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ORIGINAL RESEARCH

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Enhancement plaque control in preschool children by an intelligent brushing guide device

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Abstract

This study aims to investigate the impact of a tooth-brushing guidance system on the enchancement of the dental plaque removal in preschool children. In this study, we selected a group of 124 healthy children in which their aged were between 3 and 5 years old following by treatment at the Pediatric Dentistry Center at Jinzhou Stomatological Hospital (JinZhou, Liaoning Province, China). We then followed up to check and identify the Turesky modification of the Quigley-Hein plaque index (TMQHPI). Study group was randomly assigned to an experimental group in which they received constantly guidance on intelligent tooth-brushing and a control group which was used by manual brushing techniques. The total numbers in each group were 62 participants that were gone under the clinical investigation for seven days. The plaque index of both groups were assessed by using a plaque display instrument and a periodontal probe for up day 28. It was shown that the experimental group had a lower average TMQHPI value (0.98 ± 0.15) in comparison with control group (1.41 ± 0.17), and this difference was statistically significant ($p < 0.05$). The experimental group had a significantly lower TMQHPI value (0.89 ± 0.13) on the tongue/palatal side of the anterior teeth area in comparison with control group (1.41 ± 0.17) ($p < 0.05$). We observed that experimental group showed significantly lower TMQHPI value (1.16 ± 0.12) on the tongue/palatal side of the posterior dental region in comparison with control group (1.70 ± 0.13) ($p < 0.05$). It was confirmed a significant difference in the average plaque clearance rate between the experimental and control groups ($p < 0.05$). Our study clearly indicates that a developed method of toothbrush guide effectively improved the removal rate of plaque compared with manual tooth-brush, specifically in hard-to-reach areas like the tongue and palate.

Keywords

Dental plaque; Smart toothbrush; Pediatric dentistry; Tooth-brushing

1. Introduction

In general, to prevent oral conditions such as tooth decay in children there are certain care methods of brushing techniques that can effectively remove food debris and certain dental plaque from their mouths [1]. There are many studies that clearly show preschool-aged children are required parental guidance during brushing their teeth [2]. Although there are still several key factors that needed to be improved both by parents and children that may be faced to several difficulties in mastering key aspects of proper tooth-brushing techniques, including brushing strength, angle and duration [3]. For instance, we have observed that the primary methods for teaching proper manual tooth brushing are those that have shown commonly in large scale of people in using conventional method as well as in multimedia teaching method. We clearly observe that in the former group; there was significant variation in the teaching that results in lack of standardization and poor repeatability. In this regard, the standard tooth-brushing model have significant dependence values on the lecturer's level of teaching that will be resulting in lack of consistency and requiring manpower with poor reproducibility. On the other hand, we are able to see that the latter group exhibits higher levels of comprehension with limited opportunities for interaction. We have to bring in our mind that certain methods such as PowerPoint slides (PPT), pictures, flash animations and videos may not be exactly able to capture crucial details of the horizontal vibration brushing technique [4]. With above explanations, we certainly confirm that the above concerns not only result in inadequate cleaning but also may have potential harm to their teeth and gums. Among many important factors that we need to concern about them, brushing time is very important that leads to incomplete removal of dental plaque from the teeth. Secondly, when brushing coverage is insufficient on the inner surfaces of teeth will be resulting in incomplete cleaning. Thirdly, following non-standard brushing techniques such as horizontal or vertical

brushing instead of the recommended method will be resulting in damage to both teeth and gums [5, 6].

The aim of the present study is to compare differences of plaque control and safety between children using an intelligent toothbrush guide and those using a manual toothbrush in order to quantitatively assess the effectiveness of tooth-brushing and establish a basis for selecting efficient and convenient oral hygiene tools.

