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Intelligent Technology for Superior Cleaning of Teeth and Gums

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Introduction

Early power toothbrushes, introduced commercially in the 1960s, were often designed based on the conventional manual toothbrush. Movement generally simulated hand motion, back-and-forth or side-to-side, offering little cleaning advantage over manual toothbrushes. These early commercially available power toothbrushes maintained a clear lack of superiority compared with manual toothbrushes, and problems with mechanical breakdowns caused their sales to decrease significantly following their initial introduction.

A new rechargeable electric toothbrush has been developed which demonstrates superior plaque removal and provides a higher level of technology or “intelligence” to help users brush better than with similar devices, and reinforce dental professional recommendations for tooth brushing. This was achieved through a combination of high frequency cleaning, electronic sensors, and ergonomics. By acting in concert, these features help compensate for less-than-adequate brushing technique to achieve superior cleaning without significant retraining of the user.

Research into candidate technologies for oral care devices was conducted in a variety of global markets. This resulted in a detailed analysis of multiple technologies in an effort to understand the strengths and weaknesses of each, and to identify a lead candidate for development. During the course of this assignment, sonic cleaning and, specifically, products offered by Omron Healthcare Company in Japan were identified as leads. Omron is a worldwide leader in medical home healthcare and wellness products using unique sensing and control technologies.

Sensing and control refers to smart technologies (as seen in compact, lightweight, easy, efficient, fast, and optimal solutions) that, unlike conventional sensing technologies, are not limited strictly to data input function, but rather integrate the areas of sensing and control to output high-value information for subsequent human or system processing.

These guiding principles manifest themselves in the Colgate® ProClinical™ A1500 electric toothbrush, which provides unique sensing and control technologies that automatically select the best bristle movement for the position in the mouth of the brush to effectively remove plaque, while being gentle on the gums. This Special Issue of The Journal of Clinical Dentistry discusses the product attributes, and demonstrates how this specially engineered sonic powered toothbrush with unique sensing and control technologies combines these key features into an intelligent technology and design that automatically adjusts the speed and motion of brush strokes for superior cleaning of teeth and gums.

High Frequency Cleaning

To consumers who have accepted that they need to do more with their oral health, and to dental professionals who promote effective oral hygiene routines, there is understanding and agreement that a powered toothbrush provides more effective cleaning than a manual toothbrush. The Colgate ProClinical A1500 electric toothbrush uses high frequency brush strokes which are referred to as sonic (cleaning). Sonic is defined as having a frequency within the audibility range of the human ear, which is well established as being roughly 20Hz to 20kHz. Since all the modes of the Colgate ProClinical A1500 electric toothbrush operate at a frequency range between 20,000–32,500 strokes per minute, which translates to 334Hz–542Hz, these movements are in the frequency of those defined as sonic.

Figure 1. Model A1500 LED handle display in Auto Mode at 45º angle.

The Colgate ProClinical A1500 electric toothbrush has three settings or modes: Auto, Optimum, and Deep Cleaning. By pressing the Mode button on the handle display (Figure 1), these different modes provide high frequency or sonic bristle strokes, while incorporating unique movements to enhance the cleaning effect for different parts of the mouth. The Auto Mode function is designed to allow the brush to automatically adjust as the handle is rotated by the user to different orientations in
the mouth. These automatic adjustments are signaled to the user by audible speed changes from the toothbrush. The Optimum Mode is mid-speed and operates at a frequency of 27,000 strokes per minute. The Optimum Mode operates with up-down and side-to-side strokes to clean along the gum line (Figure 2). The Deep Clean Mode has faster speed and operates at a frequency of 32,500 strokes per minute with up-down strokes that clean deep behind and between teeth (Figure 3).

Auto Mode for Intelligent Cleaning

Previous research has indicated that people rarely change their personal brushing technique irrespective of the design of the toothbrush used. The challenge has continually been to design a toothbrush that could help the user overcome poor brushing techniques. By incorporating an Auto Mode into the Colgate ProClinical A1500 electric toothbrush, electronic sensors automatically adjust the speed and motion for the best cleaning experience without forcing the user to change these speeds manually. It also utilizes an LED display that helps to guide the user to the proper 45° brushing angle along the gumline.

The electronic sensors that automatically adjust the speed and motion are accelerometers, which are electromechanical components used to measure acceleration forces. By measuring these forces, the accelerometer determines the tilt angle of a particular device. For example, accelerometers are found in smart phones and other devices to deliver screen orientation (landscape or portrait) among other features. By combining multiple accelerometers, the Colgate ProClinical A1500 electric toothbrush will adjust the speed and action of the head based on location.

Early qualitative research highlighted the benefits of the Auto Mode. Respondents involved in consumer studies using the Colgate ProClinical A1500 electric toothbrush understood the automatic speed changes provided additional value to their brushing experience. These consumers appreciated that the brush had different speeds for different parts of the mouth and associated this with a higher degree of sophistication or a “smarter brush.”

This intelligence was further supported by research conducted by Omron with the assistance of the Nippon School of Dentistry in Japan. Their studies indicated that there needs to be a guiding tool for easy implementation and usage of a 45° brushing angle for the gumline. As part of the Bass Method, tilting the (front) bristles of the toothbrush to a 45° angle on the tooth axis to allow part of the bristles to make contact with the gingival sulcus improves plaque removal with little tooth abrasion, but can be a difficult position for patients to achieve. Based on their investigation while using an electric toothbrush with accelerometers, it was shown that the angles that are difficult to achieve in the Bass tooth brushing method can be easily reproduced when using the Omron toothbrush. Therefore, based on the Auto Mode and display feature illuminating a “45” with a blue light on the handle display, the brushing angle can be confirmed and is thought to be efficient with guiding the patient’s brushing angle.

Clinical Evaluations

The Colgate ProClinical A1500 electric toothbrush was evaluated in two in vivo clinical trials.

1. The Colgate ProClinical A1500 electric toothbrush with the Triple Clean refill brush head was compared to two commercially available power toothbrushes. Plaque and gingivitis were assessed at baseline and after four weeks of use. Plaque was also assessed after a single use. The
Colgate ProClinical A1500 electric toothbrush provided a statistically significantly greater level of efficacy in the removal of dental plaque after a single tooth brushing and after four weeks’ use when compared to two commercially available power toothbrushes. This new sonic powered toothbrush with sensing and control technology also provided a statistically significantly greater level of efficacy in the reduction of gingivitis and gingival bleeding when compared to one of the commercially available power toothbrushes.

2. The Colgate ProClinical A1500 electric toothbrush with the Triple Clean refill brush head was compared to a regular manual flat-trim toothbrush. Plaque and gingivitis were assessed at baseline, four weeks, and 12 weeks of use. Plaque was also assessed after a single brushing. The Colgate ProClinical A1500 electric toothbrush provided statistically significantly greater reductions in supra-gingival plaque, gingivitis, and gum bleeding when compared to the manual flat-trim toothbrush at all post-baseline evaluations.

Laboratory Evaluations
The Colgate ProClinical A1500 electric toothbrush was evaluated in two in vitro studies.

1. The Colgate ProClinical A1500 electric toothbrush with the Triple Clean and Sensitive refill heads was compared to a manual flat-trim toothbrush for interproximal access efficacy (IAE). Overall IAEs for the Colgate ProClinical A1500 electric toothbrush with the Triple Clean and Sensitive refill heads were statistically significantly greater than the manual flat-trim toothbrush. The Colgate ProClinical A1500 electric toothbrush with the Sensitive refill head demonstrated increased efficiencies compared to the Triple Clean refill heads for IAE means.

Ergonomics and Usability Evaluations
The handle design of the Colgate ProClinical A1500 electric toothbrush is more than simply an interface between the working head of the toothbrush and the person using it. The design of the brush combines both ergonomics and style to achieve a better intuitive brushing experience. The angle of the toothbrush handle is different than other power toothbrushes and is perceived to make reaching and cleaning back teeth easier. The lightweight design of the device and the diameter of the handle also contribute to its function by making it more maneuverable. The handle function is further enhanced by special thumb indents to help the user orient the brush correctly. These thumb indents help the user position the brush at 45° which is the recommended angle to clean along the gumline. This is confirmed to the user when the 45° angle blue light in the handle display is illuminated, signaling to the consumer that they have achieved the proper brushing angle. These ergonomic features, along with the high frequency cleaning and sensor technology, all contribute to improved brushing during clinical trials. Two studies were conducted evaluating the ergonomics of the new power toothbrush along with its consumer usability.

1. A complete ergonomic evaluation of the Colgate ProClinical A1500 electric toothbrush was performed comparing it to two commercially available power toothbrushes. All three toothbrushes have adequate grip zones, provide grip security, and provide easy access to the on/off button. The handle of the Colgate ProClinical A1500 electric toothbrush angles downward and provides additional advantages through improved grip security and visibility. It is also relatively easy to use with its changes in speeds, brush movements, and resulting changes in audible feedback.

2. A longitudinal usability evaluation of the Colgate ProClinical A1500 electric toothbrush was conducted among users of manual toothbrushes. Users commented that this toothbrush was easier to maneuver within the mouth, which resulted in a cleaner feeling. Additionally, consumers spent more time brushing their teeth and more time on individual sections of the teeth in comparison to the time spent with a manual toothbrush.

Conclusions
The Colgate ProClinical A1500 electric toothbrush provides a combination of features that contribute to the brushing experience and efficacy for users. By utilizing high frequency brushing with electronic sensors and ergonomics, these features automatically adjust to achieve superior cleaning without significant retraining of the user. The following articles in this Special Issue will further emphasize this by assessing both clinical and ergonomic performance to support this new electric toothbrush. These studies demonstrate how the Colgate ProClinical A1500 electric toothbrush combines these key features into an intelligent technology and design that automatically adjusts the speed and motion of brush strokes for superior cleaning of teeth and gums.

References
accelerometer in powered toothbrush, Japanese Society of Periodontology, 52nd Spring Scientific Meeting, May 2009, Okayama, Japan. Presentation P-45


Comparative Efficacy of a Specially Engineered Sonic Powered Toothbrush with Unique Sensing and Control Technologies to Two Commercially Available Power Toothbrushes on Established Plaque and Gingivitis

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Abstract

• **Objective:** To evaluate the efficacy on plaque and established gingivitis of a new specially engineered sonic powered toothbrush with unique sensing and control technologies as compared to two commercially available power toothbrushes.

• **Methods:** This examiner-blind, three-treatment, parallel clinical study assessed plaque reduction via the comparison of pre- to postbrushing after a single use, and following four weeks’ use measured by the Rustogi Modification of the Modified Navy Plaque Index. This study also assessed gingivitis using the Löe and Silness Gingival Index after four weeks’ use. Qualifying adult male and female subjects from the northern New Jersey area reported to the study site after refraining from all oral hygiene procedures for 24 hours, and from eating, drinking, or smoking for four hours. Following an examination for gingivitis and plaque (pre-brushing), they were randomized into three balanced groups, each group using one of the three study toothbrushes in the order specified by a predetermined randomization plan. Subjects were instructed to brush their teeth for two minutes under supervision with their assigned toothbrush according to the manufacturers’ instructions and a commercially available toothpaste (Colgate® Cavity Protection), after which they were once again evaluated for plaque (post-brushing). Subjects were then dismissed from the study site with the toothpaste and their assigned toothbrush to use at home twice daily for the next four weeks. They again reported to the study site at which time they were evaluated for plaque and gingivitis.

• **Results:** One-hundred eighty-four subjects complied with the protocol and completed the clinical study. Relative to the two commercially available toothbrushes, the new specially engineered sonic powered toothbrush with unique sensing and control technologies provided statistically significantly (p < 0.05) greater reductions in whole mouth plaque index scores (21.9 and 25.8%, respectively), gingival margin plaque index scores (14.5% and 18.9%, respectively), interproximal plaque index scores (160.0% and 136.4%, respectively), facial plaque index scores (17.9% for both), lingual plaque index scores (29.2% for both), and interproximal lingual plaque index scores (200.0% and 350.0%, respectively) after a single tooth brushing. Relative to the two commercially available toothbrushes, the new sonic powered toothbrush also provided statistically significantly (p < 0.05) greater reductions in whole mouth plaque index scores (47.4% and 40.0%, respectively), gingival margin plaque index scores (46.2% and 40.7%, respectively), interproximal plaque index scores (650% and 1400%, respectively), facial plaque index scores (47.6% and 40.9%, respectively), lingual plaque index scores (47.1% and 31.6%, respectively), and interproximal lingual plaque index scores (350.0% and 500.0%, respectively) after four weeks. There was no statistically significant (p > 0.05) difference between the two commercially available toothbrushes for any plaque index score comparison. Relative to one of the commercially available toothbrushes, the new sonic powered toothbrush provided statistically significant reductions (p < 0.05) in gingival index scores (25.0%) and gingivitis severity scores (33.3%) after four weeks of product use. There were no statistically significant (p > 0.05) differences in gingivitis or gingivitis severity index scores between the new sonic powered toothbrush and the other commercially available toothbrush.
**Introduction**

The control of bacterial biofilm, also known as dental plaque, is essential for the maintenance of oral health. Plaque acts as a reservoir for bacteria and left alone will eventually inflame the gingiva, resulting in periodontal diseases such as gingivitis and periodontitis. Even though the marketplace in the past twenty years has been flooded with new products containing chemotherapeutic agents claiming to help control plaque, effective tooth brushing continues to be the best to disrupt and control plaque biofilm.  

