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Effects of an electric toothbrush combined with 3-color light-emitting diodes on antiplaque and bleeding control: a randomized controlled study

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ABSTRACT

Purpose: This randomized controlled study aimed to evaluate the effects of an electric toothbrush with 3 colors of light-emitting diodes (LEDs) on antiplaque and bleeding control.
Methods: This randomized, placebo-controlled, double-blinded, parallel-group clinical trial included 50 healthy adults with gingivitis, who were randomly assigned to 2 groups. The experimental group used electric toothbrushes with 3 colors of LEDs and the control group used the same electric toothbrush as the experimental group, but with LED sources with one-hundredth of the strength. The subjects used the electric toothbrush 3 times a day for 4 minutes each time. As clinical indices, bleeding on marginal probing (BOMP), the Löe-Silness gingival index (GI), and the Turesky-Quigley-Hein plaque index (QHI) were assessed at baseline, at 3 weeks, and at 6 weeks.
Results: There were significant decreases in all clinical indices (BOMP, GI, QHI) in both the experimental and control groups compared to baseline at 3 weeks and at 6 weeks. In a comparison between the experimental and control groups, no statistically significant differences were observed for any clinical indices at 3 weeks ($P>0.05$). However, at 6 weeks, statistically significant differences were observed between the experimental and control groups in BOMP and GI, which are indicators of gingival inflammation ($P<0.05$).
Conclusions: This study demonstrated that an electric toothbrush combined with 3-color LEDs reduced gingival bleeding and inflammation after 6 weeks.

Keywords: Biofilm; Dental plaque; Gingivitis; Toothbrushing

INTRODUCTION

Gingivitis is an inflammatory periodontal disease associated with the accumulation of dental biofilm [1]. It leads to gingival redness, bleeding, and edema [2]. Gingivitis rarely presents with conspicuous clinical symptoms, meaning that patients with gingivitis may not recognize that they have the disease [3]. Gingivitis increases the risk of inflammation, and consequently causes tooth loss [4]. Appropriate measures should be taken at the appropriate time for gingivitis. The symptoms of gingivitis can be relieved by plaque control, such as scaling and root planing (SRP). However, without continuous home care after SRP, dental

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

plaque will continue to accumulate, leading to repeated clinical inflammatory symptoms, such as swelling and bleeding [5]. Therefore, in addition to professional care, home care for controlling dental plaque is needed.

Recently, light-emitting diode (LED) technology has attracted attention as a cost-effective technology with antibacterial effects. A study found that bacteria and spores were susceptible to LEDs at 405 nm [6]. Another study found that LEDs around 460 nm exerted effective antibacterial activity, particularly against *Escherichia coli* O157:H7 [7]. Other researchers have demonstrated that 630-nm LEDs inactivated selected microorganisms [8]. Furthermore, some researchers have studied the antibacterial effects of combining multiple LED wavelengths, rather than using a single LED. Guffey and Wilborn [9] found that the combination of 405-nm and 880-nm LEDs had antibacterial effects on *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

Since the antimicrobial activity of LEDs has been confirmed, attempts have been made to combine toothbrushes with LEDs. We recently observed that *in vitro*, erythrosine-treated LED toothbrushes efficiently diminished the number of *Porphyromonas gingivalis* cells attached to titanium and zirconia surfaces compared to a commercial photodynamic treatment kit [10,11]. Additionally, Lee [12] reported that an LED electric toothbrush was an effective tool for patients with gingivitis based on results from 4 weeks of use.

Even though various LED toothbrushes have been introduced, research about which wavelength is the most efficient at eliminating dental plaque and inflammation has not been conducted. The effectiveness of powered brushes combined with 3 LEDs as a home-care tool for gingivitis has not been previously examined, and few randomized controlled clinical trials have investigated the efficacy of LED toothbrushes on dental plaque. The objective of this study was to evaluate the antiplaque and bleeding control effects of an electric toothbrush combined with 3 LED colors among patients with gingivitis.

