be supported, considering the several merits mentioned, if the non-inferiority could be validated.

II. Materials and Methods

1. Toothbrushing instruction system

1.1 Smart mirror system

The smart mirror system comprises a 3D motion-capture toothbrush with a 3D accelerometer and an mirror that displays the 3D location and movement of the toothbrush. It constitutes an oral hygiene control system using information technology (IT) for both analyzing and modifying toothbrushing habits with instant feedback. All tooth surfaces were segmented into 16 sites, comprising anterior facial and lingual (palatal), right posterior occlusal, buccal, and lingual (palatal), and left posterior occlusal, buccal, and lingual (palatal) in maxillary and mandibular teeth. The system plays a video in a mirror that the patients should follow. The subjects are told to brush their teeth while viewing the instruction (rolling method) video in the mirror. The location and movement of the brush were recorded and transferred to a computer wirelessly, and the data were analyzed to determine whether or not the subjects brushed well (Figure 1). A time period of 10 seconds was allocated for brushing in each of the 16 sites. The brushing data were analyzed and the results were reported immediately after the TBI.

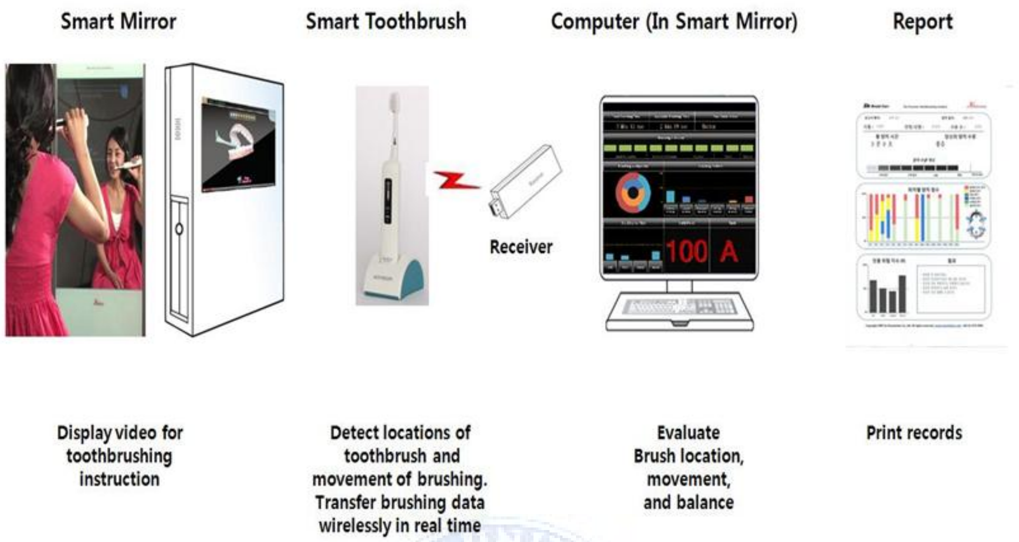

Figure 1. Flowchart of computer-assisted toothbrushing instruction (Smart mirror system).

1.2 Smartphone system

The entire smartphone system comprises three parts: a toothbrush holder, a smartphone APP, and a normal toothbrush. The holder comprises a three-axis accelerometer that can detect 3D motion during toothbrushing, and it transfers data instantly to the smartphone APP, which is linked to the same network via Bluetooth. All data were sent to a server. Two versions of the APP were developed: one for the users and the other for the dental health managers who monitor the toothbrush effect for all users. At one end of the holder is a tube fabricated out of rubber material, making it easy to adapt so that most toothbrushes will connect to it. All subjects were provided with the same toothbrush, which was designed for children, and fluoride toothpaste for use during the experiment (Figure 2).

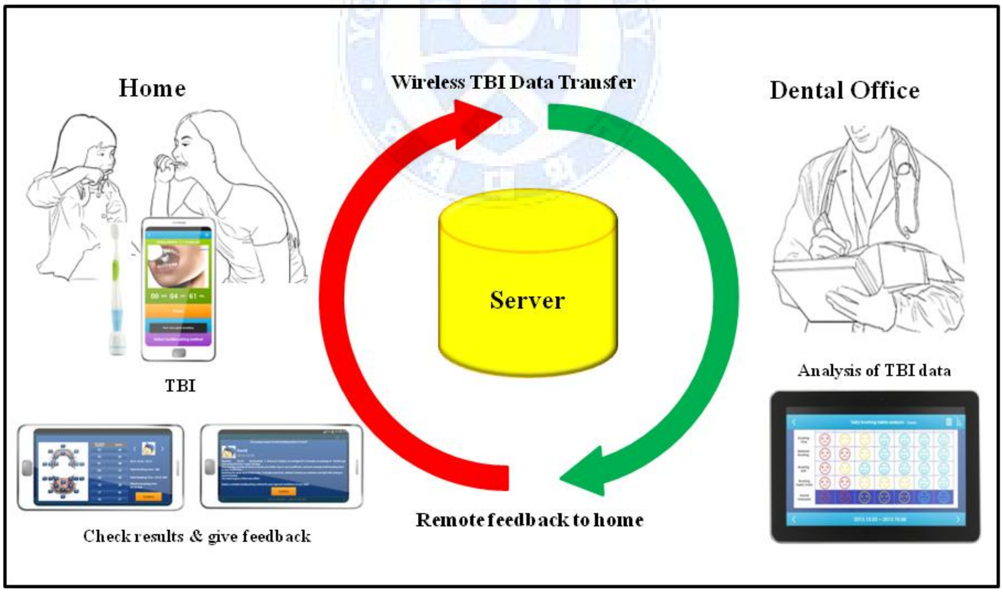

Figure 2. Smartphone-based remote toothbrushing monitoring system. TBI, tooth brushing instruction. (Smartphone system).

2. Experimental design

2.1 TBI using smart mirror system in dental clinic for adults and children

This clinical research was approved by the institutional review board of the dental hospital at Yonsei University (IRB number: 2-2008-0005). The subjects consisted of 60 Korean adults (36 females, 24 males, ranging in age from 20 to 57, with a mean age of 35.7) who were selected from 78 volunteers, and 42 children (21 females, 21 males, ranging in age from 6 to 12, with a mean age of 9.64) who were selected from 52 volunteers. It is reasonable that people with poor oral conditions need more toothbrush instruction, so the inclusion criteria were determined as the presence of gingivitis or periodontitis or dental caries, and Quigley-Hein index >1.5, whilst the exclusion criteria were the presence of rampant dental caries, undergoing orthodontic treatment, or medical compromise.

The subjects were randomly assigned into 2 groups containing 30 each for adults or 21 each for children, by throwing a coin. Those in the control group received traditional TBI while those in the experimental group were instructed with the smart mirror system. The same toothpaste (2080, Aekyung, Korea) and toothbrushes with same type and length of flat-trimmed nylon bristle were provided to both groups.

Figure 3 shows the flowchart of this study for adults, the only difference of the study design for children was that the 10 month visit was excluded.