Tooth brushing is the most widely used form of oral hygiene, but is often far from satisfactory in removing and controlling plaque. The clinical effectiveness of tooth brushing is dependent on a number of factors, including toothbrush design and tooth brushing methods, time, and frequency. Mechanical removal of plaque by tooth brushing is greatly dependent on the skills, perseverance, and motivation of the individual and is, therefore, highly variable and inconsistent in the general population. It has been reported that, on average, the plaque removal of users of manual toothbrushes after a single brushing is 43%.  

Power toothbrushes were introduced in the 1960s and have evolved from those which simulated back-and-forth or side-to-side hand motion to the sonic and oscillating-rotating technologies that are found in the most recently marketed power toothbrushes. A new specially engineered sonic powered toothbrush with unique sensing and control technologies has been introduced by the Colgate-Palmolive Company (New York, NY, USA). This examiner-blind, three-treatment, parallel clinical study evaluated the efficacy of this new toothbrush compared to two commercially available power toothbrushes, the Oral-B® Smart Series 5000 Power Toothbrush (Procter & Gamble Co., Cincinnati, OH, USA) and the Sonicare™ Flexcare Power Toothbrush (Philips Sonicare, Stamford, CT, USA) used in the Clean Mode with Flossaction brush head; and the Triple Clean brush head (Colgate-Palmolive Company, New York, NY, USA) used in the Daily Clean Mode with Flossaction brush head.

**Materials and Methods**

This independent clinical study employed an examiner-blind, three-treatment, parallel design. Adult male and female subjects from the northern New Jersey, USA area were enrolled into the study based upon the following criteria:

1. Subjects had to be between the ages of 18 and 70 years inclusive, in generally good health, and possess a minimum of 20 uncrowned permanent natural teeth (excluding third molars). They needed to be available for the duration of the study and to sign an informed consent form.
2. Subjects were required to present a mean Rustogi Modification of the Modified Navy Plaque Index score of 0.6 or greater and a Löe and Silness Gingival Index score of at least 1.0 at their screening examination.
3. Subjects were excluded from the study if they had orthodontic appliances, removable prostheses or partial dentures, tumors of the soft or hard tissues of the oral cavity, advanced periodontal disease, or five or more carious lesions requiring restorative treatment.
4. Subjects were also excluded if they had received a dental prophylaxis within one month prior to entry into the study, or if they had received antibiotic therapy or steroids any time during the month prior to entry into the study. Pregnant or lactating women were also excluded.
5. Subjects were excluded if they had a history of allergies to oral care products, personal care consumer products or their ingredients, or if they had any medical condition that would preclude them from not eating and drinking for four hours prior to their examination.

Subjects reported to the study site after refraining from any oral hygiene procedures for 24 hours and from eating, drinking, and smoking for four hours. Following an examination for gingivitis (baseline) and supragingival plaque (pre-brushing), qualified subjects were randomized based on their plaque scores into three balanced groups. Groups were assigned to one of the three study toothbrushes in the order specified by a predetermined randomization plan. The three toothbrushes were:

1. TC: Colgate® ProClinical™ A1500 Power Toothbrush with the Triple Clean brush head (Colgate-Palmolive Company, New York, NY, USA) used in the Auto Mode;
2. PG: Oral-B Smart Series 5000 Power Toothbrush (Procter & Gamble Co., Cincinnati, OH, USA) used in the Daily Clean Mode with Flossaction brush head; and
3. PH: Sonicare Flexcare Power Toothbrush (Philips-Sonicare Co., Stamford, CT, USA) used in the Clean Mode with Contoured brush head.

Subjects were provided with their assigned toothbrush and commercially available fluoride toothpaste (Colgate® Cavity Protection) and were instructed to brush their teeth for two minutes under supervision and according to the manufacturer's instructions, after which time they were once again evaluated for plaque (post-brushing). Subjects were then given their assigned toothbrush and toothpaste for use at home for the next four weeks. At the end of four weeks, subjects reported to the study site after refraining from any oral hygiene procedures for

**Conclusion:** A new specially engineered sonic powered toothbrush with unique sensing and control technologies provides significantly greater levels of efficacy on the removal of dental plaque after a single tooth brushing and after four weeks’ use when compared to two commercially available power toothbrushes. The new sonic powered toothbrush also provides significantly greater levels of efficacy on the reduction of gingivitis and gingival bleeding when compared to one of the commercially available power toothbrushes.
Clinical Scoring Procedures

Gingivitis. Gingivitis was scored according to the Löe-Silness Gingival Index as modified by Talbott, et al. Each tooth was scored in six areas: mesiofacial, midfacial, distofacial, mesiolingual, midlingual, and distolingual as follows:

0 = Absence of inflammation
1 = Mild inflammation: slight change in color and little change in texture
2 = Moderate inflammation: moderate glazing, redness, edema, hypertrophy; tendency to bleed on probing
3 = Severe inflammation: marked redness and hypertrophy; tendency to bleed spontaneously

Third molars and teeth with cervical restorations or prosthesis crowns were excluded from the scoring procedure. Whole mouth mean scores were obtained by averaging the values recorded from all scoreable tooth surfaces.

Gingivitis Severity Index. In addition to calculating a mean Löe-Silness Gingival Index score for each subject, a mean Gingivitis Severity Index was also calculated for each subject. This index allows for a comparison of the gingival sites that received the Löe-Silness Gingival Index scores of 2 and 3 (i.e., bleeding sites). The mean Gingivitis Severity Index was calculated for each subject by dividing the total number of gingival sites scored 2 or 3 by the total number of teeth scored in the mouth.

Dental Plaque. Plaque was scored according to the Rustogi Modification of the Modified Navy Plaque Index. Supragingival plaque on the facial and lingual surfaces of each tooth was disclosed and recorded as present or absent on nine discrete areas of the tooth (Figure 1). Third molars were excluded from the scoring procedure. From these site-wise scores, a plaque score was determined for each subject by calculating the proportion of sites in the mouth at which plaque was present. Six parameters were evaluated as follows:

Whole Mouth scores – A, B, C, D, E, F, G, H, I for both facial and lingual surfaces
Gumline (Gingival Margin) scores – A, B, C
Interproximal scores – D, F
Facial scores – A, B, C, D, E, F, G, H, I
Lingual scores – A, B, C, D, E, F, G, H, I
Interproximal lingual scores – D, F

The same dental examiner conducted all of the dental examinations performed in the study. The examiner had been trained, calibrated, and was highly experienced as to the clinical scoring procedures used in this study.

Oral Soft Tissue Assessment

The dental examiner visually examined the oral cavity and peri-oral area at each visit. These examinations included evaluation of the soft and hard palate, gingival mucosa, buccal mucosa, mucogingival fold areas, tongue, sublingual and submandibular areas, salivary glands, and the tonsilar and pharyngeal areas.

Adverse Events

Adverse events were obtained from subjects and from dental examinations by the examining dentist.

Statistical Methods

Statistical analyses were performed separately for the gingivitis assessments and dental plaque assessments. Comparisons of the treatment groups with respect to baseline gingival index scores and plaque index scores were performed using an analysis of variance (ANOVA). Comparisons of the treatment groups with respect to baseline-adjusted gingival and plaque scores at the follow-up examinations were performed using analyses of covariance (ANCOVAs). After the initial brushing, the response used for the between-product analysis was the difference between the pre- and post-brushing mean values. After four weeks, the response used for the between product analysis was the four-week endpoint. Post-ANCOVA pair-wise comparisons of the study treatments were performed using Tukey’s test for multiple comparisons. All statistical tests of hypotheses were two-sided, and employed a level of significance of $\alpha = 0.05$.

Results

One-hundred eighty-four (184) subjects entered, complied with the protocol, and completed the clinical study. The gender and age for the subjects who completed the study are presented in Table I. Throughout the study, no adverse effects of the oral hard or soft tissues were observed by the dental examiner or reported by the participants.

<table>
<thead>
<tr>
<th>Number of Subjects</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toothbrush</td>
<td>Male</td>
</tr>
<tr>
<td>TC</td>
<td>18</td>
</tr>
<tr>
<td>PG</td>
<td>12</td>
</tr>
<tr>
<td>PH</td>
<td>16</td>
</tr>
</tbody>
</table>

Table II presents a summary of the mean plaque scores for each of the six site-wise plaque indices taken at each of the measurement time points. Table III presents a summary of the mean gingivitis and mean gingivitis severity scores at each of
the measurement time points. Tables II and III also contain comparisons of the percent differences in the each of the treatments at each of the time points. No statistically significant differences were indicated among the three power toothbrush groups with respect to any of the plaque or gingivitis scores at the pre-brush examination.

**Removal of Supragingival Plaque After a Single Tooth Brushing**

**Whole Mouth.** Relative to the PG and the PH groups, the TC group exhibited statistically significantly (21.9% and 25.8%, respectively) greater reductions in whole mouth plaque scores. There was no statistically significant difference between the PG and PH groups in whole mouth plaque reduction.

**Gingival Margin.** Relative to the PG and the PH groups, the TC group exhibited statistically significantly (14.5% and 18.9%, respectively) greater reductions in gumline (gingival margin) plaque scores. There was no statistically significant difference in gingival margin plaque scores between the PG and PH groups.

**Interproximal.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (160.0% and 136.4%, respectively) greater reductions in interproximal plaque scores. There was no statistically significant difference between the PG and PH groups in interproximal plaque scores.

**Facial.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (17.9% for both) greater reductions in facial plaque scores. There was no statistically significant difference between the PG and PH groups in facial plaque scores.

**Lingual.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (29.2% for both) greater reductions in lingual plaque scores. There was no statistically significant difference between the PG and PH groups in lingual plaque scores.

**Interproximal Lingual.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (200.0% and 350.0%, respectively) greater reductions in interproximallingual plaque scores.