2. Methods

2.1 Basic information

In this study, we selected a group of 124 healthy children who met the inclusion and exclusion criteria from the Pediatric Dentistry Center at Jinzhou Stomatological Hospital (JinZhou, Liaoning Province, China). We set up a randomized controlled trial conducted at a single center. To conduct the research, in the experiment group, the presence of 20 primary teeth in the oral cavity that in all parts should be free from carious lesions, including those that have been treated with fillings, and limited to the occlusal surface. In the group of 3 to 5 years old, a serious confirmation from their families were obtained. Exclusion criteria that were also selected in this study were the presence of dental caries, tooth defects, pre-formed crowns, gingivitis and oral mucosal diseases (such as edema, bleeding or ulcers), good oral hygiene habits and complete dentition. We then divided the children into two groups of the intelligent brushing guide (experimental group), and the manual brushing group (control group), each consisting of 62 cases. Both group A and group B had an equal number of 31 male and female participants, all aged between 3 and 5 years old. The study design is shown in Fig. 1.

2.2 Instruction on proper brushing techniques

We confirmed in our study that the experimental group was followed according to the guidance of Beijing Huilian Technology Co., Ltd. for and Peking University School and Hospital of Stomatology. The special design that was used in the toothbrush was composed of three rows and six beams, each with eight-millimeter small heads containing Polyamide (PA) bristles. The bristle tips are rounded with moderate hardness (13C), while the handle is made from food-grade Polypropylene (PP) material. Both the experimental and control groups were then utilized toothbrushes with identical bristle types. The amount of fluoride toothpaste used for children was 50 g per unit which is manufactured by Fujian Aijie Liri Chemical Co., Ltd (Company Limited). The toothpaste was then fortified with fluoride at a concentration of 1000 ppm. In our study, we designed the specific operational method by inserting the manual toothbrush into the tail of the intelligent tooth-brushing guide and then connecting it to the mobile app *via* Bluetooth which then it leads children through the app tutorial by quantifying a 3-minute brushing time and completing all brushing steps as instructed in the entire method. We confirmed in our study that control group was followed by manual tooth brushing using both horizontal vibratory and circular arc techniques. The utilization of toothbrushes and toothpaste was consistent across all aforementioned groups. During the study, each group's parents were independently instructed by an assistant, without the examiner's involvement, and allowed to repeatedly practice on a dental model attached to a head phantom. Finally, the participants were supervised until they had mastered the correct tooth brushing technique (Fig. 2).

2.3 Trial protocol

Following the evaluation for all groups continues in formations were obtained from both children and their parents prior to enrollment and the enrolled participants visited the hospital where they were briefed on each group's respective tooth brushing methods and completed all necessary testing requirements. In order to collect all the necessary of test evaluation to have the Baseline Data, all the group members were randomly assigned to either the experimental or control group where they were provided a toothbrush and timer. First, both groups were asked to brush their teeth for one week. Also, both the experimental and control groups were asked to use toothbrushes, which were then reused by both cohorts after a one-week washout period. After week 4, the oral plaque index was assessed, which provided the final data. All participants in this study were strictly asked to follow the study protocol which was confirmed not to have any oral cleaning measures such as using a dental irrigator, mouthwash, dental floss, gum, *etc.*, within 24 hours prior to the next visit followed by a clear instruction to brush their teeth twice daily, with parental assistance, for a duration of 3 minutes per session using 1 cm of toothpaste. Tutorial on how to quantify brushing time in the app was written clearly for all users to brush the lateral side of the left lower molar for 10 seconds and then brush the lateral side of the left lower canine and lower incisor each for 6 seconds. Also, it was guided that the lateral side of the right lower canine should be brushed for 6 seconds, the lateral side of the right lower molar for 10 seconds, the medial side of the right lower molar for 12 seconds, and the medial side of the right lower canine for 6 seconds. For the inner sides of the lower incisors and left lower canine, it was asked to brush for 6 seconds each, while the inner side of the left lower molar was asked to brush for 12 seconds. Additionally, the outer side of the left upper molar was asked to brush for 10 seconds. The left upper canine was asked to brush laterally for 8 seconds, the upper incisor for 6 seconds, the right upper canine for 8 seconds, and the right upper molar for 10 seconds. 12 seconds of brushing were applied to the inner side of the right upper molar, 6 seconds to the inner side of the right upper canine, 6 seconds to the inner side of the upper incisor, 6 seconds to the inner side of the left upper canine, and 12 seconds to the inner side of the left upper molar. The left upper occlusal surface was brushed for 4 seconds, followed by the right upper occlusal surface. Finally, the left lower occlusal surface and the right lower occlusal surface were asked to brush for 4 seconds.