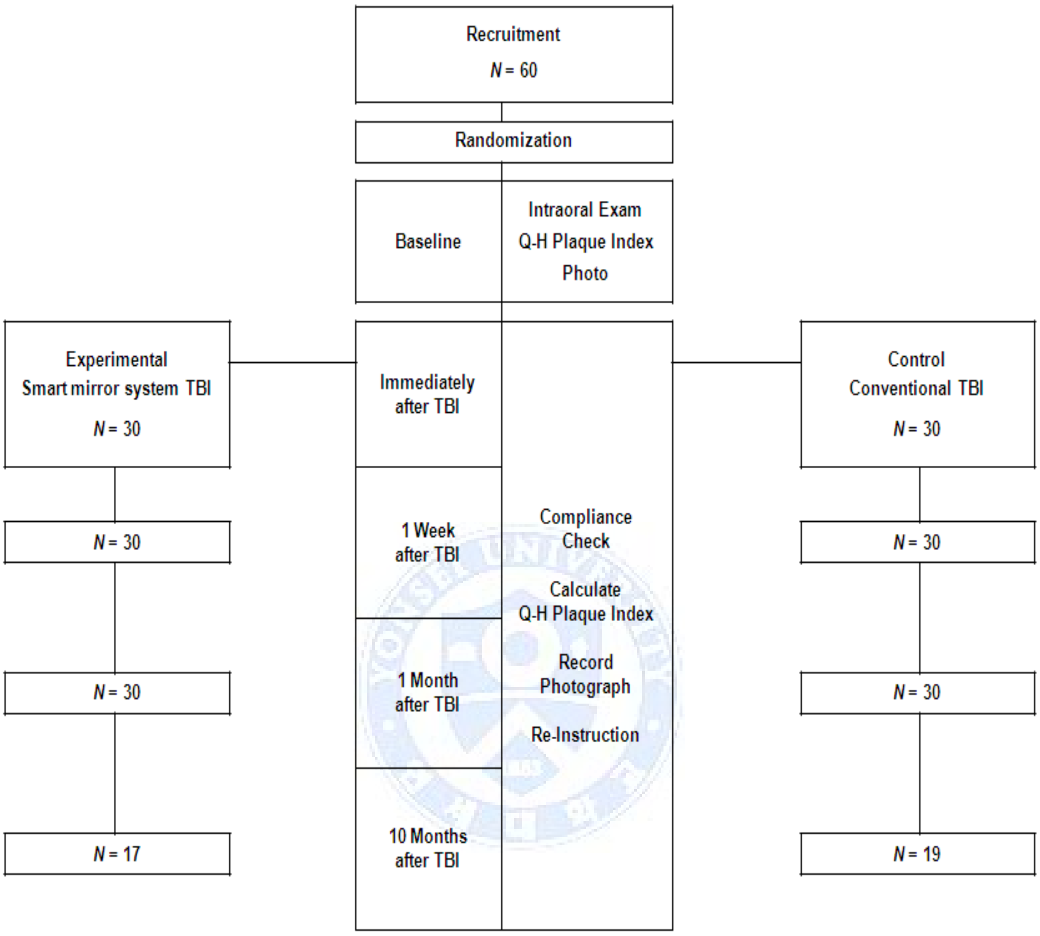

Figure 3. Study design (Smart mirror system - adults).

At the first visit the volunteers provided consent. To record the initial status, a disclosing solution (Two-Tone, Young Dental manufacturing company, Earth City, MO, USA) was applied to the surfaces of all teeth by swishing for 1 minute.

After mouth gargling, the Turesky modification of the Quigley-Hein index (Quigley and Hein, 1962, Turesky *et al*., 1970, Table 1) was measured by visual inspection and subsequently confirmed with photography.

Table 1. Modified plaque scoring system of Turesky

Description	Score
No plaque	0
Isolated flecks of plaque at the cervical margin of the tooth	1
A thin continuous band of plaque (up to 1 mm) at the cervical margin of the tooth	2
A band of plaque wider than 1 mm covering less than one-third of the tooth crown	3
Plaque covering at least one-third but less than two-thirds of the tooth crown	4
Plaque covering two-thirds or more of the tooth crown	5

Scoring by the Turesky modification:
(1) All teeth assessed except third molars (no more than 28)
(2) A staining solution is used to show plaque deposits (Quigley and Turesky used basic fuchsin)
(3) Both the facial and lingual surfaces examined (no more than 56)
(4) A score is assigned to each facial and lingual nonrestored surface
Total score = SUM (scores for all facial and lingual surfaces)
Index = (total score) / (number of surfaces examined)

The smart mirror TBI system was applied to the experimental groups, while conventional TBI was performed in the control group. After instrumentation, the disclosing solution was applied again and the plaque index was re-evaluated.

Three subsequent visits were at about 1 week, 1 month, and 10 months (adults only) after TBI to examine the short-term and long-term maintenance effectiveness of TBI. The subjects were asked to brush their teeth before coming to the dental clinic and the plaque index was evaluated in the same manner as at the first visit, using disclosing solution and clinical photographs. The subjects were instructed to brush their teeth at home for 3 minutes three times daily, after each meal, as recommended by the Korean Dental Association. All subjects participated in every trial except for the last visit (10 months after TBI), when only 17 from the experimental group and 19 from the control group visited.

One dental hygienist who was blinded to both groups scored the amounts of plaque on the buccal and lingual surfaces of all teeth except for the third molars.

The percentages of plaque removal at each surfaces and whole mouth were determined with the formula: percentage plaque reduction = (pre-post)/pre x 100 (pre = prebrushing plaque value; post = postbrushing plaque value). To reduce subjectivity errors associated with assessing the plaque index by visual inspection, clinical photographs were used for confirmation. The examiner exhibited a demonstrated intra-examiner unweighted kappa statistic of 0.81 for the plaque index.

2.2 TBI using smartphone system at home for children

In total, 102 students from an elementary school in Gyeonggi-do, Korea were recruited to this study (Figure 4). All of the children volunteered to take part in the study after reading a recruitment letter that provided a written explanation of the study background. Consent to participate was obtained from both the children and their parents. The following inclusion criteria were applied: (1) age 7 - 12 years, (2) dentition comprising more than 12 teeth, (3) good general health, and (4) able to use a smartphone. The exclusion criteria were the presence of (1) systemic diseases, (2) periodontitis, (3) a fixed orthodontic appliance, and (4) allergies to dental materials. This clinical study was approved by the Public Institutional Bioethics Committee designated by the Minster of Health and Welfare of Korea (approval number: P01-201406-BM-32-02).

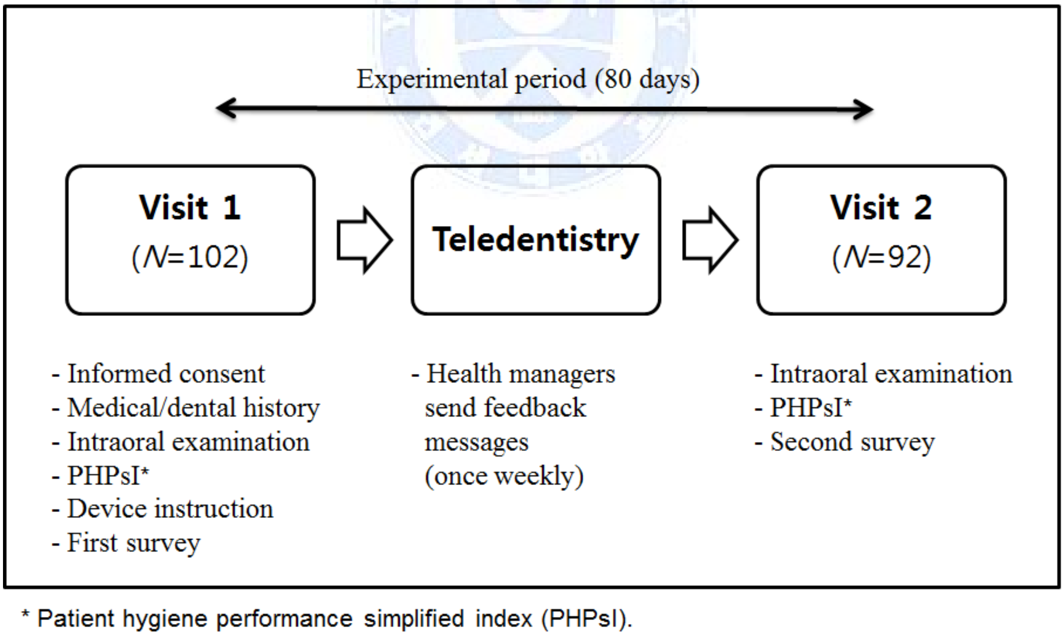

Figure 4. The flowchart of TBI with smartphone system for children.

The present study was carried out by three health managers (dental hygienists) who are experts in TBI and dental plaque examination. These three health managers had a demonstrated inter-examiner unweighted kappa statistic of 0.73 for the dental plaque index. At baseline (July 23, 2014), all subjects were told to brush their teeth before attending school, where their dental plaque status was recorded using an index system developed by Podshadley and Haley in 1968 (Figure 5), called the Patient Hygiene Performance Simplified Index (PHPsI; Disclosing Solution Concentrate, Sultan Healthcare, Hackensack, NJ, USA), which involves assessing the plaque indices on the labial surfaces of the maxillary right and mandibular left central incisors (tooth numbers 11 and 31, respectively), the buccal surfaces of the maxillary right and left first molars (tooth numbers 16 and 26, respectively), and the lingual surfaces of the mandibular left and right first molars (tooth numbers 36 and 46, respectively).