MATERIALS AND METHODS

Study design

A randomized, parallel-group, double-blinded, controlled clinical trial was designed to test the efficacy of an electric toothbrush with 3 colors of LEDs on controlling dental plaque and bleeding. After a screening test, the subjects were listed in alphabetical order by their names. The manufacturer of the toothbrushes provided 2 types of LED toothbrushes, which were distributed to the participants in the 2 groups using computer-generated randomly allocated numbers. All experiments were conducted in a double-blind fashion. The person who divided the participants into 2 groups according to the type of LED toothbrush was different from the person who examined clinical parameters at each visit. All clinical examinations were performed by only 1 experimenter to calibrate the measurements of the parameters.

The protocol was approved by the institutional review board of Kyoungpook National University Dental Hospital (KNUDH-2018-12-04-01). The subjects voluntarily participated in this clinical study and provided written informed consent.

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Participants and eligibility criteria

Fifty patients (35 men and 15 women) with gingivitis visited the Department of Periodontology at Kyoungpook National University Dental Hospital. Twenty-five were in the experimental group, and 25 were in the control group. Recruitment was conducted from July 2019 through September 2019, when the last examination was conducted.

The participants were between 18 and 70 years of age, and they had at least 20 natural teeth excluding the third molar. Furthermore, only participants were of good general health, with no history of allergies or hypersensitivity to the experimental products including disclosing agents, toothbrushes, and dentifrices. Only non-smokers were included.

Individuals who failed to satisfy these criteria were excluded from this trial. Patients who had severe periodontitis or caries or who used removable partial dentures or orthodontic appliances (except lingual retention wires) were also excluded. Additionally, those who were pregnant, lactating, in poor general health, or immunodeficient were excluded.

Two weeks before the baseline study assessments, the participants who met our inclusion criteria underwent screening tests, and those who had mean value of Turesky-Quigley-Hein plaque index (QHI) scores of at least 1.5 and mean value of bleeding on marginal probing (BOMP) of at least 1.5 were selected as the final participants.

Experimental protocol

In this experiment, patients were assessed 3 times at 3-week intervals (Figure 1). During each visit, 3 parameters were measured: QHI, BOMP, and the Löe-Silness gingival index (GI). Prior to the experiment, all participants were given instructions on how and when to use the toothbrush. In addition, they were instructed not to use any other mouth washes or oral hygiene tools. The participants were encouraged to use the toothbrushes 3 times a day for 4 minutes each time. Moreover, the participants were asked not to consume food or drinks within 12 hours before each visit.

Materials

The experimental group used electric 3-color LED toothbrushes (SMART E-Care, AinA, Daegu, Korea), while the control group used electric toothbrushes with 1/100 of the LED output power of the experimental brushes. The LED sources of the toothbrushes consisted of 2 blue sources, 1 red source, and 1 white source (Table 1).

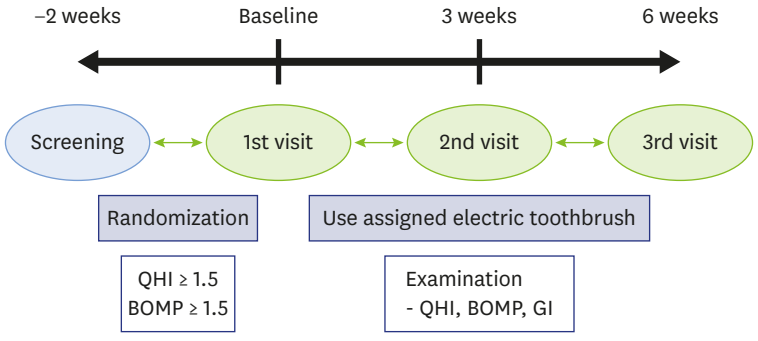

Figure 1. Overview of the experimental protocol.
QHI: Turesky-Quigley-Hein plaque index, BOMP: bleeding on marginal probing, GI: Löe-Silness gingival index.