We confirmed that the tutorial for this app was compatible with both mobile phones and tablets, integrating tooth-brushing animation content with the assessment of brushing actions. This enables us to easily evaluate of brushing effectiveness based on factors such as duration, coverage rate and technique.

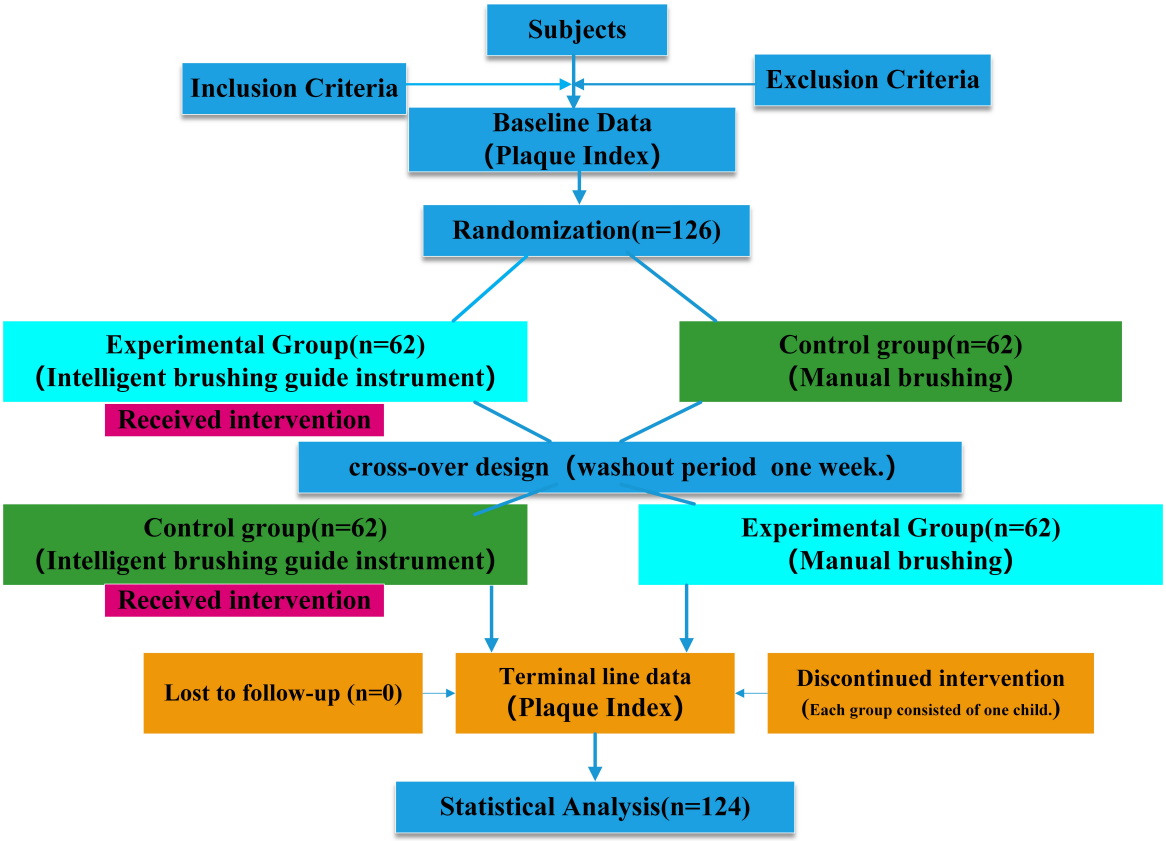

FIGURE 1. Figure of study design.