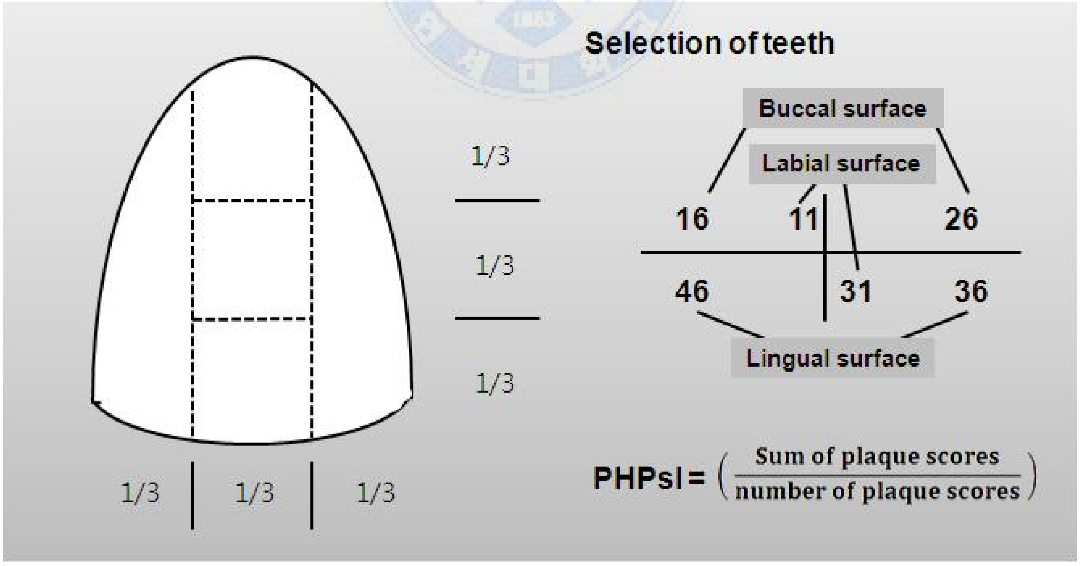

Figure 5. Patient hygiene performance simplified index (PHPsI).

The children then completed a survey (Table 2). All of the subjects were helped with installing the smartphone APP on their smartphones or, in the case of children who did not own a smartphone, their parents' device, and were taught how to use the system. Their email addresses were used to register a unique ID.

They were asked to brush their teeth by following precisely the animation displayed on their smartphone at least twice daily, and then to save and send the data to the server. The health managers sent feedback messages to all subjects once weekly according to the data received from them. Messages were thus individualized according to the toothbrushing scores generated by the system relative to toothbrush performance at 1 of 25 default segments of the entire dentition. The students were informed that an oral care suite was available for all of the participants to use during the experiment, and that the most active ones would receive a special gift.

The PHPsI was measured again at the second appointment (October 12, 2014), and all subjects were asked to complete a secondary survey, which was the same as the survey completed at baseline except for an additional three questions (Table 2).

Children who spent less than two minutes on toothbrushing or brushed their teeth less than two times each day were assigned into group one, the rest were assigned into group two. The data from the two groups were then compared.

Table 2. The surveys for children at baseline and the second visit. (Smartphone system)

Surveys	Questions	Descriptions
First survey (baseline)	Q1	Have you ever received toothbrushing instruction?
	Q2*	How long does it take for you to brush your teeth?
	Q3*	How many times do you usually brush your teeth each day?
Second survey (second visit)	Q4	Do you think you need a health manager to monitor your toothbrushing practice?
	Q5	What do you think is the most useful function of this system?
	Q6	Do you think your toothbrushing skill has been improved by using this system?

*Questions also included in the second survey

3. Statistical analysis

3.1 TBI with smart mirror system

Statistical analysis was performed using the SAS software package (version 9.1, SAS Institute, Cary, NC, USA) for adults and IBM SPSS statistics (version 21, SPSS Inc, Chicago, IL) for children. The statistical analysis used the linear mixed model with parameters of time period (baseline, immediately, 1 week, 1 month, and 10 months after TBI) for adults and repeated measures ANOVA (baseline, immediately, 1 week and 1 month) for children. Student *t*-test was conducted and 95% confidence interval of the difference was analysed for both experiments. The lower limit for non-inferiority was set at 15%, for an 15% statistically significance in plaque reduction is needed to provide evidence of greater effectiveness in the cleaning of teeth (ADA, Acceptance Program Guidelines-Toothbrushes, 2012).

3.2 TBI with smartphone system

The mean PHPsI was calculated for each participant at both appointments. Changes in the mean PHPsI for all participants, and in the plaque indices for tooth numbers 16, 26, 36, 46, 11, and 31 between baseline and 80 days were analyzed using the Mann-Whitney U test. The two groups were compared regarding the changes in PHPsI using repeated measures ANOVA. Statistical analyses were conducted using SPSS software (version 21, SPSS Inc, Chicago, IL).

Except where stated otherwise, the data are presented as mean±SD values, and the threshold for statistical significance was set at $P<.05$.

III. Results

1. Efficacy of smart mirror system in adults

Among all participants, 93% were right-handed. The maximum and minimum numbers of teeth were 28 and 12, respectively (26.4±2.8 teeth). Most of the participants (75%) had not received TBI previously (Table 3).

The mean prebrushing plaque scores for the whole mouth were 2.26 and 2.17 in the smart mirror group and conventional-TBI group, respectively. Table 4 presents the changes in the plaque index. In all subjects, the plaque index had changed most significantly at the first visit. For both groups, TBI effects of each period at all sites(whole mouth, buccal, and lingual) proved beneficial in terms of plaque reduction ($P<0.0001$), while there were no statistical differences between two groups ($P>0.05$).

Table 3. Demographics (N=60). Except where stated otherwise, the data are N (%) values (adults)

Characteristics	
Age (years)	
Mean ± SD	35.7 ± 10.9
Range	20 - 57
Gender	
Female	36 (60%)
Male	24 (40%)
Hand typically used for brushing	
Right	56 (93%)
Left	1 (2%)
Ambidextrous	3 (5%)

Table 4. Turesky-modified Quigley-Hein plaque indexes and plaque reduction percentages (adults)

	Whole mouth		Buccal		Lingual	
	Smart mirror TBI	Conventional TBI	Smart mirror TBI	Conventional TBI	Smart mirror TBI	Conventional TBI
Baseline	2.26 ± 0.83	2.17 ± 0.81	2.03 ± 0.88	1.99 ± 0.73	2.49 ± 0.93	2.35 ± 1.03
Immediately after TBI	0.89 ± 0.65	1.02 ± 0.6	0.80 ± 0.71	0.85 ± 0.58	0.98 ± 0.68	1.19 ± 0.75
1 Week after TBI	1.37 ± 0.59	1.14 ± 0.68	1.18 ± 0.55	1.04 ± 0.64	1.56 ± 0.76	1.24 ± 0.79
1 Month after TBI	1.23 ± 0.50	1.06 ± 0.53	1.12 ± 0.52	0.99 ± 0.65	1.34 ± 0.61	1.13 ± 0.58
10 Months after TBI	1.89 ± 0.72	1.77 ± 0.69	1.61 ± 0.77	1.60 ± 0.87	2.17 ± 0.85	1.93 ± 0.73
Mean decrease	39.88%	42.95%	40.94%	45.84%	38.04%	39.74%
P-value*	0.9035		0.609		0.8734	

* Group interaction by linear mixed model

The effects over the whole mouth did not differ between smart mirror system and conventional TBI (P=0.9035). In the experimental group, the plaque index for the whole mouth decreased from 2.26 to 0.89, the reduction percentage over the entire study period was 39.88%, and the incremental reductions were 62.64%, 38.55%, 43.34%, and 14.97% immediately, 1 week, 1 month, and 10 months after TBI, respectively. In the control group, the plaque index for the whole mouth decreased from 2.17 to 1.02, the mean plaque reduction over the entire study period was 42.95%, and the incremental reductions were 54.86%, 48.40%, 49.54%, and 18.99% immediately, 1 week, 1 month, and 10 months after TBI, respectively (Figure 6, Figure 7). Non-inferiority of changes in percentage of mean plaque reduction for whole mouth was validated immediately after TBI. There were no significant differences in the plaque-removal effects on both the buccal and lingual sides with both methods (P=0.18 and P=0.69, respectively). Non-inferiority of smart mirror system in plaque reduction percentage immediately after TBI at all researched sites was validated.

Furthermore, sub-analysis was done at maxillary molars. Significant differences were found at both groups immediately, 1 week, 1 month, and 10 months after TBI, while statistical analysis revealed no differences between two groups regarding plaque index reduction (P=0.296). Non-inferiority was validated in changes in percentage of mean plaque reduction immediately and one week after TBI for maxillary molars (Figure 8).