---

**Table II**

Summary of the Plaque Scores for Subjects Who Completed the Four-Week Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Toothbrush</th>
<th>N</th>
<th>Pre-Brushing Scores¹ (Mean ± SD)</th>
<th>Post-Single Brushing Scores (Mean ± SD)</th>
<th>Difference Pre- to Post-Brushing</th>
<th>% Difference after Single Brushing² (Mean ± SD)</th>
<th>Four-Week Scores (Mean ± SD)</th>
<th>Four-Week Difference</th>
<th>% Difference after Four Weeks² (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Mouth</td>
<td>TC</td>
<td>62</td>
<td>0.68 ± 0.05</td>
<td>0.29 ± 0.07</td>
<td>0.39 ± 0.08</td>
<td>21.9% (PG: 0.40 ± 0.07, PH: 0.28 ± 0.08)</td>
<td>47.4%</td>
<td>NS</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>0.67 ± 0.05</td>
<td>0.35 ± 0.06</td>
<td>0.32 ± 0.06</td>
<td>NS</td>
<td>0.48 ± 0.08, 0.19 ± 0.09</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>0.67 ± 0.04</td>
<td>0.36 ± 0.05</td>
<td>0.31 ± 0.06</td>
<td>0.47 ± 0.07</td>
<td>0.20 ± 0.07</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Gumline (gingival margin)</td>
<td>TC</td>
<td>62</td>
<td>1.00 ± 0.02</td>
<td>0.72 ± 0.14</td>
<td>0.26 ± 0.23</td>
<td>160%</td>
<td>136%</td>
<td>0.85 ± 0.16, 0.15 ± 0.16</td>
<td>650%</td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>1.00 ± 0.01</td>
<td>0.45 ± 0.17</td>
<td>0.55 ± 0.17</td>
<td>NS</td>
<td>0.74 ± 0.17</td>
<td>0.26 ± 0.17</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>0.99 ± 0.02</td>
<td>0.53 ± 0.15</td>
<td>0.46 ± 0.15</td>
<td>14.5% (PG: 0.62 ± 0.15, PH: 0.38 ± 0.15)</td>
<td>46% (PG: 0.38 ± 0.15, PH: 0.38 ± 0.15)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Interproximal</td>
<td>TC</td>
<td>62</td>
<td>1.00 ± 0.02</td>
<td>0.74 ± 0.22</td>
<td>0.26 ± 0.23</td>
<td>160%</td>
<td>136%</td>
<td>0.85 ± 0.16, 0.15 ± 0.16</td>
<td>650%</td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>0.99 ± 0.07</td>
<td>0.89 ± 0.10</td>
<td>0.10 ± 0.13</td>
<td>NS</td>
<td>0.97 ± 0.07</td>
<td>0.02 ± 0.10</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>0.99 ± 0.08</td>
<td>0.88 ± 0.12</td>
<td>0.11 ± 0.12</td>
<td>NS</td>
<td>0.98 ± 0.06</td>
<td>0.01 ± 0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Plaque Facial</td>
<td>TC</td>
<td>62</td>
<td>0.70 ± 0.07</td>
<td>0.24 ± 0.07</td>
<td>0.46 ± 0.09</td>
<td>17.9% (PG: 0.39 ± 0.09, PH: 0.31 ± 0.01)</td>
<td>47.6%</td>
<td>40.9%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>0.70 ± 0.07</td>
<td>0.31 ± 0.09</td>
<td>0.39 ± 0.08</td>
<td>NS</td>
<td>0.48 ± 0.08</td>
<td>0.21 ± 0.10</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>0.69 ± 0.05</td>
<td>0.30 ± 0.06</td>
<td>0.39 ± 0.07</td>
<td>NS</td>
<td>0.47 ± 0.09</td>
<td>0.22 ± 0.09</td>
<td>NS</td>
</tr>
<tr>
<td>Plaque Lingual</td>
<td>TC</td>
<td>62</td>
<td>0.65 ± 0.06</td>
<td>0.34 ± 0.08</td>
<td>0.31 ± 0.09</td>
<td>29.2% (PG: 0.40 ± 0.07, PH: 0.25 ± 0.10)</td>
<td>47.1%</td>
<td>31.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>0.64 ± 0.05</td>
<td>0.40 ± 0.07</td>
<td>0.24 ± 0.07</td>
<td>NS</td>
<td>0.47 ± 0.09</td>
<td>0.17 ± 0.09</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>0.65 ± 0.06</td>
<td>0.41 ± 0.07</td>
<td>0.24 ± 0.08</td>
<td>NS</td>
<td>0.46 ± 0.06</td>
<td>0.19 ± 0.09</td>
<td>NS</td>
</tr>
<tr>
<td>Plaque Interproximal Lingual</td>
<td>TC</td>
<td>62</td>
<td>1.00 ± 0.01</td>
<td>0.82 ± 0.27</td>
<td>0.18 ± 0.28</td>
<td>200%</td>
<td>350%</td>
<td>0.82 ± 0.24, 0.18 ± 0.24</td>
<td>350%</td>
</tr>
<tr>
<td></td>
<td>PG</td>
<td>60</td>
<td>1.00 ± 0.03</td>
<td>0.94 ± 0.15</td>
<td>0.06 ± 0.15</td>
<td>NS</td>
<td>0.96 ± 0.14</td>
<td>0.04 ± 0.14</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>62</td>
<td>1.00 ± 0.01</td>
<td>0.96 ± 0.13</td>
<td>0.04 ± 0.13</td>
<td>NS</td>
<td>0.97 ± 0.12</td>
<td>1.03 ± 0.12</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹Groups are not statistically significantly different from each other at baseline (pre-brushing scores).

²After the initial brushing, statistically significant (p < 0.05) percentage differences based on the difference from pre-brushing values are indicated as per the ANCOVA comparison of the differences from pre-brushing values are shown. NS indicates groups are not statistically different.

³After four weeks of brushing, statistically significant (p < 0.05) percentage differences based on the four-week difference from pre-brushing values are indicated as per the ANCOVA comparison of the four-week values. NS indicates groups are not statistically different.
plaque scores. There was no statistically significant difference between the PG and PH groups in interproximal lingual plaque scores.

**Reduction of Gingivitis after Four Weeks**

Relative to the PH group, the TC group exhibited a statistically significant 25.0% greater reduction in gingival index scores. There was no statistically significant difference in gingival index scores between the TC group and the PG group. In addition, there was no statistically significant difference in gingival index scores between the PG and PH groups.

**Reduction of Gingivitis Severity after Four Weeks**

Relative to the PH group, the TC group exhibited a statistically significant 33.3% greater reduction in gingivitis severity index scores. There was no statistically significant difference in gingival index scores between the TC group and the PG group. In addition, there was no statistically significant difference in gingival index scores between the PG and PH groups.

**Reduction of Supragingival Plaque after Four Weeks**

Table II presents a summary of the six plaque index scores at baseline and after four weeks of twice-daily tooth brushing.

**Whole Mouth.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (47.4% and 40.0%, respectively) greater reductions in whole mouth plaque scores. There was no statistically significant difference in whole mouth plaque scores between the PG and PH groups.

**Gingival Margin.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (46.2% and 31.6%, respectively) greater reductions in gingival margin plaque scores. There was no statistically significant difference in plaque scores between the PG and PH groups.

**Interproximal.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (350.0% and 500.0%, respectively) greater reductions in interproximal lingual plaque scores. There was no statistically significant difference between the PG and PH groups in lingual plaque scores.

**Discussion**

Daily tooth brushing remains the most common procedure to remove plaque. It is estimated that between 80–90% of the population in industrialized countries uses a toothbrush once or twice a day.9,10 Proper tooth brushing removes plaque from the teeth and surrounding areas, and thus is essential in preventing the initiation and proliferation of subgingival pathogenic biofilm bacteria and gingivitis.11,12 A proper toothbrush is, therefore, important to maintain good oral health. Power toothbrushes were introduced about 50 years ago, and have progressed to the most recently marketed brushes which are designed with sonic and oscillating-rotating technologies. The purpose of this clinical study was to assess the plaque and gingivitis efficacy of a new specially engineered sonic powered toothbrush with unique sensing and control technologies when compared to two commercially available power toothbrushes, the Oral-B Smart Series 5000 Power Toothbrush and the Sonicare Flexcare Power Toothbrush.

The data from this study demonstrate that this new sonic powered toothbrush provides a statistically significantly greater level of efficacy in the removal of dental plaque after a single tooth brushing and after four weeks of use when compared to the Oral-B Smart Series 5000 Power Toothbrush and the Sonicare Flexcare Power Toothbrush on all measures; whole mouth, gumline (gingival margin), interproximal, facial, lingual, and interproximal lingual plaque scores. There were no statistically significant difference between the PG and PH groups in facial plaque scores.

**Lingual.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (47.1% and 31.6%, respectively) greater reductions in lingual plaque scores. There was no statistically significant difference between the PG and PH groups in lingual plaque scores.

**Interproximal Lingual.** Relative to the PG and PH groups, the TC group exhibited statistically significantly (350.0% and 500.0%, respectively) greater reductions in interproximal lingual plaque scores. There was no statistically significant difference between the PG and PH groups in interproximal lingual plaque scores.

**Table III**

<table>
<thead>
<tr>
<th>Parameter Toothbrush</th>
<th>Pre-Brushing Scores(^1)</th>
<th>Four-Week Scores (\text{Mean} \pm \text{SD})</th>
<th>%Difference after Four Weeks(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC 62</td>
<td>1.75 ± 0.15</td>
<td>1.46 ± 0.14</td>
<td>NS 25.0%</td>
</tr>
<tr>
<td>PG 60</td>
<td>1.77 ± 0.23</td>
<td>1.51 ± 0.14</td>
<td>NS</td>
</tr>
<tr>
<td>PH 62</td>
<td>1.78 ± 0.17</td>
<td>1.54 ± 0.18</td>
<td>NS</td>
</tr>
<tr>
<td>TC 62</td>
<td>0.73 ± 0.07</td>
<td>0.45 ± 0.14</td>
<td>NS 33.3%</td>
</tr>
<tr>
<td>PG 60</td>
<td>0.74 ± 0.11</td>
<td>0.51 ± 0.14</td>
<td>NS</td>
</tr>
<tr>
<td>PH 62</td>
<td>0.74 ± 0.08</td>
<td>0.53 ± 0.15</td>
<td>NS</td>
</tr>
</tbody>
</table>

\(^1\) Groups are not statistically significant different from each other at baseline (pre-brushing scores).

\(^2\) At four weeks, statistically significant (p < 0.05) percentage differences based on the four-week difference from baseline are indicated as per the ANCOVA comparison of the four-week values are shown. NS indicates groups are not statistically different.
statistically significant differences between the two commercially available power toothbrushes on any of the plaque measurements. The new sonic powered toothbrush provides a statistically significantly greater level of efficacy in the reduction of gingivitis and gingival bleeding than the Sonicare Flexcare Power Toothbrush; however, it was not significantly different from the Oral-B toothbrush on these measures. The Oral-B Smart Series 5000 Power Toothbrush was equivalent to the Sonicare Flexcare Power Toothbrush in the reduction of gingivitis and gingival bleeding.

Conclusion

This new specially engineered sonic powered toothbrush with unique sensing and control technologies provides superior cleaning as measured by plaque removal when compared to two commercially available power toothbrushes after one use and after four weeks of use. It is also superior in efficacy to one of the commercially available power toothbrushes after four weeks with respect to gingivitis and gingival bleeding.

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References

A Clinical Study Comparing the Supragingival Plaque and Gingivitis Efficacy of a Specially Engineered Sonic Powered Toothbrush with Unique Sensing and Control Technologies to a Commercially Available Manual Flat-Trim Toothbrush

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Abstract

• **Objective:** This study was designed to evaluate the efficacy of a new specially engineered sonic powered toothbrush with unique sensing and control technologies, as compared to a manual flat-trim toothbrush on supragingival plaque and established gingivitis.

• **Methods:** This examiner-blind, two-treatment, parallel clinical research study assessed plaque removal via the comparison of pre- to post-brushing after a single use, and again after four- and 12-weeks’ use using the Rustogi Modification of the Modified Navy Plaque Index. This study also assessed gingivitis at four and 12 weeks using the Löe and Silness Gingival Index. Qualifying adult male and female subjects from the southern Florida area reported to the study site after refraining from any oral hygiene procedures for 24 hours, and from eating, drinking, and smoking for four hours. Following an examination for plaque (pre-brushing) and gingivitis, they were randomized (for both plaque and gingivitis) into two balanced groups, each group using one of the two study toothbrushes. Subjects were instructed to brush their teeth for two minutes under supervision with their assigned toothbrush according to the manufacturer’s instructions, and commercially available toothpaste (Colgate® Cavity Protection Toothpaste), after which they were again evaluated for plaque (post-brushing). Subjects were then dismissed from the study site with the toothpaste and their assigned toothbrush to use at home twice daily for the next 12 weeks. They again reported to the study site after four and 12 weeks of product use, at which time they were evaluated for plaque and gingivitis.

• **Results:** Seventy-six out of 82 enrolled subjects complied with the protocol and completed the clinical study. The new specially engineered sonic powered toothbrush with unique sensing and control technologies provided statistically significant reductions in gingival and gingivitis severity index scores after four and 12 weeks of product use. The manual toothbrush provided a statistically significant reduction in gingival index score only at the 12-week time point. Relative to the manual toothbrush group, after a single tooth brushing and after four and 12 weeks, the new sonic powered toothbrush provided statistically significantly greater reductions in whole mouth plaque index scores (1.6, 2.05, and 1.9 times, respectively), gingival margin plaque index scores (12.0, 90.0, and 8.2 times, respectively), and interproximal plaque index scores (2.0, 3.2, and 2.1 times, respectively). Relative to the manual toothbrush group after four and 12 weeks, the new sonic powered toothbrush provided statistically significant reductions in gingival index scores of 11.0 and 7.0 times, respectively, and in gingivitis severity index scores of 3.0 and 3.5 times, respectively. All statistically significant reductions were at the $p \leq 0.05$ level.

• **Conclusion:** The new specially engineered sonic powered toothbrush with unique sensing and control technologies provides statistically significant and clinically relevant levels of efficacy in the removal of supragingival dental plaque after a single tooth brushing, and after four and 12 weeks’ use. The new sonic powered toothbrush also provides statistically significantly greater levels of efficacy in the reduction of supragingival plaque, gingivitis, and gingival bleeding when compared to a manual flat-trim toothbrush.

(J Clin Dent 2012;23[Spec Iss A]:A11-A16)
**Introduction**

It is well understood that plaque removal by way of an effective daily home care regimen is an important element of oral health. Dental plaque affects both pathologic and cosmetic conditions, among them caries, gingivitis, periodontitis, and mouth odor. Even with effective tooth cleaning, bacteria re-colonize the tooth surface, most notably around the gingival margin and interdental spaces. The developing biofilm (plaque) releases a variety of biologically active products that diffuse into the gingival epithelium to initiate the host response that, if persistent, can result in gingivitis. Left untreated, periodontal pockets may form, bone could resorb, and eventually teeth might be lost. Further, current research has shown that oral inflammation caused by prolonged exposure of the gum tissues to bacteria in dental plaque is associated with various systemic diseases, including diabetes, coronary heart disease, peripheral arterial disease, cardiovascular disease, ischemic stroke, low birth weight, preterm babies, and osteoporosis.