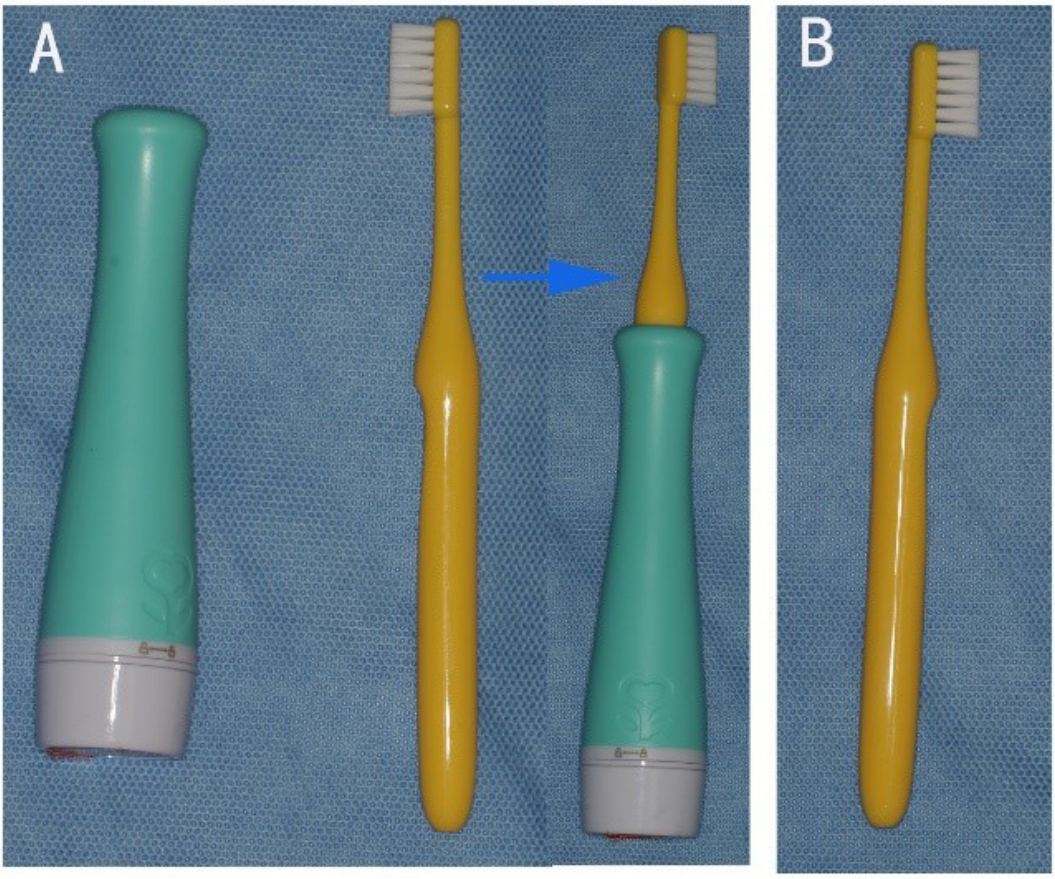

FIGURE 2. Test products. (A) Intelligent tooth brushing guide and toothbrush; (B) Manual toothbrush.