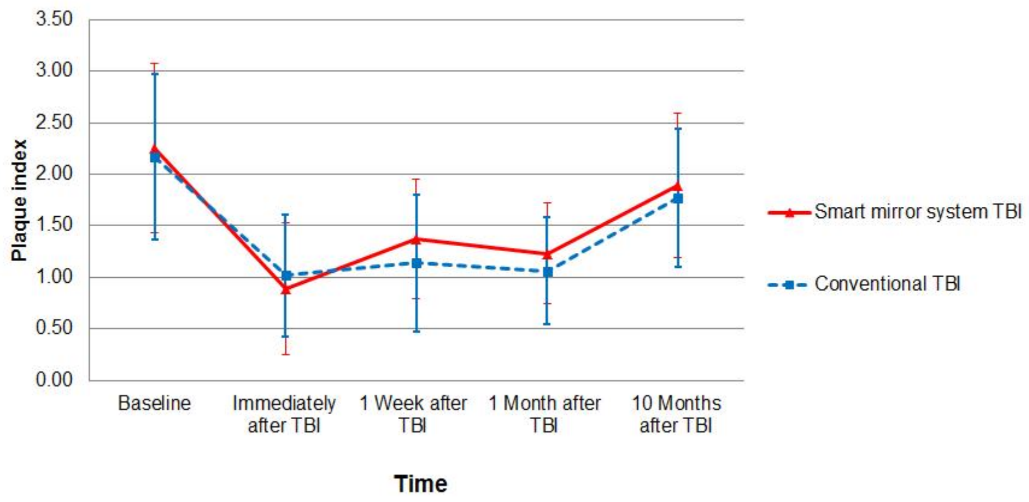

Figure 6. Changes in plaque indexes of whole mouth at four time points of both Smart mirror system TBI and Conventional TBI (adults).

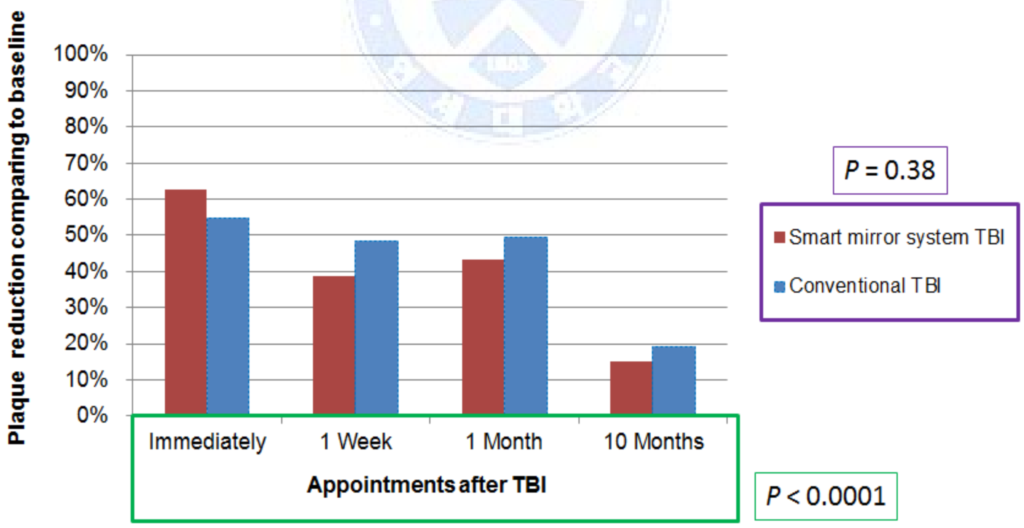

Figure 7. Changes in percentage of mean plaque reduction compare with baseline for whole mouth (adults).

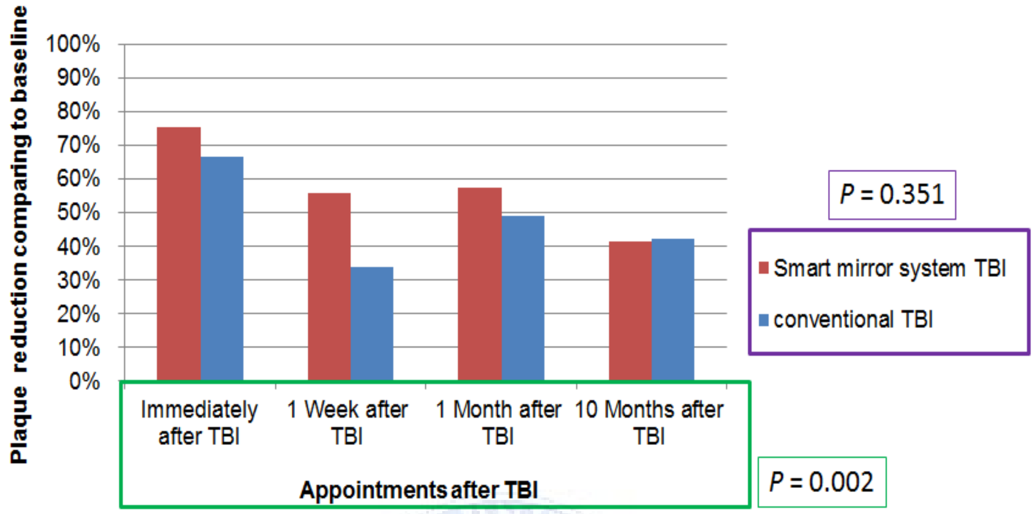

Figure 8. Changes in percentage of mean plaque reduction compare with baseline for maxillary molars (adults).

2. Efficacy of smart mirror system in children

Among all participants, 93% were right-handed. The maximum and minimum numbers of teeth were 28 and 12, respectively (21.93±4.06 teeth) (Table 5).

The mean pre-brushing plaque scores for the whole mouth were 3.31 and 3.21 in the computer-assisted-TBI and conventional-TBI groups, respectively. Table 6 shows the changes in the plaque index. According to the statistical analysis, TBI effects of each period for both groups proved beneficial in terms of plaque reduction percentage for whole mouth ($P < 0.0001$). The effects over the whole mouth did not differ between computer-assisted TBI and conventional TBI (P=0.424).

In the experimental group, the plaque index for the whole mouth decreased from 3.31 to 1.99, the mean plaque reduction over the entire study period was 40.5%, and the incremental reductions were 40.33%, 40.33%, and 40.84% immediately, 1 week, and 1 month after TBI, respectively. In the control group, the plaque index for the whole mouth decreased from 3.21 to 2.06, the mean plaque reduction over the entire study period was 40.57%, and the incremental reductions were 37.67%, 35.06%, and 48.96% immediately, 1 week, and 1 month after TBI, respectively (Table 6, Figure 9, Figure 10). There were no significant differences in the plaque-removal effects on both buccal and lingual sides with both methods (P=0.694 and P=0.258, respectively). Non-inferiority of the smart mirror system in plaque reduction percentage at all researched sites was validated for the first two time points (immediately, one week after TBI).

Furthermore, sub-analysis was done at maxillary molars. Significant differences were found at both groups immediately, 1 week, and 1 month after TBI ($P < 0.0001$). The smart mirror system showed better result in plaque index reduction, while statistical analysis revealed no significant differences (P=0.118, Figure 11).