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Table 1. Power of the light sources

Color	Experimental group	Control group
Blue	17.00 mW/cm²±20%	0.18 mW/cm²±20%
	18.50 mW/cm²±20%	0.18 mW/cm²±20%
Red	10.00 mW/cm²±20%	0.13 mW/cm²±20%
White	16.50 mW/cm²±20%	0.20 mW/cm²±20%

The electric toothbrushes with 3 LEDs (SMART E-Care, AinA, Daegu, Korea) consisted of LEDs emitting 3 colors (2 blue sources, 1 red source, and 1 white source). The power of each source is indicated in Table 1.
LED: light-emitting diode.

Both groups used the same standard toothpaste (Perioe New Fresh Alpha Toothpaste, LG Household Chemical Co., Ltd, Korea) (Figure 2). In order to assess the extent of dental plaque and to obtain QHI scores, we used a disclosing agent (IC-Disclosing Solution, Il Chung Dental, Seoul, Korea) to visualize the plaque on the dentition. The use of any other oral hygiene products except for the given brushes and toothpaste was strictly prohibited.

Clinical parameters

The QHI, GI, and BOMP were measured as clinical parameters [13]. Six of the Ramfjord teeth, not the entire dentition, were examined [14].

Gingival bleeding

To evaluate the degree of gingival bleeding, we used BOMP to assess the presence of bleeding after probing the marginal gingiva with a periodontal probe [15]. The bleeding in the gingival areas within 30 seconds after probing with a periodontal probe was scored as 0, 1, or 2. The bleeding was scored as 0 if there was no bleeding, 1 if there was only a pin prick, and 2 if there was excessive bleeding. The GI was also measured to observe inflammation, manifesting as redness, edema, and bleeding [16].

Dental plaque

Among the various methods for measuring dental plaque, the QHI was chosen [17]. We examined 6 regions of each tooth using a disclosing agent.

Figure 2. Electric toothbrush with a LED (SMART E-Care, AinA, Daegu, Korea).
The light of the toothbrushes consisted of 2 blue sources on the upper row, and 1 red and 1 white source on the lower row. The appearance of the LED toothbrushes used in the control and experimental groups was identical. The difference between the toothbrushes used in the control and experimental groups was the power of the LEDs.
LED: light-emitting diode.

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Statistical analysis

The results were analyzed by repeated-measures analysis of variance (ANOVA), and *P*-values <0.05 were considered to indicate statistical significance. All analyses were carried out using SPSS for Windows version 25 (IBM Corp., Armonk, NY, USA). The paired *t*-test and the independent *t*-test were performed to evaluate within- and between-group differences in LED effects at 3 and 6 weeks.

RESULTS

The experiment was conducted for 6 weeks, with 50 participants who were evenly divided between the experimental and control groups, with no dropouts. No adverse effects were reported, including tooth staining, dental hypersensitivity, or soft tissue reactions.

BOMP

The mean values of BOMP at baseline were 1.65±0.12 in the experimental group and 1.64±0.13 in the control group. The mean values at 3 weeks were 1.31±0.24 in the experimental group and 1.42±0.24 in the control group, and the mean values at 6 weeks were 0.82±0.22 in the experimental group and 1.06±0.24 in the control group (Figure 3). As time passed, both the experimental and control groups showed a decreased bleeding tendency. In both groups, there was a statistically significant difference in the values at 3 weeks and 6 weeks from baseline (P<0.05). According to repeated-measures ANOVA, in a comparison between the experimental and control groups, the experimental group had a significantly greater tendency for BOMP to decrease (P<0.05). A statistically significant difference between the groups was not detected from baseline through 3 weeks (P>0.05); however, at 6 weeks, a significantly greater reduction was observed in the experimental group (P<0.05) (Figure 3).