We have set up a compete guidance in this app and developed it as a precise technique that utilizes horizontal vibration for brushing. This app certainly guides the applicants to step by step to follow up the order from brushing back teeth, using gentle pressure to guide the bristles into the spaces between the teeth from both inside and outside with angles of 45 degrees following by focusing on two or three teeth at a time, and repeating short horizontal movements at least five times. Then, the applicant needs to ensure that the bristles maintain a consistent angle and position during horizontal vibration, while avoiding contact with the gingival sulcus. Next, the applicant needs to rotate the toothbrush handle in the direction of tooth growth, brushing downwards on upper teeth and upwards on lower teeth following by shaking at least 5 times at each position before brushing, and then repeating this process for each position at least once. When brushing the inner surface of the front teeth, then the applicant needs to hold the brush handle upright and uses either the front or back bristles of the brush head to clean. For lower teeth, the applicant needs to start from bottom and move upwards as well as for upper teeth needs to start from top and move downwards. When cleaning the occlusal surfaces of posterior teeth, it is necessary to aim the bristles of toothbrush toward these surfaces following using a back-and-forth motion to brush. When brushing the last tooth surface, the applicant needs to open mouth widely and hold the brush handle upright so that the bristles can move from the inner side of the final lower tooth along the gum line to its outer surface.

When brushing the buccal surface of the posterior teeth with occlusion is established, the applicant needs to insert the toothbrush into the buccal embrasure and gently place it on the gingival margin of the maxillary last molar. Next, the applicant needs to begin by pulling from the maxillary gingiva towards the mandibular gingiva following by reversing direction and pulling from the mandibular gingiva towards the maxillary gingiva before moving forward to clean the anterior teeth area. When brushing the lingual (palatine) side of the posterior teeth, the applicant needs to place toothbrush horizontally on the lingual (palatine) surface of last molar following by apply gentle pressure while vibrating back and forth and gradually moving towards the canine. When brushing the lingual (palatal) surface of the anterior teeth, the applicant needs to apply gentle pressure and move the brush head back and forth from the gum line to the biting edge. When brushing the occlusal surface, the applicant needs to angle the bristles towards the occlusal plane and then apply gentle pressure while moving back and forth over a short distance. In this specific description of the circular brushing technique, the same toothbrush head material and toothpaste were used in both groups.

2.4 Dental plaque index (PLI) and the rate of plaque clearance

In this study, we assessed the Plaque Index (PLI) at both baseline and endpoint (day 28). The Turesky Modified Quigley-Hein plaque index (TMQHPI) was applied to assess the Plaque Index. After the tooth surface was dried, then we applied intelligent plaque display instrument in conjunction with a periodontal probe. Each tooth was evaluated based on the following criteria. When measured the parameter values, the measurement values were indicated as following indicators in our experiments: 0 indicates that there is no plaque present on the tooth surface. A score of 1 indicates the presence of scattered punctate plaques in the gingival margin area of the cervical region. A value of 2 indicates the presence of plaque at the cervical margin with a thickness less than 1 mm. A score of 3 points is designated to indicate the presence of plaque that measures $\geq$1 mm in width encircling the tooth cervix and covers one-third of the crown surface area. A value of 4 indicates that between one-third and two-thirds of the total crown surface area is occupied by plaque present around the cervical region of the tooth. A value of 5 indicates that more than two-thirds of the crown's surface is occupied by plaque surrounding the tooth's neck. In our experiments, those techniques for determining plaque removal were improved. The plaque clearance rate can be calculated by subtracting the mean dental plaque index after brushing from the mean dental plaque index before brushing, dividing this difference by the mean dental plaque index before brushing, and then multiplying the result by 100%.

2.5 Improved quality management

In our experiment, we set up the instruments which were equipped accordingly and utilized uniformly. To enhance the quality of the obtaining experimental data, all clinical inspectors underwent in detail for both training and testing. In adherence to the principle of blinding, examiners assessing plaque were kept unaware of the brushing method and toothbrush usage in both groups. The consistency of their sample examination results was verified and calibrated against those of senior physicians, with the calculation of a kappa value. A kappa value greater than or equal to 0.81 was deemed as meeting the qualification standard.

2.6 Improved statistical techniques

The data obtained from the clinical examination were analyzed using SPSS software (Statistical Package for the Social Sciences, version 21.0, IBM Corp., Armonk, NY, USA). The measurement data were presented as the mean $\pm$ standard deviation ($\bar{x} \pm s$). If the data follows a normal distribution, the Paired Samples *t*-test should be used to compare between experimental and control groups. Analysis of variance was used to evaluate the differences among distinct groups in the crossover design. The difference observed was found to be statistically significant, with a p value of less than 0.05.