The most common method of supragingival plaque control is by tooth brushing, which is the mechanical removal of plaque. Tooth brushing is an essential tool in keeping teeth clean and in maintaining good oral hygiene. The problem is that most people do not brush effectively, *i.e.*, frequently enough, for long enough, or with appropriate brushing technique to achieve sufficient plaque removal. Because tooth brushing is so important to oral health, toothbrush design is important to the effectiveness of any brush in removing plaque. That is why it is very important that consumers choose a brush they will actually use and use effectively. For a long time, the only available toothbrush type was a manual one. Electric toothbrushes were then introduced, and subsequently comparisons among the various types of toothbrushes elicited discussion and study.

Numerous clinical studies have been reported that compare the plaque and gingivitis efficacy of a manual toothbrush to that of a power or electric toothbrush with varied results. Published Cochrane systematic reviews in 2003 and 2005 suggest one type of powered brush was superior to manual tooth brushing for the removal of plaque and reduction of gum inflammation. However, that review did not allow direct comparison between the different types of powered toothbrushes. A subsequent review has reported that brushes with a rotation oscillation action reduced plaque and gingivitis more than those with a side-to-side action in the short term. However, the difference was small and its clinical importance unclear. Due to the low numbers of trials using other types of powered brushes, no other definitive conclusions can be drawn regarding the superiority of one type of powered toothbrush over another.

The newer power toothbrushes have other benefits. They are now available with timers to help increase brushing time, and some have smaller and lighter heads to improve brushing technique, thus creating a more enjoyable brushing experience. In addition, power toothbrushes have been shown to have an advantage for special needs patients, including those with orthodontics, those who are debilitated, the elderly, and children. As previously mentioned, further trials of good quality are required to establish if other types of powered brushes are better at reducing plaque and gingivitis.

A new specially engineered sonic powered toothbrush with unique sensing and control technologies has been introduced by the Colgate-Palmolive Company. This examiner-blind, two-treatment, parallel clinical study evaluated the efficacy of this new sonic powered toothbrush in removing dental plaque and reducing gingivitis over a 12-week period as compared to a manual flat-trim toothbrush. This study assessed plaque in the whole mouth, at the gingival margin, and at interproximal sites by comparing pre- and post-brushing plaque levels using the Rustogi Modification of the Modified Navy Plaque Index after a single use and again after four-weeks’ and 12-weeks’ twice-daily use. Additionally, a comparison of the occurrence of gingivitis using the Löe and Silness Gingival Index and gingival bleeding using the Gingivitis Severity Index prior to the pre-brushing plaque examination and again after four and 12 weeks of product use was evaluated. The study protocol was submitted to and approved by an Institutional Review Board.

**Materials and Methods**

This independent clinical study employed an examiner-blind, two-treatment, parallel design. Adult male and female subjects from the southern Florida area were enrolled into the study based upon the following criteria:

1. Subjects had to be between the ages of 18 and 70, inclusive, in generally good health, and possess a minimum of 20 uncrowned permanent natural teeth (excluding third molars). They needed to be available for the duration of the study, and to sign an informed consent form.

2. Subjects were required to present a mean Rustogi Modification of the Modified Navy Plaque Index score of 0.6 or greater and a Löe and Silness Gingival Index score of at least 1.0 at their screening examination.

3. Subjects were excluded from the study if they had orthodontic appliances, removable prostheses or partial dentures, tumors of the soft or hard tissues of the oral cavity, advanced periodontal disease, or five or more carious lesions requiring restorative treatment.

4. Subjects were also excluded if they had received a dental prophylaxis within one month prior to entry into the study, or if they had received antibiotic therapy or steroids any time during one month prior to entry into the study. Pregnant or lactating women were also excluded.

5. Subjects were excluded if they had a history of allergies to oral care products, personal care consumer products or their ingredients, or if they had any medical condition that would preclude them from not eating and drinking for four hours prior to their examination.

Subjects reported to the study site after refraining from any oral hygiene procedures for 24 hours and from eating, drinking, or smoking for four hours. Following an examination for gingivitis (baseline) and supragingival plaque (pre-brushing), qualified subjects were randomized based on their plaque scores into two balanced groups. Groups were assigned one of the two study toothbrushes:

1. TC: Colgate® ProClinical™ A1500 Power Toothbrush with the Triple Clean Brush Head (Colgate-Palmolive Company, New York, NY, USA) using the Auto Mode; and

Subjects were provided with their assigned toothbrush and commercially available fluoride toothpaste (Colgate® Cavity Protection, Colgate-Palmolive Company, New York, NY, USA) and were instructed to brush their teeth for two minutes according to the manufacturer’s instructions under supervision, after which time they were again evaluated for plaque (post-brushing). Subjects were then given their assigned toothbrush and toothpaste for use at home for the next 12 weeks. Subjects were instructed to refrain from using any other oral hygiene products such as other dentifrices or toothbrushes, mouthrinses, dental flosses, and interdental stimulators while they were participating in the study. There were no restrictions regarding diet and smoking habits during the course of the study. Subjects returned to the study site for an evaluation of plaque and gingivitis after four and 12 weeks, during the course of the study. Subjects returned to the study site for an evaluation of plaque and gingivitis after four and 12 weeks, again refraining from any oral hygiene procedures for 24 hours and from eating, drinking, or smoking for four hours.

Clinical Scoring Procedures

Gingivitis. Gingivitis was scored according to the Löe-Silness Gingival Index as modified by Talbott, et al.21 Each tooth was scored in six areas: mesiofacial, midfacial, distofacial, mesiolingual, midlingual, and distolingual as follows:

0 = Absence of inflammation
1 = Mild inflammation: slight change in color and little change in texture
2 = Moderate inflammation: moderate glazing, redness, edema, hypertrophy; tendency to bleed on probing
3 = Severe inflammation: marked redness and hypertrophy; tendency to bleed spontaneously

Third molars and teeth with cervical restorations or prosthetic crowns were excluded from the scoring procedure. Whole mouth mean scores were obtained by averaging the values recorded from all scoreable tooth surfaces.

Gingivitis Severity Index. In addition to calculating a mean Löe-Silness Gingival Index score for each subject, a mean Gingivitis Severity Index was also calculated for each subject.21 This index allows for a comparison of the gingival sites that received Löe-Silness Gingival Index scores, i.e., scores of 2 and 3 (bleeding sites). The mean Gingivitis Severity Index was calculated for each subject by dividing the total number of gingival sites scored 2 or 3 by the total number of teeth scored in the mouth.

Dental Plaque. Plaque was scored according to the Rustogi Modification of the Modified Navy Plaque Index. Supragingival plaque on the facial and lingual surfaces of each tooth was disclosed and recorded as present or absent on nine discrete areas of the tooth (Figure 1). Third molars were excluded from the scoring procedure. From these site-wise scores, a plaque score was determined for each subject by calculating the proportion of sites in the mouth at which plaque was present. Three areas were evaluated as follows:

Whole Mouth scores – A,B,C,D,E,F,G,H,I
Gingival Margin scores – A,B,C
Interproximal scores – D,F

The same dental examiner performed all the dental examinations in the study. The examiner had been trained, calibrated, and was highly experienced as to the clinical scoring procedures used in this study.

Oral Soft Tissue Assessment. The dental examiner visually examined the oral cavity and peri-oral area at each visit using a dental light and dental mirror. These examinations included evaluation of the soft and hard palate, gingival mucosa, buccal mucosa, mucogingival fold areas, tongue, sublingual and submandibular areas, salivary glands, and the tonsilar and pharyngeal areas.

Adverse Events

Adverse events were obtained from subjects and from dental examinations by the examining dentist.

Statistical Methods

Statistical analyses were performed separately for the gingivitis assessments and plaque assessments. Comparison of the treatment groups with respect to baseline gingival index scores and plaque index scores were performed using an analysis of variance (ANOVA). Within-treatment comparison of the baseline gingivitis and pre-brushing plaque index scores were performed using paired t-tests. Comparisons of the treatment groups with respect to baseline-adjusted gingival and plaque scores at the follow-up examinations were performed using analyses of covariance (ANCOVAs). The response used for the between-product analyses was the four- and 12-week endpoints, and the response for the within-product analyses was the difference between pre- and post-brushing mean values. All statistical tests of hypotheses were two sided and employed a level of significance of $\alpha = 0.05$.

Results

Eighty-two (82) subjects were entered into the study and 76 subjects complied with the protocol and completed the clinical study. The gender and age for the subjects who completed the study are presented in Table I. No adverse effects were observed by the dental examiner or reported by the participants during the 12-week study; six subjects did not complete the study due to...
either protocol non-compliance or an event unrelated to the use of the test products.

Table II presents a summary of the mean plaque scores for each of the three plaque indices measured at each of the measurement time points. Table III presents a summary of the mean gingivitis and mean gingivitis severity scores measured at each of the measurement time points. Tables II and III also contain a comparison of the differences in the each of the treatments at each of the time points. No statistically significant differences were indicated among the two toothbrush groups with respect to any of the plaque or gingivitis scores at the pre-brush examination.

**Removal of Supragingival Plaque After a Single Tooth Brushing**

- **Whole Mouth Plaque.** Toothbrush TC exhibited a statistically significantly ($p < 0.05$) greater reduction in whole mouth plaque scores of 0.40 as compared to 0.25 for Toothbrush I.
- **Gingival Margin Plaque.** Toothbrush TC exhibited a statistically significantly ($p < 0.05$) greater reduction in gingival margin plaque scores of 0.12 as compared to 0.01 for Toothbrush I.
- **Interproximal Plaque.** Toothbrush TC exhibited a statistically significantly ($p < 0.05$) greater reduction in interproximal plaque scores of 0.74 as compared to 0.37 for Toothbrush I.

**Reduction of Gingivitis After Four Weeks**

- **Gingivitis.** Toothbrush TC exhibited a statistically significantly ($p < 0.05$) greater reduction in gingival index scores of 0.09 as compared to an increase of 0.01 for Toothbrush I.

### Table I

**Summary of Age and Sex Characteristics for Subjects Who Completed the Clinical Study**

<table>
<thead>
<tr>
<th>Toothbrush</th>
<th>Number of Subjects</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>TC</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>26</td>
</tr>
</tbody>
</table>

### Table II

**Summary of Pre- and Post-Brushing Four-Week and 12-Week Plaque Scores for Subjects Who Completed the 12-Week Study**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Toothbrush</th>
<th>N</th>
<th>Pre-Brushing Scores$^1$ (Mean ± SD)</th>
<th>Post-Initial Brushing Scores (Mean ± SD)</th>
<th>Initial Difference</th>
<th>Reduction$^2$</th>
<th>4-Week Scores</th>
<th>4-Week Difference</th>
<th>Reduction$^3$</th>
<th>12-Week Scores</th>
<th>12-Week Difference</th>
<th>Reduction$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Mouth</td>
<td>TC</td>
<td>40</td>
<td>0.75 ± 0.09</td>
<td>0.35 ± 0.08</td>
<td>0.40 ± 0.08</td>
<td>1.6x</td>
<td>0.30 ± 0.09</td>
<td>0.45 ± 0.08</td>
<td>2.05x</td>
<td>0.20 ± 0.06</td>
<td>0.55 ± 0.08</td>
<td>1.9x</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>36</td>
<td>0.74 ± 0.09</td>
<td>0.49 ± 0.08</td>
<td>0.25 ± 0.05</td>
<td></td>
<td>0.52 ± 0.09</td>
<td>0.22 ± 0.07</td>
<td>0.45 ± 0.12</td>
<td>0.29 ± 0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gumline (gingival margin)</td>
<td>TC</td>
<td>40</td>
<td>1.00 ± 0.00</td>
<td>0.88 ± 0.10</td>
<td>0.12 ± 0.10</td>
<td>12x</td>
<td>0.82 ± 0.14</td>
<td>0.18 ± 0.14</td>
<td>0.90 ± 0.16</td>
<td>0.59 ± 0.16</td>
<td>0.41 ± 0.16</td>
<td>8.2x</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>36</td>
<td>1.00 ± 0.00</td>
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<td>0.95 ± 0.13</td>
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</tr>
<tr>
<td>Interproximal</td>
<td>TC</td>
<td>40</td>
<td>0.99 ± 0.05</td>
<td>0.25 ± 0.27</td>
<td>0.74 ± 0.28</td>
<td>2x</td>
<td>0.12 ± 0.21</td>
<td>0.87 ± 0.22</td>
<td>3.2x</td>
<td>0.02 ± 0.07</td>
<td>0.97 ± 0.08</td>
<td>8.1x</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>36</td>
<td>0.99 ± 0.04</td>
<td>0.62 ± 0.25</td>
<td>0.37 ± 0.24</td>
<td></td>
<td>0.72 ± 0.24</td>
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<td>0.53 ± 0.36</td>
<td>0.46 ± 0.36</td>
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</tbody>
</table>

$^1$Groups are not statistically significantly different from each other at baseline (pre-brushing scores).
$^2$After the initial brushing, statistically significant ($p < 0.05$) reductions based on the difference from pre-brushing values are indicated as per the ANCOVA comparison of the differences from pre-brushing values are shown.
$^3$After four weeks of brushing, statistically significant ($p < 0.05$) reductions based on the four-week difference from pre-brushing values are indicated as per the ANCOVA comparison of the four-week values.
$^4$After 12 weeks of brushing, statistically significant ($p < 0.05$) reductions based on the 12-week difference from pre-brushing values are indicated as per the ANCOVA comparison of the 12-week values.