GI

The GI was measured to quantify the degree of gingival inflammation, with scores from 0 to 3. The mean values of the GI at baseline were 1.63±0.19 in the experimental group and 1.64±0.18 in the control group. The mean values at 3 weeks were 1.44±0.26 in the

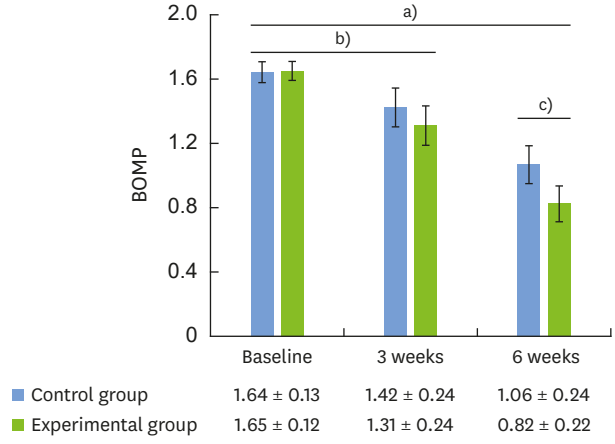

Figure 3. BOMP in the experimental and control groups.
BOMP: bleeding on marginal probing.
[a]Statistically significant difference from baseline to 6 weeks in both groups. [b]Statistically significant difference from baseline to 3 weeks in both groups. [c]At 6 weeks, in the experimental group, a significantly greater reduction was observed compared to the control group.

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experimental group and 1.50±0.23 in the control group, and the mean values at 6 weeks were 0.95±0.30 in the experimental group and 1.21±0.25 in the control group (Figure 4). Over time, both the experimental and control groups showed a tendency toward decreased inflammation. Within each group, there was a statistically significant difference in the values at 3 weeks and 6 weeks from baseline (P<0.05). According to repeated-measures ANOVA, the experimental group showed a significantly greater tendency for the GI to decrease from baseline through weeks 3 and 6 (P<0.05). At 3 weeks, a statistically significant difference was not observed between the experimental and control groups (P>0.05); however, at 6 weeks, the experimental group showed a significantly greater reduction in the GI than the control group (P<0.05) (Figure 4).

QHI

After the teeth and adjacent gingiva were lightly dried using compressed air and stained using disclosing agents, each tooth was scored from 0 to 5. In this experiment, the mean QHI values at baseline were 2.25±0.44 in the experimental group and 2.30±0.40 in the control group. The mean values at 3 weeks were 1.95±0.37 in the experimental group and 2.01±0.45 in the control group, and the mean values at 6 weeks were 1.53±0.39 in the experimental group and 1.66±0.39 in the control group (Figure 5). Both groups showed a tendency for the QHI to decrease compared to baseline at 3 weeks and at 6 weeks, and the reduction was statistically significant in both the experimental and control groups (P<0.05). In a comparison between the experimental and control groups, there was no statistically significant difference between the groups at either week 3 and or week 6 (P>0.05) (Figure 5).

DISCUSSION

The aim of the study was to investigate the adjunctive effect of toothbrushes combined with LEDs at 3 wavelengths on dental plaque and bleeding. For all parameters (BOMP, GI, QHI), both the experimental and control groups showed decreases from baseline to the final visit at 6 weeks. These results are consistent with a meta-analysis published in 2005 [18]. This 6-week clinical controlled study showed that self-performed dental care among gingivitis

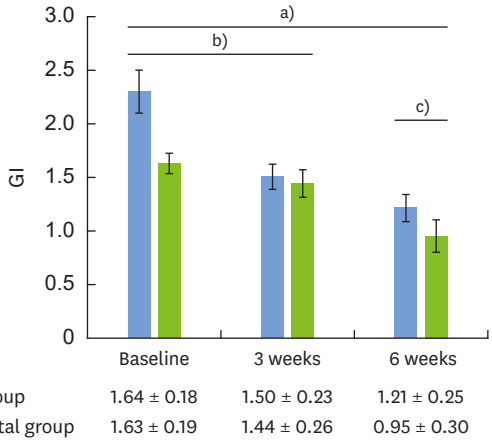

Figure 4. GI in the experimental and control groups.
GI: Löe-Silness gingival index.
[a]Statistically significant difference from baseline to 6 weeks in both groups. [b]Statistically significant difference from baseline to 3 weeks in both groups. [c]At 6 weeks, in the experimental group, a significantly greater reduction was observed compared to the control group.