3. Results

3.1 Evaluation of the plaque control between two groups before and after full mouth brushing

During this study we confirmed that from total 124 healthy children, one case in each of the experimental and control groups was unable to complete the study within the designated timeframe. Our results clearly indicated that the experimental

group exhibited a statistically significant decrease in TMQHPI values in comparison with control group ($p = 0.017$) after tooth brushing. Table 1 shows the TMQHPI values of the average plaque index that were compared between both groups before and after full-mouth brushing.

TABLE 1. TMQHPI values of the average plaque index.

Group	Cases	Before brushing	After brushing
Experimental group	61	2.80 ± 0.17	0.98 ± 0.15^a
Control group	61	2.78 ± 0.21	1.41 ± 0.17^a
t value		0.346	3.343
p value		0.765	0.017

Note: In comparison with the control group, [a]Avg ± Standard Deviation (SD). $p < 0.05$, Paired Samples t-test.

3.2 Comparison of two brushing methods for controlling dental plaque in the anterior teeth region

During the experiment following tooth brushing, we found that there was no significant difference in TMQHPI values between the experimental and control groups on the labial side of the anterior teeth area ($p = 0.703$). Following brushing, we found that the TMQHPI values on the tongue/palatal side of the anterior teeth area in the experimental group were significantly lower than that in the control group ($p = 0.021$) (Table 2).

3.3 Comparison of two different brushing methods for controlling dental plaque in the posterior area

In the buccal region of posterior teeth, we found that there were no statistically significant differences in TMQHPI values between the experimental and control groups post-brushing ($p = 0.751$). Also, after tooth-brushing, the experimental group showed a significantly lower TMQHPI value than the control group in the posterior dental region on the tongue/palatal side ($p = 0.027$). Table 3 shows the TMQHPI values of the posterior teeth area between two groups before and after brushing.

3.4 The rate of plaque clearance between the two groups

In our experiment, we found that the average plaque clearance rate showed a significant difference between the experimental and control groups ($p = 0.012$). The plaque clearance rate of the labial surface of the anterior teeth did not show significantly differences between the experimental and control groups ($p = 0.634$). The experimental group showed a significantly higher rate of plaque clearance on the lingual/palatal side of the anterior teeth in comparison with control group ($p = 0.027 < 0.05$). The buccal plaque clearance rate of the posterior teeth did not show significantly differences between the experimental and control groups ($p = 0.754 > 0.05$). The plaque clearance rate on the lingual/palatal aspect of posterior teeth differed significantly between the test and control groups ($p = 0.033$) (Table 4).

4. Discussion

There is confirmation from the Fourth National Oral Health Epidemiological Survey that the prevalence of deciduous dental caries among 5-year-old children in China is alarmingly high at 70.1%, with Liaoning province exhibiting a higher rate (87.3%) than the national average [7, 8]. It has been shown in other research study that the presence of any amount of plaque plays a crucial role in preventing dental caries and periodontal disease among children [9]. It has come to our consideration that oral health education is an essential component of children's daily oral diagnosis and treatment [10]. In this regard, following utilizing appropriate brushing tools, mastering correct brushing techniques such as the horizontal vibration and arc methods, as well as adhering to a minimum of twice-daily brushing is an effective means of controlling plaque [11]. On the contrary, preschool children showed poor plaque removal efficacy and even reluctance towards oral hygiene practices due to improper brushing techniques, neglect of key areas requiring cleaning, and insufficient duration of tooth-brushing. It has been shown that improper brushing techniques may cause some sort of damage to both soft and hard tissues of mouth. For instance, incorrect vertical brushing may lead to gingival recession and wedge-shaped defects [12].