### Table III

**Summary of the Gingivitis and Gingivitis Severity Scores for Subjects Who Completed the 12-Week Study.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Toothbrush</th>
<th>N</th>
<th>Pre-Brushing Scores$^1$ (Mean ± SD)</th>
<th>4-Week Scores (Mean ± SD)</th>
<th>4-Week Difference</th>
<th>Reduction$^2$</th>
<th>12-Week Scores (Mean ± S.D.)</th>
<th>12-Week Difference</th>
<th>Reduction$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gingivitis</td>
<td>TC</td>
<td>40</td>
<td>1.16 ± 0.20</td>
<td>1.07 ± 0.29</td>
<td>0.09 ± 0.20</td>
<td>11x</td>
<td>0.74 ± 0.29</td>
<td>0.42 ± 0.24</td>
<td>7x</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>36</td>
<td>1.11 ± 0.13</td>
<td>1.12 ± 0.14</td>
<td>-0.01 ± 0.05</td>
<td></td>
<td>1.05 ± 0.18</td>
<td>0.06 ± 0.11</td>
<td></td>
</tr>
<tr>
<td>Gingivitis Severity</td>
<td>TC</td>
<td>40</td>
<td>0.18 ± 0.21</td>
<td>0.15 ± 0.20</td>
<td>0.03 ± 0.04</td>
<td>3x</td>
<td>0.04 ± 0.09</td>
<td>0.14 ± 0.15</td>
<td>3.5x</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>36</td>
<td>0.15 ± 0.17</td>
<td>0.14 ± 0.15</td>
<td>0.01 ± 0.11</td>
<td></td>
<td>0.11 ± 0.14</td>
<td>0.04 ± 0.12</td>
<td></td>
</tr>
</tbody>
</table>

$^1$Groups are not statistically significantly different from each other at baseline (pre-brushing scores).
$^2$At four weeks, statistically significant ($p < 0.05$) reductions based on the four-week difference from baseline are indicated as per the ANCOVA comparison of the four-week values are shown.
$^3$At 12 weeks, statistically significant ($p < 0.05$) reductions based on the 12-week difference from baseline are indicated as per the ANCOVA comparison of the 12-week values are shown.
Gingivitis Severity. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in gingivitis severity index scores of 0.03 as compared to 0.01 for Toothbrush I.

Removal of Supragingival Plaque After Four Weeks
Whole Mouth Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in whole mouth plaque scores of 0.45 as compared to 0.22 for Toothbrush I.

Gingival Margin Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in gingival margin plaque scores of 0.18 as compared to 0.002 for Toothbrush I.

Interproximal Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in interproximal plaque scores of 0.87 as compared to 0.27 for Toothbrush I.

Reduction of Gingivitis After Twelve Weeks
Gingivitis. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in gingival index scores of 0.42 as compared to 0.06 for Toothbrush I.

Gingivitis Severity. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in gingivitis severity scores of 0.14 as compared to 0.04 for Toothbrush I.

Removal of Supragingival Plaque After Twelve Weeks
Whole Mouth Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in whole mouth plaque scores of 0.55 as compared to 0.29 for Toothbrush I.

Gingival Margin Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in gingival margin plaque scores of 0.41 as compared to 0.05 for Toothbrush I.

Interproximal Plaque. Toothbrush TC exhibited a statistically significantly (p < 0.05) greater reduction in interproximal plaque scores of 0.97 as compared to 0.46 for Toothbrush I.

Discussion
The removal of supragingival plaque (biofilm) is essential in preventing gingivitis. The mechanical removal of plaque by tooth brushing is still the best way to attain a plaque-free mouth. The American Dental Association recommends twice-daily, two-minute tooth brushing as being effective to remove plaque and deliver fluoride. When brushing, most people tend to form patterns that miss areas, such as the interproximal and gum margin areas. There are basically two types of toothbrushes: manual and power. Power brushing is designed to mechanically remove as much plaque as possible, particularly in inaccessible areas of the oral cavity, such as fissures, interproximal, and sub-gingival areas. The motion from a power toothbrush has been demonstrated in vitro to drive fluid dynamic forces beyond the reach of the toothbrush bristles into inaccessible interproximal spaces, resulting in improved biofilm removal in these areas.23

The purpose of this clinical study was to assess the plaque and gingivitis efficacy of a new specially engineered sonic powered toothbrush with unique sensing and control technologies when compared to a commercially available manual flat-trim toothbrush. The data from this study demonstrate that the new sonic powered toothbrush provides statistically significantly greater levels of efficacy in the removal of dental plaque after a single tooth brushing and after four and 12 weeks of use when compared to a manual flat-trim toothbrush on all measured sites: whole mouth, gumline (gingival margin), and interproximal. The new sonic powered toothbrush also provides statistically significantly greater levels of efficacy in the reduction of gingivitis and gingival bleeding when compared to the manual flat-trim toothbrush after four and 12 weeks of use.

It can be concluded that this new specially engineered sonic powered toothbrush with unique sensing and control technologies provides statistically significantly greater levels of efficacy in the removal of dental plaque after a single tooth brushing and after four and 12 weeks, and greater levels of efficacy in the reduction of gingivitis and gingival bleeding after four and 12 weeks of use when compared to a manual flat-trim toothbrush.

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References


Laboratory Evaluation of Plaque Removal at Interproximal Sites by a Specially Engineered Powered Toothbrush with Unique Sensing and Control Technologies

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Abstract

• **Objective:** This laboratory study compared a specially engineered sonic powered toothbrush with unique sensing and control technologies and having two different brush heads to a manual flat-trim toothbrush for their ability to remove plaque at interproximal sites.

• **Methods:** Interproximal access efficacy (IAE) was measured as the maximum width of plaque removed from the artificial plaque substrate around the teeth. Six brushes of each product were tested four times for a total of 24 tests. Results from these tests were statistically analyzed using an analysis of variance (ANOVA). A post hoc Tukey test for pair-wise comparisons, with a minimum significance level of 0.05, was used to identify significant mean differences between the test products.

• **Results:** Relative to the manual flat-trim toothbrush, the sonic powered toothbrush, equipped with either the Triple Clean or Sensitive refill brush head, had statistically significantly higher IAE means (p < 0.001). In addition, when equipped with the Sensitive refill brush head, the new sonic powered toothbrush showed increased efficiencies compared to when it was equipped with the Triple Clean brush head with respect to IAE means.

• **Conclusion:** The specially engineered sonic powered toothbrush with unique sensing and control technologies had higher interproximal access efficacy compared to a manual flat-trim toothbrush, particularly with the Sensitive brush head.

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Introduction

It has been accepted that the two most common dental diseases, dental caries and periodontal disease, can be prevented or alleviated by adequate removal of dental plaque. These deposits accumulate primarily at interproximal sites and on the gingival third of the premolar and molar teeth, and then proliferate below the gingival margin. The primary reason why dental plaque thrives in these areas is that they are the most difficult areas to access when brushing. These are the same areas predominantly associated with gingivitis and related periodontal diseases, because of this plaque accumulation.

There have been many oral hygiene devices designed to augment dental plaque removal via tooth brushing, such as interdental brushes and various types of floss. While these adjunct devices are readily available, they are underutilized, which leaves the toothbrush as the primary plaque removal device for most individuals. The challenge has been to design a toothbrush with enhanced capability to remove dental plaque from hard-to-reach areas, such as the gingival margin, the gingival sulcus, and interdental surfaces, and thereby improve general oral health. The past fifty years has seen the development of many manual toothbrush designs based on scientific research that have focused on all aspects of the toothbrush. Toothbrush handles have been redesigned to be more ergonomically acceptable, and have additions such as thumb rests and ripples in the handle to improve grip and control. Toothbrush heads have been designed in a variety of sizes and shapes that include circular, oval, and diamond-shaped, as well as angulation of the head placement. Notably, toothbrush bristles have received the most attention in reconfiguration and new designs. Examples of toothbrush bristle designs include flat, bi-level, multi-level, multi-tufted, V-shaped, curved, rippled, angled, tapered, and bristles that change color to indicate length of use (or wear indicators).

Toothbrush stiffness depends on several factors, including bristle diameter, tuft hole diameter, tuft hole packing factor, tuft height, and the product trim profile. Generally, the higher the tuft or trim height the softer the product will be. Conversely, the shorter the tuft or trim height the stiffer or firmer the product will be. The longer a filament/strand/bristle the more pliable or flexible it will be. The
shorter the filament/strand/bristle the less pliable or more rigid or stiffer it will be.

Regarding bristle stiffness, the soft bristle has been established as the professional standard for recommendation to patients. While medium and hard bristle toothbrushes are still available, toothbrush manufacturers and dental professionals have focused on providing the soft texture bristle toothbrushes. With proper tooth brushing technique, soft bristle toothbrushes have many advantages over stiffer bristled brushes, as the soft bristles can remove dental plaque and biofilm more efficiently in the cervical, proximal, and marginal areas of the tooth, as well as being safe for cleaning the gingival sulcus without causing soft tissue trauma, as a result of their pliability.

The first modern powered toothbrush was reported in the literature in 1938, and a more advanced version, Broxodent by E.R. Squibb & Sons Company, was introduced after World War II in Switzerland. In 1961, General Electric introduced a rechargeable cordless powered toothbrush.16 Each of these toothbrushes had basic designs modeled after manual toothbrushes. Both models had similar reciprocal brushing actions. Clinical research on these powered toothbrushes compared them to manual toothbrushes, with the results ranging from no significant difference between manual and powered toothbrushes14,15 to reporting that powered toothbrushes improved gingivitis.16 These early powered toothbrushes were not overwhelmingly popular with dental professionals because they felt that compulsive brushers would use them excessively and damage supporting soft tissues.16

Interest in powered toothbrushes was renewed in the 1980s when several technological advances were made; additional advances have continued to date.17-24 The speed at which some powered bristles vibrate is now labeled as sonic or ultrasonic. The brush head motions currently available include simple rotary, vertical vibration, three-dimensional counter-rotational pulsation plus oscillation, and one particular brush that has individual tufts of bristles that rotate 1.5 turns in one direction and 1.5 turns in the opposite direction.25 Many of the shapes of powered brush heads mirror those of manual toothbrushes, but some powered brushes also include round brush heads.

The majority of the changes that appear in all aspects of contemporary toothbrush design and materials have focused on improving dental plaque removal, especially in the hard-to-reach areas, at the gingival margin, the gingival sulcus, and the interproximal spaces. There have been numerous clinical trials and laboratory studies comparing the efficacy and safety of these new, unique, or enhanced toothbrushes. Many studies, both clinical and laboratory, have concluded that powered toothbrushes are safe and equal to or superior to manual toothbrushes in dental plaque removal.25-30

The purpose of this laboratory study was to evaluate a new specially engineered sonic powered toothbrush with unique sensing and control technologies, with two different brush heads, was compared to a manual flat-trim toothbrush for their ability to remove plaque at interproximal sites using a laboratory assay known as Interproximal Access Efficacy (IAE).31,32 The following test products were used.

TC: Colgate® ProClinical™ A1500 Power Toothbrush with Triple Clean Brush Head (Colgate-Palmolive Company, New York, NY, USA)
S: Colgate® ProClinical™ A1500 Power Toothbrush with Sensitive Brush Head (Colgate-Palmolive Company, New York, NY, USA)
I: Manual flat-trim toothbrush; Oral-B® Indicator Toothbrush (Procter & Gamble Company, Cincinnati, OH, USA)

In the assay, six brushes from each test product group were evaluated four times for a total of 24 tests. All toothbrushes were stored in the laboratory at a temperature of 67–70°F for at least 48 hours before testing. The laboratory equipment was fabricated to the design of Nygaard-Ostby, et al.28 and was further modified to the design of Shi, et al. to affix toothbrushes by the handle.44

In the IAE assay, the brushing technique involved independent evaluations of each toothbrush in a vertical and horizontal brushing motion with tooth shapes simulating anterior and posterior teeth. The brushing apparatus was set to brush for 15 seconds at two strokes per second with a 50 mm stroke. The maximum width of artificial plaque removed from the plaque substrate placed around the teeth was recorded in centimeters (cm). Toothbrushes TC and S were evaluated using the Auto Mode, i.e., with the power on.

Before and after the assay completion, the brush heads were visually examined for bristle integrity. The same examiner performed both efficacy and toothbrush integrity evaluations.