Table 5. Demographics (N=42). Except where stated otherwise, the data are N (%) values (children)

Characteristics	
Age (years)	
Mean ± SD	9.64 ± 1.96
Range	6 - 12
Gender	
Female	21 (50%)
Male	21 (50%)
Hand typically used for brushing	
Right	39 (93%)
Left	3 (7%)
Ambidextrous	0 (0%)

Table 6. Turesky-modified Quigley-Hein plaque indexes and plaque reduction percentages (children)

	Whole mouth		Buccal		Lingual	
	Smart mirror TBI	Conventional TBI	Smart mirror TBI	Conventional TBI	Smart mirror TBI	Conventional TBI
Baseline	3.31 ± 0.80	3.21 ± 0.81	3.77 ± 0.92	3.65 ± 0.88	2.86 ± 0.90	2.76 ± 0.96
Immediately after TBI	1.99 ± 0.73	2.06 ± 0.90	2.03 ± 0.78	2.12 ± 0.99	1.96 ± 0.79	1.99 ± 0.97
1 Week after TBI	2.01 ± 0.78	2.12 ± 0.98	2.11 ± 0.97	2.24 ± 1.07	1.91 ± 0.81	2.01 ± 0.96
1 Month after TBI	1.88 ± 0.67	1.72 ± 0.95	1.91 ± 0.90	1.90 ± 1.13	1.86 ± 0.65	1.54 ± 0.82
Mean decrease	40.50%	40.57%	46.69%	43.83%	31.05%	33.89%
P-value*	0.424		0.694		0.258	

* Group interaction by repeated-measures ANOVA

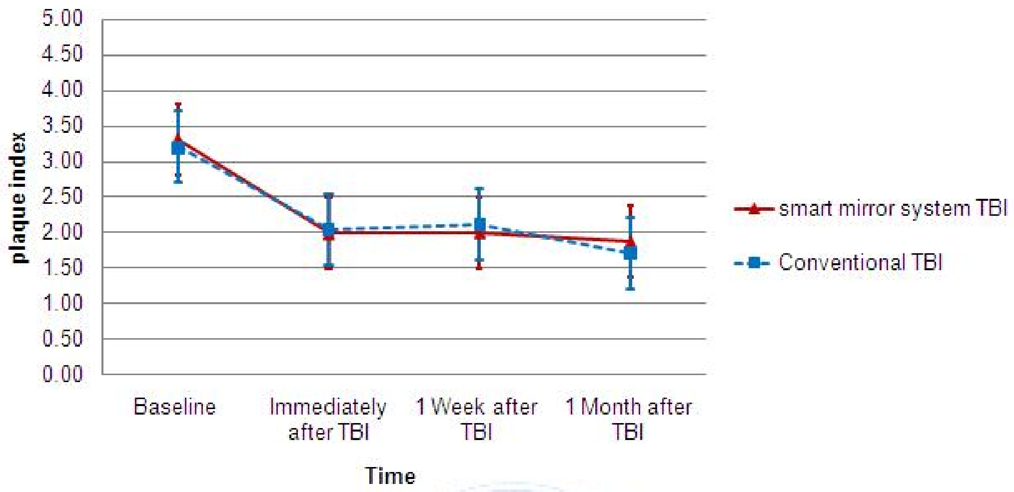

Figure 9. Changes in plaque indexes of whole mouth at four time points of both Smart mirror system TBI and Conventional TBI (children).

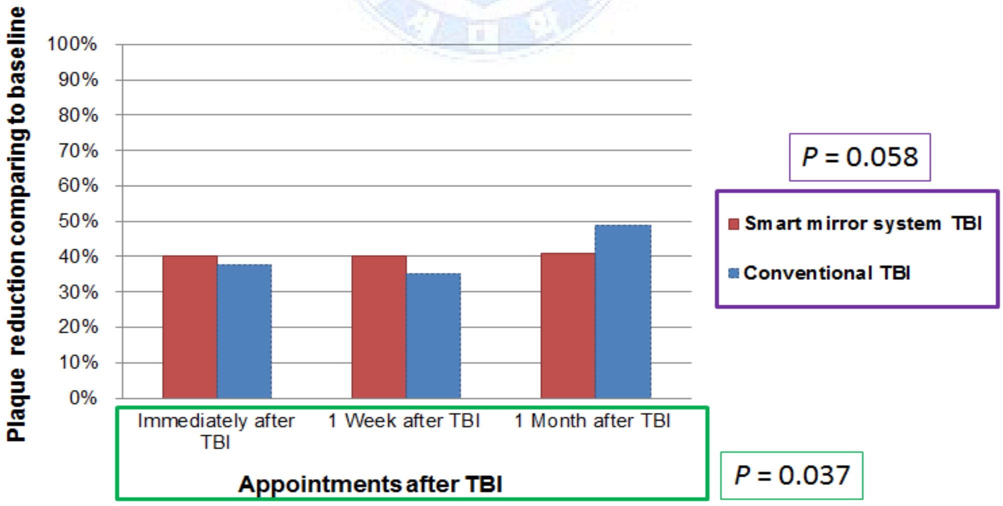

Figure 10. Changes in percentage of mean plaque reduction compare with baseline for whole mouth (children).

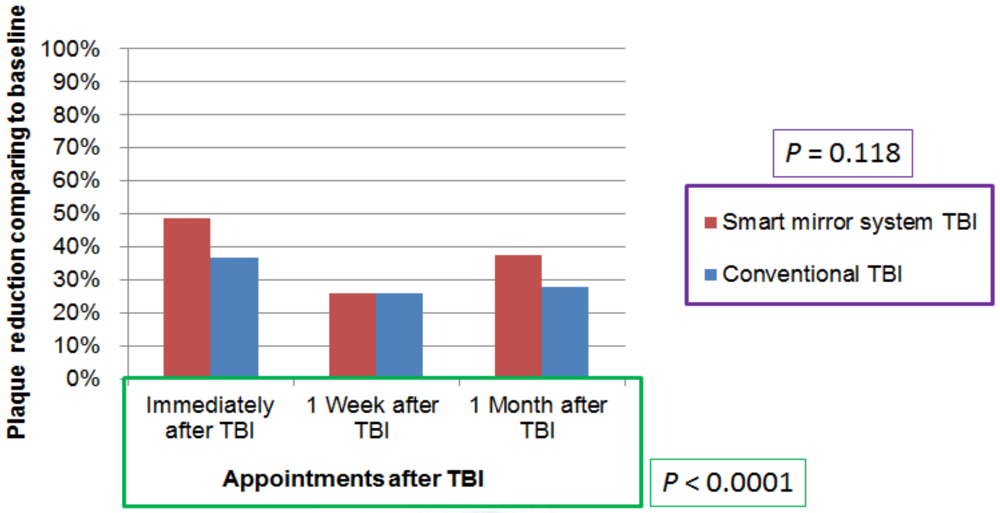

Figure 11. Changes in percentage of mean plaque reduction compare with baseline for maxillary molars (children).

3. Efficacy of smartphone system in children

In total, 102 subjects were recruited, of whom 92 (48 males and 44 females) completed the 80-day experimental protocol between July and October 2014. These 92 students ranged in age from 7 to 12 years (mean=10.75 years, Table 7). The subject dropouts were due to withdrawal at the first appointment (N=1), withdrawal during the experimental period (N=3), and neglecting to send data to the server (N=6).

Stratification of the 92 subjects into two groups according to their toothbrushing habits resulted in 55 students in group 1 and 37 students in group 2.

Table 7. Demographics (N=92). Except where stated otherwise, the data are N (%) values (Smartphone system)

Characteristics	
Age (years)	
Mean ± SD	10.75 ± 1.79
Range	7 - 12
Gender	
Female	44 (48%)
Male	48 (52%)
Hand typically used for brushing	
Right	76 (83%)
Left	7 (7%)
Ambidextrous	9 (10%)

3.1 Comparison of PHPsI changes between two groups

The mean PHPsI values of the two groups at baseline were 2.55±0.96 and 2.69±1.07, and 1.81±0.81 and 1.80±0.80 at 80 days, respectively (P=0.041). Significant reduction in mean PHPsI values were found (P<0.0001), however, statistic analysis revealed no significant difference between two groups at any of the two time points (Table 8).

Table 8. PHPsI results. Data are mean and standard-error values

	Baseline	80 days	P*	Reduction (%)
Total (N=92)	2.61 ± 1.00	1.81 ± 0.80	< 0.0001	22.49 ± 45.03%
Group 1† (N=55)	2.55 ± 0.96	1.81 ± 0.81	< 0.0001	20.33 ± 47.10%
Group 2‡ (N=37)	2.69 ± 1.07	1.80 ± 0.80	< 0.0001	25.70 ± 42.19%

* Comparison between baseline and 80days by repeated measures ANOVA

† Students who brush their teeth < 2 mins

‡ Students who brush their teeth ≥ 2 mins

3.2 Plaque changes by site of dentition

The mean PHPsI values for the labial surfaces of tooth numbers 11 and 31 were improved by 0.26 and 0.64 respectively, for group 1 and 2, and the buccal surfaces of tooth numbers 16 and 26 were improved by 1.25 and 1.22 respectively, for group 1 and 2, and the lingual surfaces of tooth numbers 36 and 46 were improved by 0.71 and 0.82 respectively, for group 1 and 2. The percentage of PHPsI reduction for each site of the dentition (i.e. labial, buccal, and lingual) was found to be statistically significant ($P<0.001$), with no significant difference between the teeth within each site in terms of plaque reduction. The Mann-Whitney U test revealed that there were no significant differences in PHPsI reduction between the two groups at the buccal surfaces of tooth numbers 16 and 26 ($P=0.697$), the lingual surfaces of tooth numbers 36 and 46($P=0.490$), and the labial surfaces of tooth numbers 11 and 31($P=0.220$, Figure 12).