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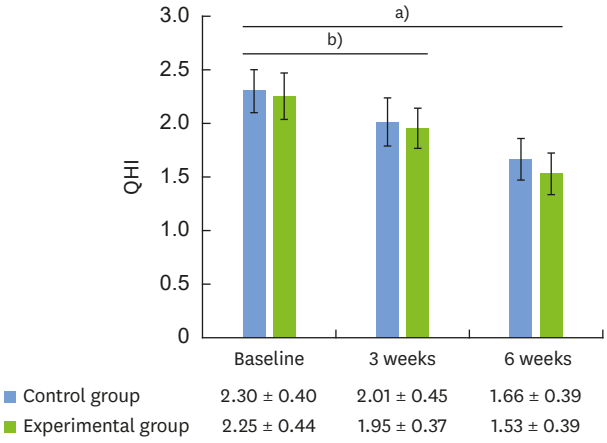

Figure 5. The QHI.
QHI: Turesky-Quigley-Hein plaque index.
[a]Statistically significant difference from baseline to 6 weeks in both groups. [b]Statistically significant difference from baseline to 3 weeks in both groups.

patients reduced dental plaque and gingival inflammation. All subjects were shown colored visualizations of dental plaque and received instructions on toothbrushing at every visit. These steps had a positive effect on gingival inflammation, even though this trial lasted for only 6 weeks. Furthermore, clinical studies have demonstrated that powered toothbrushes not only promote brushing motivation with adequate duration and frequency, but also are more effective at removing causes of inflammation than manual toothbrushes [19]. Based on these findings, oral self-performed care (e.g., electric toothbrushing) can have positive effects on reducing gingival inflammation.

To estimate bleeding, BOMP was measured, because it was appropriate to examine the inflammation in gingivitis through gentle probing around the marginal gingiva, not into the pocket [20]. The presence of bleeding is considered to be the earliest symptom of inflammation [21]. At 6 weeks, the experimental group, which used a 3-color complex LED toothbrush, showed a statistically significant reduction in BOMP compared to the control group. Based on these experimental results, we conclude that the electric LED toothbrush was more effective than other non-LED electric toothbrushes.

The GI, a parameter indicating gingival inflammation, yielded similar results as BOMP. In the intragroup analysis, both groups had statistically significant reductions over time. These results indicate that inflammation was reduced by the mechanical motions of the electric toothbrush. The experimental group had a lower mean GI score than the control group at 6 weeks, suggesting that the LEDs exerted additional positive effects on inflammation.

Through BOMP and GI tests, we confirmed the effects of the 3-component complex LED, and these results are in concordance with our previous findings of the reduction of *P. gingivalis* on sand-blasted titanium disks with LED toothbrushes *in vitro* [10]. Furthermore, our results agree with those of another *in vitro* study reporting that LED toothbrushes with erythrosine reduced microorganism growth on dental biofilms attached to a zirconia surface [11].

Both the control and experimental groups had statistically significant reductions in QHI over time, but no significant difference was found between the control group and the experimental group. This indicates that the LEDs had an insignificant effect on plaque

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control. Bernimoulin [22] suggested that within a few seconds in the oral environment, various microorganisms first colonize supragingivally, forming dental plaque. We assumed that these results were affected by experimental protocols that we could not control, such as restricting the subjects' oral hygiene activities 12 hours before our measurements.

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