Results for all brushing comparisons were statistically analyzed using an analysis of variance (ANOVA). A post hoc Tukey test for pair-wise comparisons with a minimum significance level of 0.05 was used to identify significant mean differences between the test products.

Results

Toothbrush Bristle Integrity

A summary of IAE means for both anterior- and posterior-shaped teeth is presented in Table I. The IAE means on anterior and posterior tooth shapes with vertical brushing are statistically significantly higher for the TC and S groups than for the I group (p < 0.001). On both anterior and posterior tooth shapes, the S group has statistically significantly higher mean IAE compared to the TC group (p < 0.001). With horizontal brushing, the mean IAE on anterior tooth shapes is statistically significantly higher for the TC and S groups than for the I group (p < 0.001). Overall results combining IAE data using vertical and horizontal brushing motions and anterior and posterior tooth shapes are depicted graphically in Figure 1. The overall IAE means for the TC and S groups are statistically significantly higher compared to the overall mean IAE value for the I group (p < 0.001). The S group has statistically significantly higher mean IAE compared with the TC group (p < 0.001).
Table I
Interproximal Access Efficacy on Anterior and Posterior Shaped Teeth

<table>
<thead>
<tr>
<th>Toothbrush Group</th>
<th>Vertical Brushing</th>
<th>Horizontal Brushing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anterior Teeth</td>
<td>Posterior Teeth</td>
</tr>
<tr>
<td>TC</td>
<td>1.20 ± 0.05</td>
<td>1.38 ± 0.08</td>
</tr>
<tr>
<td>S</td>
<td>1.34 ± 0.07</td>
<td>1.58 ± 0.08</td>
</tr>
<tr>
<td>I</td>
<td>0.87 ± 0.09</td>
<td>1.08 ± 0.04</td>
</tr>
</tbody>
</table>

Figure 1. Overall mean IAE (±SD)

Discussion

There are many clinical methods to assess plaque removal with toothbrushes and other oral hygiene aids and devices. These methods are based on plaque indices because they provide a quantitative measure for analyzing dental conditions in individuals and groups. Most clinical studies are designed to evaluate plaque removal on specific surfaces of the teeth, especially the areas that individuals have a hard time reaching with a toothbrush, such as the gingival margin, the gingival sulcus, and the interproximal areas. Therefore, plaque indices that focus on these areas are selected to use as part of the study design. Popular plaque indices used in clinical toothbrush evaluations and comparisons include the Turesky Modification of the Quigley-Hein Index, the Proximal Marginal Index, the Green and Vermillion Oral Hygiene Index, and the Rustogi Modification of the Modified Navy Plaque Index.56

The laboratory method used in this study has been predictive of clinical efficacy for toothbrushes.4,39,42,47,57 A key element of these methods is the use of a pressure-sensitive plaque substrate54 that can be used on tooth contours and under the gingival margin with wet brushing conditions. The gingival margins for the laboratory models were replicated according to textbook descriptions, and the artificial plaque material was adhered to the substrate in order to provide comparative measures of the removal of perigingival and/or supragingival artificial plaque. Toothbrushes can be tested using simulated clinical brushing conditions. The toothbrushes can be tested in vertical and horizontal directions of artificial anterior and posterior teeth, and in a wet environment with brushing timed in seconds.

Clinical studies are usually tightly controlled, but standardization and uncontrollable variables are vulnerable areas. Some variables that are impossible to control are subject-to-subject differences in tooth brushing and variations in brushing pressures and techniques. These particular variables have been eliminated with the laboratory methods used in this study to evaluate interproximal access. Further, laboratory testing is economical, faster, and more standardized than a clinical trial.

The results of the laboratory assessments of a new specially engineered sonic powered toothbrush with unique sensing and control technologies with either of two different brush heads indicate that the toothbrush bristles penetrate into interproximal areas. Since dental plaque is difficult to remove in these areas, and they are vulnerable to dental caries, gingivitis, and more advanced forms of periodontal disease, the new sonic powered toothbrush with either brush head is expected to be highly efficacious for plaque removal in vivo and may, therefore, offer advantages in the prevention of dental caries and periodontal disease.

Conclusion

Relative to the manual flat-trim toothbrush, the specially engineered sonic powered toothbrush with unique sensing and control technologies, equipped with either the Triple Clean or Sensitive refill brush head, has statistically significantly higher IAE means (p < 0.001). In addition, when equipped with the Sensitive refill brush head, this new sonic powered toothbrush shows increased efficiencies as compared to when it is equipped with the Triple Clean brush head with respect to IAE means.

Acknowledgement. This study was sponsored by the Colgate-Palmolive Company.

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References

Laboratory Evaluation of Extrinsic Stain Removal by a Specially Engineered Sonic Powered Toothbrush with Unique Sensing and Control Technologies

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Abstract
• Objective: The purpose of this laboratory study was to evaluate extrinsic stain removal from teeth by a specially engineered sonic powered toothbrush with unique sensing and control technologies, using the Triple Clean and the Sensitive refill brush heads, in comparison to a manual flat-trim toothbrush.
• Methods: Twelve (12) artificially stained bovine teeth were tested with each product. The percentage of stain removed by each product was calculated by taking the ratio of the amount of stain removed by brushing for 800 strokes to the total amount of stain removed by subsequent application of a dental prophylaxis. The stain was quantified by measuring the light reflected by the stained teeth with a spectrophotometer. Data were reported as L*, lightness of the stain, and as W*, a whiteness index comprising the lightness, hue, and chroma of reflected light. Statistical analyses were performed separately for the \( \Delta L^* \) and \( \Delta W^* \) scores. Comparisons of the toothbrushes with respect to baseline-adjusted \( \Delta L^* \) and \( \Delta W^* \) scores were performed using an analysis of covariance (ANCOVA). Post-ANCOVA pair-wise comparisons of the study toothbrushes were performed using Tukey’s test for multiple comparisons. All statistical tests of hypotheses were two-sided, and employed a minimum level of significance of 0.05.
• Results: The percentage of stain removed by the sonic powered toothbrush, using either the Triple Clean brush head or the Sensitive brush head under laboratory test conditions, is superior (p < 0.05) to the percentage of stain removed by the manual flat-trim toothbrush when analyzed for both the \( \Delta L^* \) and \( \Delta W^* \) scores. The mean percentage of stain removed was 62.10 for the power toothbrush with the Triple Clean brush head, 49.01 for the power toothbrush with the Sensitive brush head, and 30.56 for the manual flat-trim toothbrush when calculated using \( \Delta L^* \) scores. The mean percentage of stain removed was 59.89 for the power toothbrush with the Triple Clean brush head, 46.83 for the power toothbrush with the Sensitive brush head, and 29.25 for the manual flat-trim toothbrush when calculated using \( \Delta W^* \) scores.
• Conclusions: This new specially engineered sonic powered toothbrush with unique sensing and control technologies effectively removes extrinsic stains from the surface of teeth under laboratory test conditions with both the Triple Clean and the Sensitive brush heads. The effectiveness of stain removal with either brush head is significantly greater than the effectiveness of stain removal of a manual flat-trim toothbrush under these conditions.

Introduction
Tooth whitening is a growing category in oral care. Various product forms, including strips, trays, mouthwashes, dentifrices, and toothbrushes all claim to deliver tooth whitening benefits of various magnitudes to the consumer. These products provide whitening through various modes of action. Bleaching agents, such as peroxide, are commonly applied to teeth with a strip or tray, but they can also be added to mouthwash and dentifrice products.\(^5,6\) Bleaching agents are known to be effective against both intrinsic and extrinsic stains as they chemically react with stain molecules to render stains colorless.\(^7\) Other whitening ingredients, including detergents and chelating molecules, are used in dentifrices and mouthwashes to assist in the removal of loosely bound extrinsic stains.\(^5,6\) Abrasives are used in dentifrices to mechanically remove extrinsic stain.\(^5,6\) To clean effectively, abrasives are scrubbed against the tooth by a toothbrush.\(^7\) The design of a toothbrush can influence the motion of the abrasive particles during brushing and have resulting impact on the effectiveness of stain removal. An in vitro brushing model was created to follow the movement of abrasive particles against toothbrush bristles during the action of brushing.\(^4\) Using this model, it was determined that when filament tufts were designed so that they deploy evenly over the surface during use, good particle trapping by the toothbrush was observed. Bristles with rounded tips were also found to be more effective than bristles with flat tips in trapping abrasive particles. Finally, power toothbrushes were found to cause greater particle movement and trapping than manual brushes.
Clinical studies have confirmed that power toothbrushes are capable of removing more extrinsic stain than manual toothbrushes. A clinically significant reduction in stain from baseline has been measured with different types of power toothbrushes.

In order to optimize dentifrice formulas and toothbrush design to maximize stain removal, in vitro models have been developed. The general procedures described in most publications are adapted from the method developed by Stookey et al. known as the Pellicle Cleaning Ratio (PCR) method. In this method, enamel blocks are cut from bovine central incisors and mounted in a resin so that only the enamel is exposed. The enamel is cycled through a staining broth consisting of food stains, salivary proteins, and bacteria that promote stain formation, until a dark, substantive film is formed on the enamel. The stained teeth are brushed on a V-8 cross-brushing machine to ensure experimental control over the applied force, speed, and slurry dilution. The Stookey et al. study found that the amount of stain removed after brushing for 800 double strokes in this model correlated well with the clinically measured stain removal for 22 different dentifrice products. Since the publication of the PCR method in 1982, it has been accepted as the industry standard method to evaluate the cleaning performance of dentifrice formulas in the laboratory. It has also been adapted to test the stain removal performance of toothbrushes. Common changes to the method include a reduction in the applied force from 250 g to 150 g when testing power toothbrushes to model consumer usage of these products. Often, the brushing machine must also undergo a change to the geometry to accommodate different toothbrush handles. In addition, rather than reporting the stain removal relative to brushing with a standard abrasive or dentifrice control, the stain removed by brushing has been reported against the total amount of stain that can be removed by treatment with an abrasive dental prophylaxis. Finally, there have been changes in grading from visual grading of stain intensity to instrumental grading of stain intensity through the measurement of reflected light. This paper describes the in vitro stain removal efficacy of a new specially engineered sonic powered toothbrush with unique sensing and control technologies, and details the adaptations made to the PCR method in this study. The stain removal performance of two different refill brush head designs is reported and compared to the performance of a flat-trim manual toothbrush. The percentage of stain removed by all three test products is reported relative to the total amount of stain removed by a dental prophylaxis.

**Materials and Methods**

The specially engineered sonic powered toothbrush with unique sensing and control technologies (Colgate ProClinical A1500 Power Toothbrush, Colgate-Palmolive Company, New York, NY, USA), fitted with either the Triple Clean refill brush head (TC) or the Sensitive refill brush head (S), was evaluated and compared to the Oral-B Indicator 40 manual toothbrush (L) labeled “soft texture” (Procter & Gamble Company, Cincinnati, OH, USA). The in vitro method to measure extrinsic stain removal used in this study closely followed that described by Stookey et al. Modifications to the method were made to accommodate the geometry and usage conditions of the power toothbrush, in the use of a spectrophotometer, and in the use of a dental prophylaxis to determine the reference for maximum stain removal.

Artificially stained bovine dental enamel blocks were purchased from Therametric Technologies, Inc. (Indianapolis, IN, USA). The 10 mm² blocks were mounted in a methacrylate resin so that only the enamel was exposed to the stain. The staining procedure closely followed that described by Stookey et al. in that enamel blocks were cycled between air and a staining broth containing coffee, tea, mucin, soy broth, and Sarcina Lutea, in a 37°C incubator, until the L* value of the specimen was between 25 and 40.

The amount of stain on the teeth was quantified by measuring the light reflected off of the surface of the tooth with a spectrophotometer (Spectroshade Micro, MHT Technologies, Milan, Italy). Measurements over the entire visible color spectrum were obtained and reported as L*, a*, and b* values in the CIELab color scale. L* is the lightness of color with L* = 100 representing diffuse white and L* = 0 representing black. The second parameter, a*, represents the positioning of the color between red and green. A positive a* value is red while a negative a* value is green. Likewise, b* is the position of a color between yellow and blue. A positive b* value is yellow while a negative b* value is blue. Together, the L*, a*, and b* values make up the coordinate of a color in CIELab space. L*, a*, and b* can be combined to calculate a whitening index. One such whitening index is W*

\[
W* = ((a*-0)^2 + (b*-0)^2 + (L* - 100)^2)^{1/2}
\]

To take a measurement, the spectrophotometer was positioned so that a single tooth was in the instrument’s field of vision and then the image was captured. The images were transferred to a computer for analysis, and software from MHT was used to define the perimeter of the entire tooth and report the L*, a*, and b* values for this area. Before baseline stain measurements were conducted, the teeth were rinsed with deionized water and air dried for 30 minutes. Reflectance data were collected with the spectrophotometer three times for each tooth and the average of these measurements was defined as the baseline L*, a*, and b* values for each tooth which were used to calculate the baseline W* value. Thirty-six teeth were sorted into three groups so that the distribution of average baseline W* values for each group was balanced. Each group was assigned to one of the test toothbrushes.