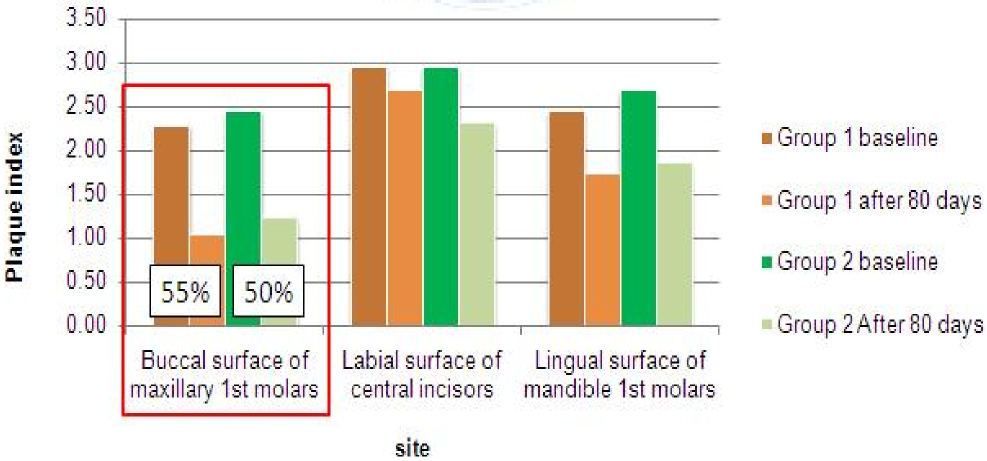

Figure 12. Changes in PHPsI by site of dentition.

3.3 Survey results

Table 2 gives the questions presented in the baseline and 80 days surveys regarding changes in the subjects'toothbrushing pattern. At the first survey, 59 (64%) of the subjects had been provided with TBI, while the remainder (*N*=33; 36%) were reported as not having had TBI. Furthermore, at baseline 90 (98%) students reported they brushed their teeth two or three times a day, while at 80 days that number had decreased to 85 (92%). As for the length of toothbrushing, 37 (40%) children took more than 2 minutes to brush their teeth at baseline, and this number increased to 50 (65%) at the 80 days appointment. At the second survey, 87 (95%) subjects felt that it was important to have a health manager who could monitor their toothbrushing-practice data and remind them of the importance of toothbrushing. Regarding the most useful function of the 44 (48%) students chose the option of "animation guidance," 26 (28%) chose "data recording function," and 21 (23%) considered that the health manager provided the most help. Fifty-one (55%) of the children reported that they believed their toothbrushing skills had improved after the intervention.

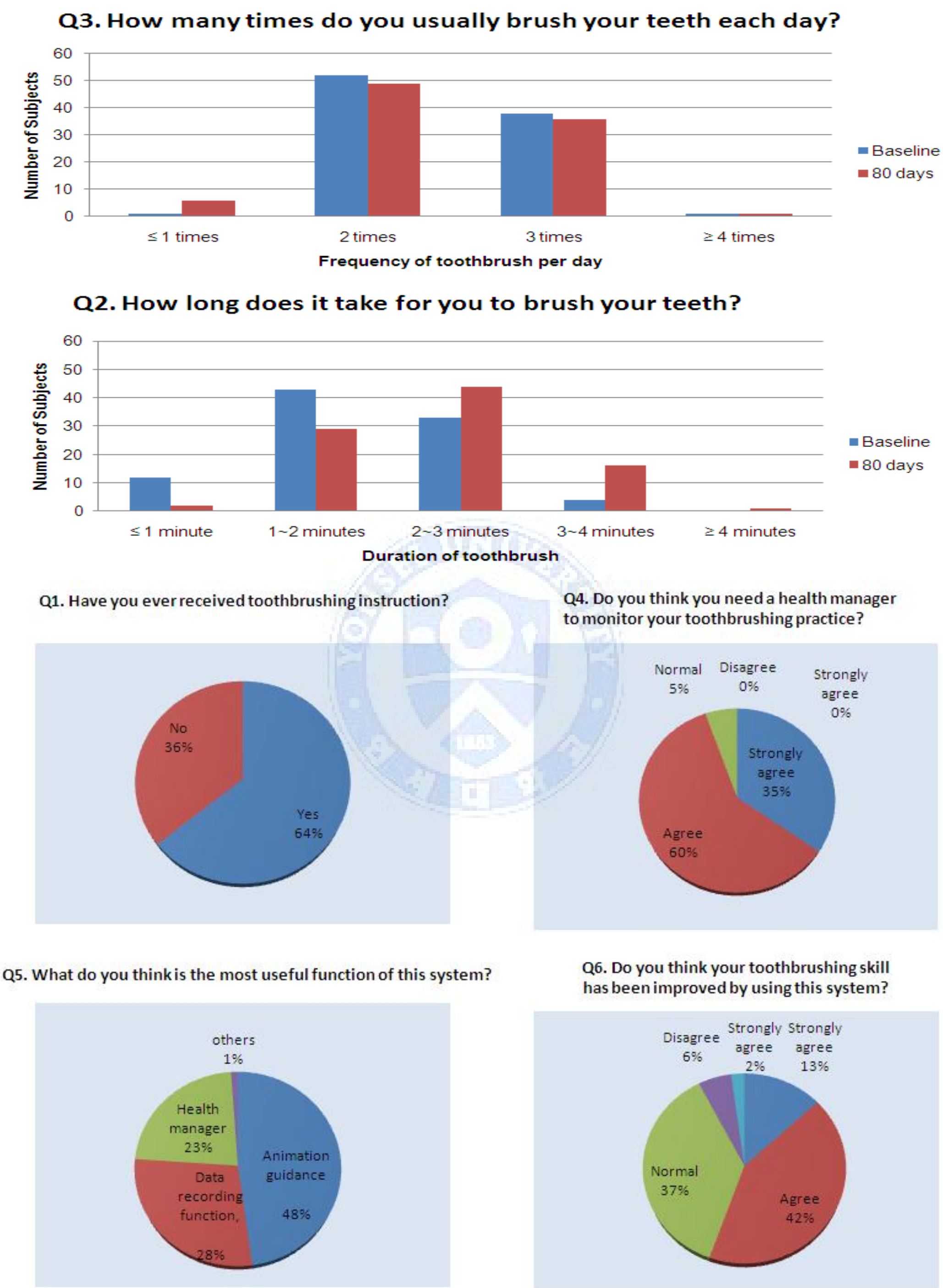

Figure 13. Results of questions at survey.

IV. Discussion

Plaque control plays a very important role in oral health, and toothbrushing is the most effective method of plaque control (Finkelstein and Grossman, 1984). However, toothbrush practice is not an innate talent, but rather a learned skill that requires professional TBI. TBI aims at maintaining the habit of teeth brushing and promoting appropriate brushing patterns (Kim *et al.*, 2009). Correct brushing patterns include holding the bristles at a 45 degree angle with the tooth surface, brushing the upper teeth from top to bottom and the lower teeth from bottom to top, and performing toothbrushing for at least a certain minimum duration (Horner and Keilitz, 1975; Yankell and Emling, 1994; Volpenhein *et al.*, 1996; Loe, 2000). In the present study, two TBI systems which were capable of detecting 3D motion were tested with children and adults as subjects, either in dental clinic or at home.

Williams *et al.* reported that toothbrushing for 1 and 3 minute using a battery-powered toothbrush was more effective for plaque removal than manual toothbrushing, and so recommended 3 minute toothbrushing for the complete removal of plaque (Williams *et al.*, 2004). Walters *et al.* investigated an Oral-B Triumph with SmartGuide device (Procter & Gamble, Cincinnati, OH, USA), which has an adjustable time setting, clinically tested oscillating-rotating technology, and a wireless remote display to encourage a good brushing technique and increase brushing time (Walters *et al.*, 2007). McCracken *et al.* also reported the usefulness of a data-logger toothbrush in promoting compliance relative to using a manual toothbrush (McCracken *et al.*, 2005). Nevertheless, these electronic toothbrushes are not able to detect the location or movement of the toothbrush in real time.