Recently, there are many new improvements in smart tooth-brushing devices in oral healthcare technology. Some of the very new technology is the sensor-based products that provide users with great performance rating as feedback on their brushing habits. Although, there are some approaches which lacks comprehensiveness and rationality which among them are scoring systems only consider brushing time while others solely rely on area recognition, without incorporating effective brushing techniques as an evaluation criterion [13, 14].

In our experiment, we confirmed that the experimental group utilized an intelligent tooth-brushing guide to implement an effective tooth-brushing tutorial, and the duration of tooth-brushing was measured for three minutes. We set of the evaluation based on the duration, frequency and technique of brushing in which the level of plaque accumulation and removal for each tooth surface were considered. Our findings indicate that a significant improvement in the effectiveness of removing dental plaque was observed. We confirmed that our results clearly indicate significant differences in both the mean plaque index and plaque clearance rate across the entire oral cavity between the experimental and control groups. The technology developed by our group as the intelligent brushing guide of the experimental group was designed based on artificial intelligence (AI) and machine learning (ML) that collects precise sensor data to inform users' brushing habits accurately. The precise algorithmic system transforms brushing data into assessments of brushing area and technique which later allows for an evaluation of the effectiveness of user's oral hygiene routine. The efficacy of tooth brushing can be assessed with a score of up to 70 points, based on factors such as effective brushing time, coverage rate and

TABLE 2. Comparison of the average TMQHPI values before and after full-mouth brushing between the two groups.

Group	Cases	Anterior labial		Tongue/palatine side of anterior area	
		Before brushing	After brushing	Before brushing	After brushing
Experimental group	61	2.76 ± 0.13	0.60 ± 0.11[a]	2.27 ± 0.12	0.89 ± 0.13[a]
Control group	61	2.72 ± 0.15	0.62 ± 0.13[a]	2.29 ± 0.14	1.41 ± 0.12[a]
t value		0.413	0.317	0.061	2.873
p value		0.679	0.703	0.852	0.021

Note: In comparison with the control group, [a]Avg ± Standard Deviation (SD). $p < 0.05$, Paired Samples t-test.

TABLE 3. The TMQHPI values of the posterior teeth area between the two groups before and after brushing.

Group	Cases	Buccal area of posterior teeth		Posterior lingual/palatine side	
		Before brushing	After brushing	Before brushing	After brushing
Experimental group	61	2.93 ± 0.12	0.93 ± 0.13[a]	2.46 ± 0.13	1.16 ± 0.12[a]
Control group	61	3.06 ± 0.13	1.06 ± 0.14[a]	2.45 ± 0.14	1.70 ± 0.13[a]
t value		0.147	0.564	0.136	2.835
p value		0.874	0.751	0.807	0.027

Note: In comparison with the control group, [a]Avg ± Standard Deviation (SD). $p < 0.05$, Paired Samples t-test.

TABLE 4. Comparison of plaque removal rates between the two brushing methods groups.

Group	Cases	Whole mouth average	Anterior labial	Tongue/palatine side of anterior area	Buccal area of posterior teeth	Posterior lingual/palatine side
Experimental group	61	61.2 ± 6.7[a]	73.3 ± 7.8[a]	55.7 ± 6.9[a]	66.3 ± 7.1[a]	41.3 ± 6.9[a]
Control group	61	50.7 ± 7.4	71.7 ± 7.3	44.3 ± 7.0	62.9 ± 6.8	31.1 ± 6.7
t value		2.433	0.587	2.213	0.319	2.105
p value		0.012	0.634	0.027	0.754	0.033

Note: In comparison with the control group. [a]Avg ± Standard Deviation (SD), $p < 0.05$. Paired Samples t-test.

method. The intelligent tooth-brushing guide combines toothbrush tutorials, music, animation and real-time feedback to effectively guide children in achieving optimal oral hygiene with joy [15, 16].