The brushing study was conducted using a V-8 mechanical cross-brushing machine. Four sample holders on the machine were each enlarged and extended to accommodate the handle of the sonic power toothbrush (Figure 1a). The remaining four sample holders were left in their original position to hold the manual flat-trim toothbrushes (Figure 1b). In order to minimize mechanical variations between test cycles, two teeth were treated.
with Toothbrush I, two were treated with Toothbrush TC, and two were treated with Toothbrush S in each test cycle. A total of six cycles and 12 teeth were tested with each product. The position of the manual flat-trim brushes was rotated between the four slots and each slot was used three times. The refill brush heads and their attached handles were rotated among their four available slots and tested in each slot three times.

The pressure applied to the power toothbrushes was adjusted to 150 grams of pressure, while 250 grams of pressure was applied to the manual brushes. Close attention was paid to the alignment of the teeth on the V-8 brushing machine to ensure uniformity of brushing patterns. Each tooth was immersed in a dentifrice slurry consisting of 25 grams of Crest® Cavity Protection (Procter & Gamble Company, Cincinnati, OH, USA) and 40 milliliters of deionized water. Before starting the brushing cycles, the power toothbrushes were set to the optimum mode. The teeth were brushed for 800 double strokes, rinsed with deionized water, and removed from the brushing machine.

The teeth were air dried for 30 minutes and three measurements were taken of each tooth as above with the spectrophotometer. Next, the remaining stain was removed from each tooth by applying a dental prophylaxis treatment (NUPRO®, Dentsply, York, PA, USA) for 10 seconds using a dental hand piece. The teeth were rinsed with deionized water, air dried for 30 minutes, and readings were taken three times for each tooth as above with the spectrophotometer. This final prophylaxis procedure provided a value for the maximum amount of the extrinsic stain that potentially could be removed from each tooth. The following equations detail how the change in L* and W* were calculated.

\[
\Delta L^*:
Stain Removed = L^*_{\text{treatment}} - L^*_{\text{baseline}}
Total Stain Available = L^*_{\text{prophylaxis}} - L^*_{\text{baseline}}
% \text{ Stain Removed} = \left( \frac{\text{Stain Removed}}{\text{Total Stain Available}} \right) \times 100%
\]

\[
\Delta W^*:
Stain Removed = W^*_{\text{treatment}} - W^*_{\text{baseline}}
Total Stain Available = W^*_{\text{prophylaxis}} - W^*_{\text{baseline}}
% \text{ Stain Removed} = \left( \frac{\text{Stain Removed}}{\text{Total Stain Available}} \right) \times 100%
\]

Statistical analyses were performed separately for the \( \Delta L^* \) and \( \Delta W^* \) values. Comparisons of the toothbrushes with respect to baseline-adjusted \( \Delta L^* \) and \( \Delta W^* \) scores were performed using an analysis of covariance (ANCOVA). Post-ANCOVA pair-wise comparisons of the study toothbrushes were performed using Tukey’s test for multiple comparisons. All statistical tests of hypotheses were two sided, and employed a minimum level of significance of 0.05.

Results and Discussion

Table I presents a summary of the baseline W* and L* scores for the toothbrushes in the study. The mean baseline W* scores were 79.21 for Toothbrush TC, 79.54 for Toothbrush S, and 79.76 for Toothbrush I. The mean baseline L* scores were 25.87 for Toothbrush TC, 25.15 for Toothbrush S, and 24.62 for Toothbrush I. No statistically significant (p > 0.05) difference was indicated among the toothbrushes with respect to baseline W* or L* scores.

Table II presents a summary of the mean percent stain removed calculated using the \( \Delta L^* \) and \( \Delta W^* \) values. Comparisons of the toothbrushes with respect to baseline-adjusted \( \Delta L^* \) and \( \Delta W^* \) scores were performed using an analysis of covariance (ANCOVA). Post-ANCOVA pair-wise comparisons of the study toothbrushes were performed using Tukey’s test for multiple comparisons. All statistical tests of hypotheses were two sided, and employed a minimum level of significance of 0.05.

<table>
<thead>
<tr>
<th>Table I</th>
<th>Mean Baseline L* and W* Values</th>
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<tbody>
<tr>
<td>Toothbrush</td>
<td>n</td>
</tr>
<tr>
<td>Toothbrush TC</td>
<td>12</td>
</tr>
<tr>
<td>Toothbrush S</td>
<td>12</td>
</tr>
<tr>
<td>Toothbrush I</td>
<td>12</td>
</tr>
</tbody>
</table>

Table II presents a summary of the mean percent stain removed calculated using the \( \Delta L^* \) scores. The mean percentage of stain removed was 62.10 for Toothbrush TC, 49.01 for Toothbrush S, and 30.56 for Toothbrush I. Relative to Toothbrush I, both Toothbrush TC and Toothbrush S exhibited statistically significant (p < 0.05) stain reductions. Relative to Toothbrush S, Toothbrush TC did not exhibit a statistically significant (p > 0.05) difference in stain removed.

Table III presents a summary of the mean percent stain removed calculated using the \( \Delta W^* \) scores. The mean
percentage of stain removed was 59.89 for Toothbrush TC, 46.83 for Toothbrush S, and 29.25 for Toothbrush I. Relative to Toothbrush I, both Toothbrush TC and Toothbrush S exhibited statistically significant (p < 0.05) stain reductions. Relative to Toothbrush S, Toothbrush TC did not exhibit a statistically significant (p > 0.05) difference in stain removed.

It is generally believed that a toothbrush can only scrub away stain molecules and cannot alter the hue or chroma of stains. In the literature, data are typically reported as changes in $L^*$ for in vitro stain removal studies, as a change in $L^*$ is thought to correlate with extrinsic stain removal. In the current study, a whitening index, $W^*$, is also reported as it is calculated using all three descriptors of a color ($L^*$, $a^*$, and $b^*$). In order to report that a color has actually become whiter, it is necessary to account for changes to all three coordinates which describe the color, even if there is no significant change in $a^*$ or $b^*$. In this study, $L^*$ became lighter and $W^*$ became whiter after brushing with each toothbrush. In addition, the change in $L^*$ and $W^*$ was greater for Toothbrush TC and Toothbrush S than for Toothbrush I, indicating that the new sonic powered toothbrush, using either of the refill brush heads, was better than the manual flat-trim toothbrush in terms of the removal of extrinsic stain as well as an increase in whiteness.

### Conclusion

A new specially engineered sonic powered toothbrush with unique sensing and control technologies, with either the Triple Clean refill brush head or the Sensitive refill brush head, was significantly more effective (p < 0.05) than a manual flat-trim toothbrush at removing extrinsic stain in this laboratory study. This sonic powered toothbrush demonstrated a greater percentage of stain removed when the results were calculated using $\Delta L^*$ and when results were calculated using the whitening index, $\Delta W^*$. These results show that removing extrinsic stain by brushing can be a meaningful way to increase the whiteness of teeth. There were no significant differences in the in vitro stain removal efficacy between the power toothbrush with the Triple Clean refill brush head and the power toothbrush with the Sensitive refill brush head.

**Acknowledgement:** These studies were sponsored by the Colgate-Palmolive Company, Piscataway, NJ, USA. The authors would like to thank Jeffrey Graham and Gerald Gontarz for assistance with modifications to the V-8 cross-brushing machine.

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### References


Ergonomic Audit of a Specially Engineered Sonic Powered Toothbrush with Unique Sensing and Control Technologies, the Sonicare FlexCare, and the Oral-B Smart Series 5000

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Abstract

• Objective: The presence of ergonomic features can impact the marketplace success of a new product. Metaphase Design Group, Inc., in partnership with the Colgate-Palmolive Company, conducted an ergonomic audit on three electric toothbrushes: a specially engineered sonic powered toothbrush with unique sensing and control technologies, the Sonicare™ FlexCare, and the Oral-B® Smart Series 5000.

• Methods: The ergonomic audit was conducted by Metaphase Design Group’s ergonomic and usability experts. Two experts used the toothbrushes over a one-week period and assessed the performance of each brush against a set of ergonomic principles.

• Results: The three toothbrushes have some solid ergonomic features. They each have adequate grip zones, provide grip security with elastomeric materials, and provide easy access to the on/off button. The most distinctive feature is the longitudinal shape of the handle of the specially engineered sonic powered toothbrush with unique sensing and control technologies. This handle angles downward at the top end and provides additional advantages through improved grip security and visibility. Yet all three toothbrushes have different opportunities for improvement. The Sonicare Flex Care toothbrush has a cluttered and complicated user interface that is difficult to read. The disadvantages of the Oral-B Smart Series 5000 toothbrush are related to its physical dimensions and audible feedback.

• Conclusion: The specially engineered sonic powered toothbrush with unique sensing and control technologies is surprising to use with its changes in speeds, brush movements, and resulting changes in audible feedback.

Introduction

Ergonomics is the application of what is known about human capabilities and limitations (both physically and cognitively) to the design of products in order to facilitate a more efficient, safe, and satisfactory use. Ergonomic evaluations focus on design features that are not obvious to the end user, yet add significant benefits to the design of a toothbrush.

When evaluating ergonomics, a product is examined to determine if it meets ergonomic principles. If the product violates these principles it then compromises its usability.

When assessing the ergonomic factors, the evaluations examine both the presence of these ergonomic features as well as the perception of ergonomic features. The perception of ergonomics is important at point-of-purchase where consumers are not able to physically handle the product, but are searching for products that appear to be easy and comfortable to use. Often, perceived ergonomics results from the use of soft touch material, generous radii on the form, uncluttered interfaces, minimal buttons, etc.

Prior to conducting an ergonomic audit, it is critical to define the target user population as well as understand the usage environment. For electric toothbrushes, it is assumed the target population is male and female adults aged 35–50 years, and the product will be used in a possibly wet, bathroom environment.

This article discusses the results from an ergonomic audit of three electric toothbrushes: a specially engineered sonic powered toothbrush with unique sensing and control technologies, the Sonicare FlexCare, and the Oral-B Smart Series 5000.

Materials and Methods

Two ergonomic experts from Metaphase Design Group used the test toothbrushes for approximately one week, and assessed the performance against a standard set of ergonomic principles that are familiar to the experts based on their experience in the field. These experts had each toothbrush’s instructional manual to use during the trials. There was no pre-determined order in which the experts used the toothbrushes.

The ergonomic principles considered in this audit were as follows:

• The product is intuitive to use; that is, the product operation needs to be designed to match how users typically think, how users typically process information, as well as users’ previous experience with products.
• The physical design of the device (e.g., size, form,
controls) needs to accommodate the user’s physical characteristics such as hand size (Figure 1).²

- The device is secure in users’ hands. Through its size, form, and materials, the product should fit comfortably and securely into a user’s hand during all tasks associated with its use.²
- The device utilizes the strongest and most intelligent digits (i.e., fingers). Digital intelligence is determined by a finger’s ability to use small, precise coordinated movements and manipulations. If digits are needed to activate controls (i.e., buttons), then the goal is to design the device so that the smart, strong digits can be used when manipulating the device. The strongest fingers (in rank order) are D1, D3 and D2. The smartest fingers (in rank order) are D2, D3, and D1 (Figure 2).²
- The device accommodates users’ range of motion. The controls and locations should be designed to work within a user’s range of motion (e.g., within reach of the digits; Figure 3).²

- The device optimizes feedback with redundancy, immediacy, and consistency. There are several types of feedback: visual, auditory, and tactile. Feedback is a significant factor in how quickly users learn and how they retain these learnings.¹
- The device’s text is legible at a glance. Factors to be considered are character size, character luminance, contrast ratio, display color, character height-to-width ratio, and character stroke width. In addition, icons should be universal or industry standard to leverage prior learning.¹

The following toothbrushes evaluated in the audit included:
1. TC: Colgate® ProClinical™ A1500 Power Toothbrush with the Triple Clean brush head (Colgate-Palmolive Company, New York, NY, USA)
2. PG: Oral-B® Smart Series 5000 Power Toothbrush (Procter & Gamble Company, Cincinnati, OH, USA)
3. PH: Sonicare™ FlexCare Power Toothbrush (Philips-Sonicare Company, Stamford, CT, USA)

Results

Handle Length

The handles for the three toothbrushes are approximately the same length (~14 cm; Figure 4). This handle length provides an adequate grip zone by accommodating both a small female hand width and a large male hand width (Table I).