The smart mirror system analyzes the position and movement of the toothbrush using a 3D accelerometer. Moreover, these digital data can be accumulated in a database for periodic assessments of the toothbrushing habit. A pattern of toothbrushing in a specific period can be analyzed, and the feedback therefrom can improve a patient's compliance with new brushing techniques. The brushing time for each site is initially set to 10 seconds, but this can easily be lengthened or shortened using software options. Moreover, oral health-care providers can emphasize particular sites requiring attention using customized settings for each individual. For example, for a patient who does not clean efficiently on the lingual side, the smart mirror system can instruct the patient to brush on the lingual side for a longer time, such as 20 seconds. In short, this smart mirror system allows patient-customized analysis, control, and instruction. These advantages would be very helpful not only for adults but also for children, since it is well known that children are more likely to have high levels of plaque, and because toothbrushing patterns are established early in childhood (Redmond *et al*., 1999; Jones *et al*., 1996), this prompted the use of children as subjects in the present study. Because of the difficulties in following up with young patients, the second part of this study excluded the one-year follow up.

Our results, with either adults or children as subjects, showed that there were no significant differences shortly after TBI in the non-inferiority trial between the experimental and control groups. In another words, the two TBI methods have statistically identical effects on plaque control; however, the smart mirror system has advantages such as individualization, data reporting, and long-term maintenance. First, individualization means that this device controls the instruction time for each patient. Second, it helps to visualize the toothbrushing movement as a score and in reports, which identify any weak sites for plaque control and motivate the patient to brush those sites. Third, the toothbrushing movement data are stored on a computer, so the pattern of toothbrushing can be analyzed and will be very useful for long-term control of dental plaque.

In the third part of present study, a smartphone system capable of detecting 3D motion was tested as an alternative method for TBI, which has the added advantage that it can provide repeated education wherever the user has a smartphone. Moreover, every week the user receives a feedback message from a health educator who is able to review their toothbrushing data, and thereby reinforce their instruction.

Comparison of the 80 days (1.81±0.80) and baseline (2.61±1.00) PHPsI values revealed a significant reduction (22.49%) that is attributable to use of the smartphone system ($P<0.001$). A school-based education program for improving oral cleanliness yielded plaque-reduction rates for boys and girls of 45.2% and 51.8%, respectively, in a leaflet-based TBI group, and 48.8% and 18.3%, respectively, in a videotape-based TBI group (Yazdani *et al.*, 2009). Furthermore, post-intervention improvements in oral performance of 84% and 77% were found for the leaflet and videotape education groups, respectively; in the present study, the smartphone system induced an increase in oral performance (in terms of PHPsI) of 75%. The difference in plaque reduction rate between the studies may be attributable to differences in baseline PHPsI between the subjects, or differences between the studies in the plaque index systems employed to evaluate oral cleanliness.

One aim of the present study was to determine the effect of the smartphone system in different sites of the dentition. The change in PHPsI on the lingual surfaces of mandibular first molar was thus compared to that of the buccal surfaces of tooth numbers 16 and 26 and the labial surfaces of tooth numbers 11 and 31. The PHPsI had decreased the most after the intervention for the buccal surfaces of tooth numbers 16 and 26, and the least for the labial surfaces of tooth numbers 11 and 31. This finding may be due to the plaque indices of the anterior dentition at baseline being the lowest of all the teeth evaluated, so that the efficacy of education would not have been as marked as in dentition with a higher initial plaque index.

According to the results of the two surveys, 90 (98%) of the students reported that they brushed their teeth two or three times a day at baseline, while that number dropped to 85 (92%) after the intervention, however, there was no statistically significant difference between the two values. Although fewer children appeared to choose to brush their teeth two or three times per day after the intervention, this does not negate the finding that they benefited from the system in terms of a reduction in the mean PHPsI and, according to the findings of the second survey, an improvement in toothbrushing skills (55% of all participants).

Following the intervention of the smartphone system, the subjects in both groups exhibited favorable improvements in dental plaque control. Van der Weijden *et al.* recommended 2 minutes of toothbrushing as a suitable interval for children (Van der Weijden *et al.*, 1996), while the system used in the present research set an interval of 3 minutes as a default. There were no significant differences found between two groups in terms of plaque index reduction, proved that the smartphone system has similar effects on children with good toothbrushing habit or poor toothbrushing habit. Regarding the question "How long does it take for you to brush your teeth?" in the surveys, 37 (40%) children reported taking more than 2 minutes at baseline, while that number at the 80 days (post–intervention) appointment had increased to 60 (65%).

However, the valuable results on the positive effects of both systems on improvement in toothbrushing skills and dental plaque control presented herein must be considered in light of several limitations. First, the method of movement detection cannot adapt to every toothbrushing method; the current software can only analyze rolling movements of the toothbrush, and the rolling method is not widely educated in other countries, hence the modified Bass or Fonse method should be integrated into the system in the future. Second, there is a weakness in sensing toothbrush movement in the palatal molar site (Kim *et al.*, 2009). Third, the smart mirror system and smartphone based system used in present study cannot detect toothbrush force applied to the tooth surfaces and integrate that into the scoring system, this may result in weak correlation between the success or failure of this instruction and the degree of plaque control. Fourth. the hawthorne effect should be considered when evaluated the effects of both systems. Lastly, the third part of the present study was not a randomized controlled clinical study, because the primary focus was to test the usability and effectiveness of the new system, and because it is not easy to control every parameter in a home setting, especially when children are involved.

Further study is required as the system is developed to analyze the correlation between the reported scores and the actual degree of dental plaque control achieved. We do not think that these 3D motion tracking TBI systems can completely replace conventional TBI systems. Periodic visits to the dental clinic and professional plaque control are still the best methods of plaque control.

However, we do think that an IT-based toothbrush can motivate patients to brush more and make other improvements to their toothbrushing habits.

V. Conclusions

The two TBI systems tested showed comparative effects in plaque control with traditional TBI. The new TBI systems can hardly replace the conventional TBI, periodic visits to the dental clinic and professional plaque control are still the best methods for oral hygiene. However, an IT-based toothbrush could motivate individuals to brush more and make other improvements to their toothbrushing habits.

References

AXELSSON, P., LINDHE, J. & NYSTROM, B. 1991. On the prevention of caries and periodontal disease. Results of a 15-year longitudinal study in adults. *J Clin Periodontol,* 18, 182-9.

AXELSSON, P., NYSTROM, B. & LINDHE, J. 2004. The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. *J Clin Periodontol,* 31, 749-57.

ENGELMAYER, H. & LANG, N. P. 1979. [Oral hygiene habits in a group of Swiss soldiers age 28-32 years]. *SSO Schweiz Monatsschr Zahnheilkd,* 89, 1103-11.

FINKELSTEIN, P. & GROSSMAN, E. 1984. The clinical quantitative assessment of the mechanical cleaning efficiency of toothbrushes. *Clin Prev Dent,* 6, 7-12.

GEBRUERS, N., VANROY, C., TRUIJEN, S., ENGELBORGHS, S. & DE DEYN, P. P. 2010. Monitoring of physical activity after stroke: a systematic review of accelerometry-based measures. *Arch Phys Med Rehabil,* 91, 288-97.

GROSSMAN, E. & PROSKIN, H. 1997. A comparison of the efficacy and safety of an electric and a manual children's toothbrush. *J Am Dent Assoc,* 128, 469-74.

HELLSTADIUS, K., ASMAN, B. & GUSTAFSSON, A. 1993. Improved maintenance of plaque control by electrical toothbrushing in periodontitis patients with low compliance. *J Clin Periodontol,* 20, 235-7.

HORNER, R. D. & KEILITZ, I. 1975. Training Mentally-Retarded Adolescents to Brush Their Teeth. *Journal of Applied Behavior Analysis,* 8, 301-309.

JEHN, M., SCHMIDT-TRUCKSAESS, A., SCHUSTER, T., HANSSEN, H., WEIS, M., HALLE, M. & KOEHLER, F. 2009. Accelerometer-based quantification of

6-minute walk test performance in patients with chronic heart failure: applicability in telemedicine. *J Card Fail,* 15, 334-40.

JONES, S., HUSSEY, R. & LENNON, M. A. 1996. Dental health related behaviours in toddlers in low and high caries areas in St Helens, north west England. *Br Dent J,* 181, 13-7.

KIM, K. S., YOON, T. H., LEE, J. W. & KIM, D. J. 2009. Interactive toothbrushing education by a smart toothbrush system via 3D visualization. *Comput Methods Programs Biomed,* 96, 125-32.