We also confirmed that in the anterior region, there was no significant difference in plaque index and plaque clearance rate on the labial aspect between the experimental and control groups. However, a statistically significant difference in plaque index was observed in the tongue/palatal area. We found that due to the anatomical structure of teeth; it is easier to position the toothbrush on the labial side of the tooth surface than on the lingual/palatal side. These findings clearly showed that there were more efficient brushing and a higher plaque clearance rate due to increased mechanical friction from bristles. Our finding also showed that the labial surface of the anterior teeth exhibited the highest plaque clearance rate in both experimental and control groups. We could find out that brushing the buccal aspect of the lip is easier and less uncomfortable than other areas where the majority of individuals adequately brush their teeth on the outer surface for a sufficient duration are considered. We could suggest that whether an intelligent brushing guide is present or not, mechanical friction from brushing alone is sufficient to effectively remove plaque [17, 18]. Our results showed that there was no statistically significant difference in plaque index or plaque clearance rate between the experimental and control group in the posterior region. However, significant differences were observed in the tongue/palate plaque index and plaque clearance rate between the experimental and control group. We found that proper toothbrush placement and tongue obstruction in the lower jaw present significant challenges for the younger children. Also, some children may experience nausea or other reactions during brushing and compromising adequate plaque removal. This finding is further supported by the data obtained in this study, which revealed that regardless of the type of toothbrush used, the labial surface of anterior teeth exhibited the highest level of plaque removal while the lingual surface of posterior teeth showed the lowest. We also observed that there were notable variations in the level of difficulty associated with brushing, depending on the position which are in good accordance with research studies [19, 20]. For the assessment of toothbrush efficacy in clinical trials, this study employed a self-controlled crossover design with a one-week washout period before and after the intervention phase. The Quigley-Hein plaque index, as modified by Turesky, was used as the observation index. Both the recording staff and clinical examiners underwent rigorous training and qualification processes.

Our results indicated that the self-brushing behavior of chil-

dren at aged 3 to 5 years old were not effective in removing dental plaque sufficiently. In this study, parents are instructed to assist their children with tooth brushing in order to prevent horizontal scrubbing, which may be difficult for children to do independently. Additionally, they should avoid applying excessive pressure on the teeth surfaces to ensure optimal plaque removal efficacy. The intelligent tooth-brushing guide is equipped with a timing management function, ensuring that the brushing time reaches three minutes. Additionally, the design and massage experience of the toothbrush can enhance children's interest in and cooperation with oral hygiene. We also confirmed that preschool, especially for children aged 3–5, is a critical period for establishing proper oral hygiene practices. It is imperative to implement targeted oral health education for children and their parents, enabling them to master essential aspects. The use of this product can improve children's oral hygiene and reduce the incidence of oral diseases, such as dental caries.

5. Conclusions

Our results clearly indicate that the utilization of an intelligent toothbrush guide can significantly enhance plaque removal efficacy compared to manual brushing, especially in hard-to-reach areas such as the tongue and palate. We confirmed that the scientific brushing program and intelligent brushing guide have great potential for use in oral health education activities aimed at children. Although, there are certain limitations in this study, and further research is necessary to assess the impact on gingival margin plaque clearance rate and gingivitis control. Also, we found that it is necessary to conduct a thorough evaluation of children's perceptions regarding the use of an intelligent tooth-brushing guide. In addition, the smart tooth-brushing guide requires the assistance of a mobile phone or tablet to access APP tutorials, and its stability needs further improvement when multiple devices are used simultaneously.

ABBREVIATIONS

PLI, Plaque Index; TMQHPI, Turesky Modified Quigley-Hein plaque index; SPSS, Statistical Package for the Social Sciences.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

MY, YZ, YNS—designed the research study. MY, YZ—performed the research. HW—provided help and advice on. MY, YZ—wrote the manuscript. JXY—contributed the resources. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted following the Declaration of Helsinki. The study protocol was reviewed and approved by the Medical Ethics Committee of Jinzhou Stomatological Hospital (JK20210702) and written informed consent was obtained from the patient's guardian.

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CONFLICT OF INTEREST

The authors have no conflicts of interest.

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