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th</td>
<td>7.59 cm</td>
<td>8.61 cm</td>
</tr>
<tr>
<td>50th</td>
<td>8.31 cm</td>
<td>9.52 cm</td>
</tr>
<tr>
<td>95th</td>
<td>9.04 cm</td>
<td>10.50 cm</td>
</tr>
</tbody>
</table>
Handle Circumference

The cross-sectional size and shape are the biggest differences between the three toothbrushes with regard to their form (Figure 5). Toothbrush TC has a cylindrical-shaped handle and the narrowest handle, making it easy to rotate and manipulate in the fingers. Toothbrush PH also has a narrow, cylindrical-shaped handle making it easy to rotate and manipulate in the fingers. Toothbrush PG has the largest handle circumference and it is more rectangular-shaped compared to the other two handles. This size and shape make the handle on toothbrush PG feel bulky in the hand and more difficult to grasp, rotate, and manipulate with the fingers than Toothbrushes TC and PH.

Elastomeric Materials

Presence. Grip security is an important feature on a device that is used in wet, bathroom environments. All three brushes have elastomeric materials applied to the back side of the handles (Figure 6) that provide grip security. These materials also offer a perception of grip security and comfort at first glance.

Texture. The elastomeric material on Toothbrush PG has rough (tight radii) texture that detracts from the perception of comfort. The elastomeric material on Toothbrush PH has subtle texture, while the elastomeric material on Toothbrush TC does not have any texture (Figure 7). In addition, the presence of texture does not necessarily increase the grip security provided by the elastomeric materials (the elastomeric material itself is a good source of grip security).

Angle

The longitudinal shape of the handle of Toothbrush TC is distinct from the other two handles. It angles downward at the
top end of the handle, rather than being nearly straight as the handles on the other two brushes (Figure 8). This angled handle provides additional advantages. It provides a notch for the index finger to nestle, thus increasing the level of grip security for some grasping patterns. The angled handle increases visibility for certain brush orientations or areas of the mouth, but in other areas the angled underside may impede visibility. Even though the handle is angled, the brush head remains approximately in line with the handle. This layout preserves a close relationship between the handle and the brush head movement, which helps to position and aim the brush.

**Controls and Display Interface**

The number of buttons and amount of information on a device often corresponds to the perceived level of complexity of a device. Without using the toothbrushes, Toothbrush PH is visually perceived to be intimidating and complex as it has two buttons and six indicators; toothbrushes TC and PG visually appear easy to use as toothbrush TC has two buttons and one display and toothbrush PG has two buttons and one display (Figure 9).

Toothbrush TC has a clean and uncluttered interface (Figure 10). This provides the perception of simplicity and ease of use. The illuminated display is legible at a glance (when it is not in the mouth). The buttons and mode descriptions (e.g., auto, optimum, and deep clean) are intuitively labeled. The

![Figure 9. Toothbrush controls and user interfaces (l to r: Toothbrushes TC, PG, PH).](image)

![Figure 10. Toothbrush TC: Controls and user interface.](image)

![Figure 11. Toothbrush PG controls and interface.](image)
The three toothbrushes have some solid ergonomic features. They each have adequate grip zones, provide grip security with elastomeric materials, and provide easy access to the on/off button. The most distinctive feature is the longitudinal shape of the handle of Toothbrush TC. Its handle angles downward at the top end and provides additional advantages through improved grip security and visibility. Yet all three toothbrushes have different opportunities for improvement.

Discussion and Conclusion
The three toothbrushes tested have some solid ergonomic features. They each have adequate grip zones, provide grip security with elastomeric materials, and provide easy access to the on/off button. The most distinctive feature is the longitudinal shape of the handle of Toothbrush TC. Its handle angles downward at the top end and provides additional advantages through improved grip security and visibility. Yet all three toothbrushes have different opportunities for improvement. Toothbrush PH has a cluttered and complicated user interface that is difficult to read. The disadvantages of Toothbrush PG are related to its physical dimensions and audible feedback. The specially engineered sonic powered toothbrush with unique sensing and control technologies is relatively easy to use with its changes in speeds, brush movements, and resulting changes in audible feedback.

As manufacturers develop their next generation products, the ergonomic audits should be leveraged along with any user feedback. The two types of data complement each other and can result in an optimized product.

Acknowledgement: This study was funded by the Colgate-Palmolive Company.

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References
Usability Research Study of a Specially Engineered Sonic Powered Toothbrush with Unique Sensing and Control Technologies

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Abstract

• Objective: This paper summarizes the results of a longitudinal usability research study of a specially engineered sonic powered toothbrush with unique sensing and control technologies.

• Methods: The usability test was conducted with fourteen (14) consumers from the St. Louis, MO, USA area who use manual toothbrushes. The study consisted of consumers using the specially engineered sonic powered toothbrush with unique sensing and control technologies for three weeks. During the study, users participated in four toothbrush trials during weekly visits to the research facility. These trials were videotaped and were analyzed regarding brushing time, behavior, and technique. In addition, the users were required to use the toothbrush twice a day for their at-home brushing.

• Results: The toothbrush had a positive impact on consumers’ tooth brushing behavior. Users spent more time brushing their teeth with this toothbrush as compared to their manual toothbrush. In addition, users spent more time keeping the sonic toothbrush in the recommended angle during use. Finally, users perceived their teeth to be cleaner when using the specially engineered sonic powered toothbrush with unique sensing and control technologies.

• Conclusion: The specially engineered sonic powered toothbrush with unique sensing and control technologies left a positive impression on the users. The users perceived the toothbrush to clean their teeth better than a manual toothbrush.

(J Clin Dent 2012;23[Spec Iss A]:A31-A34)

Introduction

Usability studies provide insight into how potential customers will interact with a new product. This article presents the results from a usability study of a specially engineered sonic powered toothbrush with unique sensing and control technologies from the Colgate-Palmolive Company. The purpose of the study was to understand how tooth brushing behavior changed over the course of the study; specifically:

• Change in brushing time when using a manual toothbrush to using an electric toothbrush;
• Change in brushing technique when using a manual toothbrush as compared to using an electric toothbrush; and
• Change in time spent in a 45° angle over the course of the study.

Materials and Methods

Fourteen (14) adult male and female subjects from the St. Louis, Missouri, USA area were enrolled into the study from April 16 through May 10, 2012 based upon the following criteria:

• 50% female and 50% male between the ages of 35 and 50;
• No dental work such as braces, dentures, removable bridge, caps, etc.;
• Brush two to three times a day;
• Use a manual toothbrush;
• Interested in using a plug-in rechargeable toothbrush (a score of 7-10 on a 10-point scale where 1 was “Not at all interested” and 10 was “Extremely interested”);
• Household income of at least $55,000;
• Completed at least two years of college; and
• Represented a distribution of glove/hand sizes.

Subjects were provided with a specially engineered sonic powered toothbrush with unique sensing and control technologies and the Triple Clean refill brush head (“TC” – Colgate® ProClinical™ A1500 Power Toothbrush, Colgate-Palmolive Company, New York, NY, USA). This model has an Auto Mode feature, and the users were asked to keep it in this mode. Auto Mode has three speeds with corresponding brush actions. The angle of the brush head against the teeth changes the speed of the brush head.

• Low speed occurs when cleaning vertical surfaces. The brush head automatically moves side-to-side.
• Mid speed occurs when the brush head is positioned approximately 45° to the gum line. The brush head automatically pivots from side-to-side and up and down.

• High speed occurs when cleaning horizontal chewing areas. The brush head automatically moves up and down.

Protocol

Before their initial visit to the test site, subjects were provided with a video camera to videotape themselves at home brushing their teeth with their manual toothbrush, which served as a baseline for the study.

During the initial visit to the test site (Trial 1), each subject was given their assigned toothbrush for use during the study.

• The instructional materials were reviewed with the respondent before being videotaped using toothbrush TC.

• All users were instructed to keep toothbrush TC in the Auto Mode during the study.

• A “fin” was attached to the bottom of toothbrush TC prior to brushing to facilitate analysis of which angle the toothbrush was in.

• After use, the users completed a brief questionnaire and participated in an interview.

Subjects were asked to complete a journal when they used toothbrush TC at home. No restrictions were placed on the use of toothpaste. The journal asked them to record the length of time they used the toothbrush and any comments regarding their experience. The journals were returned and reviewed at each visit.

All users returned to the test site after an additional week of brushing with toothbrush TC at home and were videotaped at the test site brushing their teeth with toothbrush TC (Trial 2).

After brushing, they completed a brief questionnaire.

At week 4 (Trial 4), the users again were videotaped using toothbrush TC, completed a questionnaire, and were asked a series of questions about their experience.

Finally, eight users were asked to brush again with a manual toothbrush (Colgate® 360° Toothbrush, Colgate-Palmolive Company, New York, NY, USA) and describe the differences they experienced between manual and electric toothbrushes.

Results

Brushing Time

Users increased their brushing time using toothbrush TC. During review of the at-home videotapes, it was determined that the average time users spent brushing their teeth at home with their manual brush was 54 seconds. The average time users spent using toothbrush TC ranged from an average of 99 to 107 seconds during Trials 1, 2, and 4 (Figure 1).

Brushing Technique

The users were videotaped during each trial. Analyses of the videotapes were conducted following the study. Times were recorded from the videotapes and observations were noted. In addition, the facilitators took handwritten notes during the interviews with the users.

After Trial 1, users had begun to allow toothbrush TC to do the work and spent a longer period of time in each quadrant (Figure 2). Users were observed gliding the brush head over their teeth with either a slight back and forth motion or a small circular motion. Many users commented that it took several days for them to change their behavior and let the toothbrush do the work versus having themselves do the work. As a result, users stayed in the various quadrants longer than they did when using a manual toothbrush. However, some users were observed going back to manual brushing behavior (faster, medium strokes) when in the low speed to augment the cleaning of toothbrush TC.

Brushing Angles

The Auto Mode feature on toothbrush TC has three speeds with corresponding brush actions. The angle of the brush head against the teeth changes the speed of the brush head. Users increased their time with the brush head at a 45° angle (the recommended angle) over the course of the study (Figure 3).

The users commented during the trials that they were able to detect differences in the speed of the brush because of the audible and tactile feedback from toothbrush TC. Few users paid attention to the blue light that turned on when toothbrush TC was at a 45° angle. Many users stated that they preferred
the mid (45°) and high (chewing) speeds over the low (surface) speed. The users perceived that they needed to do more work when using the low speed and that the low speed did not seem to get their teeth as clean.

Although users increased the amount of time spent in the 45° angle mode over the course of the study, it is not surprising that the most amount of brushing time was spent at low speed (Figure 3) because teeth have more vertical area compared to chewing surfaces or 45° gum lines.

**Electric vs. Manual Brushing Habits**

Users quickly reverted back to their old brushing habits when switching back to a manual toothbrush. Although users spent more time in each quadrant with toothbrush TC (Figure 4) than they did at home with a manual toothbrush (pre-study), this habit was not retained when they used a manual toothbrush again at the conclusion of their final study visit. In addition, users were observed using medium, fast strokes and moved around their mouth rapidly.

Users also reverted back to a shorter brush time when using a manual brush (Figure 5). Although a timer was no longer available with a manual brush, it should be noted that most users did not regularly use the timer on toothbrush TC during the trials because the timer was on the charging base, not the toothbrush. Since toothbrush TC does not need to charge on a daily basis, users admitted the charging base would not be sitting on their home bathroom counter because of limited counter space. Thus, to replicate their home environment at the trials, the users did not reference the timer on the charger.

A few users commented that the larger brush head on the manual toothbrush, coupled with longer strokes, allowed them to complete the task in less time. It should be noted that users had brushed their teeth with toothbrush TC less than 45 minutes prior to brushing with the manual toothbrush, meaning that their teeth were clean prior to manually brushing.

**Reach and Maneuverability**

Users sacrificed maneuverability and the ability to reach into tight spaces when returning to a manual toothbrush. During the final interview, users were asked to compare using a manual toothbrush to using toothbrush TC. Many users commented that they will miss using toothbrush TC. The users stated the brush head on toothbrush TC is smaller than that on a manual toothbrush. As a result, it is easier to get into the tight spaces (e.g., behind the molars and between teeth). Users commented that the manual brush seemed to glide over the tooth surfaces and not get into the “nooks and crannies” or behind the back teeth. The users were deprived of the “dentist-like” clean feeling when returning to a manual toothbrush.

**Further Optimization**

Toothbrush TC has been further optimized such that the timer is no longer on the charging base and is included on toothbrush TC itself. In addition, toothbrush TC includes a 30-second pacer so users can track the length of their tooth brushing session. As a result, users may further increase their tooth brushing time when using the optimized toothbrush.

**Discussion and Conclusions**

The specially engineered sonic powered toothbrush with unique sensing and control technologies left a positive impression on the users. The users perceived the toothbrush to clean their teeth better than a manual toothbrush. One reason for the clean feeling is that the users commented that they are
able to maneuver the toothbrush in their mouth easier and reach more places. The improved maneuverability and reach are a result of the smaller brush head.

The brush also changed the behavior of the users in a positive way. They spent more time brushing their teeth, more time on individual sections of the teeth, and spent more time in a 45° angle (the recommended angle).

Acknowledgement: This study was funded by the Colgate-Palmolive Company

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