KISHIMOTO, M., YOSHIDA, T., HAYASAKA, T., MORI, D., IMAI, Y., MATSUKI, N., ISHIKAWA, T. & YAMAGUCHI, T. 2009. An internet-based wearable watch-over system for elderly and disabled utilizing EMG and accelerometer. *Technol Health Care,* 17, 121-31.

LEE, H. K., HWANG, S. J., CHO, S. P., LEE, D. R., YOU, S. H., LEE, K. J., KIM, Y. H. & CHOI, H. S. 2009. Novel algorithm for the hemiplegic gait evaluation using a single 3-axis accelerometer. *Conf Proc IEEE Eng Med Biol Soc,* 2009, 3964-6.

LEE, J. W., LEE, K. H., KIM, K. S., KIM, D. J. & KIM, K. 2006. Development of smart toothbrush monitoring system for ubiquitous healthcare. *Conf Proc IEEE Eng Med Biol Soc,* 1, 6422-5.

LOE, H. 2000. Oral hygiene in the prevention of caries and periodontal disease. *Int Dent J,* 50, 129-39.

MCCRACKEN, G., JANSSEN, J., HEASMAN, L., STACEY, F., STEEN, N., DEJAGER, M. & HEASMAN, P. 2005. Assessing adherence with toothbrushing instructions using a data logger toothbrush. *Br Dent J,* 198, 29-32; discussion 24.

QUIGLEY, G. A. & HEIN, J. W. 1962. Comparative cleansing efficiency of manual and power brushing. *J Am Dent Assoc,* 65, 26-9.

REDMOND, C. A., BLINKHORN, F. A., KAY, E. J., DAVIES, R. M., WORTHINGTON, H. V. & BLINKHORN, A. S. 1999. A cluster randomized controlled trial testing the effectiveness of a school-based dental health education program for adolescents. *J Public Health Dent,* 59, 12-7.

SHARMA, S., YELURI, R., JAIN, A. A. & MUNSHI, A. K. 2012. Effect of toothbrush grip on plaque removal during manual toothbrushing in children. *J Oral Sci,* 54, 183-90.

TAYLOR, J. Y., WOOD, C. L., GARNICK, J. J. & THOMPSON, W. O. 1995. Removal of interproximal subgingival plaque by hand and automatic toothbrushes. *J Periodontol,* 66, 191-6.

TURESKY, S., GILMORE, N. D. & GLICKMAN, I. 1970. Reduced plaque formation by the chloromethyl analogue of victamine C. *J Periodontol,* 41, 41-3.

VAN DER WEIJDEN, F. A., TIMMERMAN, M. F., SNOEK, I. M., REIJERSE, E. & VAN DER VELDEN, U. 1996. Toothbrushing duration and plaque removing efficacy of electric toothbrushes. *Am J Dent,* 9 Spec No, S31-6.

VAN DER WEIJDEN, G. A., TIMMERMAN, M. F., PISCAER, M., Y, I. J. & VAN DER VELDEN, U. 2004. Plaque removal by professional electric toothbrushing compared with professional polishing. *J Clin Periodontol,* 31, 903-7.

VOLPENHEIN, D. W., HANDEL, S. E., HUGHES, T. J. & WILD, J. 1996. A comparative evaluation of the in vitro penetration performance of the improved Crest complete toothbrush versus the Current Crest complete toothbrush, the Colgate Precision toothbrush and the Oral-B P40 toothbrush. *J Clin Dent,* 7, 21-5.

WALTERS, D. L., SARELA, A., FAIRFULL, A., NEIGHBOUR, K., COWEN, C., STEPHENS, B., SELLWOOD, T., SELLWOOD, B., STEER, M., AUST, M., FRANCIS, R., LEE, C. K., HOFFMAN, S., BREALEY, G. &

KARUNANITHI, M. 2010. A mobile phone-based care model for outpatient cardiac rehabilitation: the care assessment platform (CAP). *BMC Cardiovasc Disord,* 10, 5.

WALTERS, P. A., CUGINI, M., BIESBROCK, A. R. & WARREN, P. R. 2007. A novel oscillating-rotating power toothbrush with SmartGuide: designed for enhanced performance and compliance. *J Contemp Dent Pract,* 8, 1-9.

WILLIAMS, K., FERRANTE, A., DOCKTER, K., HAUN, J., BIESBROCK, A. R. & BARTIZEK, R. D. 2004. One- and 3-minute plaque removal by a battery-powered versus a manual toothbrush. *J Periodontol,* 75, 1107-13.

YANKELL, S. L. & EMLING, R. C. 1994. Laboratory interproximal access efficacy comparison of bi-level and flat bristled toothbrushes. *J Clin Dent,* 4, 128-30.

YAZDANI, R., VEHKALAHTI, M. M., NOURI, M. & MURTOMAA, H. 2009. School-based education to improve oral cleanliness and gingival health in adolescents in Tehran, Iran. *Int J Paediatr Dent,* 19, 274-81.

ZANIN, L., MENEGHIM, M. C., ASSAF, A. V., CORTELLAZZI, K. L. & PEREIRA, A. C. 2007. Evaluation of an educational program for children with high risk of caries. *J Clin Pediatr Dent,* 31, 246-50.

Abstract(in korean)

3차원 동작인식 기능이 내장된 칫솔을 이용한 치태조절의 유용성

(지도교수 김기덕)

연세대학교 대학원 치의학과

정 진 선

IT기술의 발달로 IT기술과 BT기술을 융합한 ubiquitous/mobile healthcare 기술을 사용하여, 질환의 예방과 관리가 이루어지고 있다.

컴퓨터를 이용한 칫솔질 교육 시스템인 스마트 미러 시스템(Smart Mirror system)과 핸드폰 기반의 원격 칫솔질 모니터링 시스템인 스마트폰 시스템(Smart Phone system)을 이용하여 치태조절 효과를 일반적인 칫솔질 교육과 비교해 보았다.

성인 60명과 어린이 42명을 대상으로 무작위로 두 그룹 (일반 칫솔질 교육, Smart mirror System 칫솔질 교육)으로 배정하였고, 칫솔질 교육 전의 치태를 평가 받고, 칫솔질 교육 후 즉시, 1 주일 후, 1달 후, 10달 후 (성인만 해당 됨) 각 시기별로 Quigley-Hein 치태 지수(Q-H index)를 이용하여 치태를 평가하였다.

또한 92명의 초등학생을 대상으로 첫날과 마지막 날에 간이 구강환경관리능력지수(PHPsI)를 이용한 치태평가와 설문조사를 실시하였고, 약 80일 동안 집에서

Smartphone system을 이용하여 칫솔질을 시행하도록 하였다. 설문조사를 통해 평소 칫솔질 습관이 좋은 학생 (2분 이상 칫솔질) 과 습관이 좋지 않은 학생 (2분미만 칫솔질) 으로 두 그룹으로 나눠 교육 전후 치태개선 효과를 비교해 보았다.

Smart mirror system을 이용한 실험에서 성인과 어린이 모두 시간의 변화에 따라 Q-H index는 두 그룹 모두 감소하였다. (성인 $P<0.0001$, 소아 $P<0.0001$) 성인과 소아 모두 Smart mirror system을 이용하여 칫솔질 교육을 받은 그룹과 일반적인 칫솔질 교육을 받은 그룹은 그룹간 차이가 없었다. (성인 $P=0.9035$, 소아 $P=0.424$) 추가로 비열등성 검정을 시행했을 때 교육 초기 시점에서 Smart mirror system을 이용하여 교육한 군은 일반적인 칫솔질 방법에 비해 열등하지 않았다.
Smartphone system도 두 그룹 모두 칫솔질 교육전 후 PHPsI가 감소하였다. ($P<0.0001$) 그리고, 칫솔질 습관이 좋았던 그룹과 습관이 좋지 않았던 그룹 간에 치태 개선 효과의 차이는 없었다. ($P=0.51$)

성인과 어린이에게서 Smart mirror system을 이용한 칫솔질 교육은 치태 제거 효과가 있었으며, Smartphone system도 어린이에게서 칫솔질 교육으로 치태 제거 효과가 있었다.
두 칫솔질 교육 시스템은 전통적인 칫솔질 교육의 대안으로 사용될 수 있을 것이다.

핵심되는 말:
칫솔질 교육, 컴퓨터, 구강위생, 스마트 칫솔, 습관교정, 치태, 원격치과의료, 스마트 폰