

Efficacy Analysis of Different Toothbrush Designs on Plaque and Gingivitis in Human Factors

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Abstract. With the continuous improvement of people's income level, people can enjoy more and more delicious food. At the same time, the emphasis on oral health has reached a new level in order to enjoy good food. The toothbrush is a product closely related to oral health in People's Daily life. The combination of human factors, industrial design, and engineering design will result in products with outstanding function and beautiful appearance. An excellent toothbrush is no doubt based on people's good experience at the core, combined with innovative industrial design to produce products. This article aims to compare the advantages and disadvantages of different toothbrushes and analyze the effects of different structural designs of toothbrushes on plaque removal and gingivitis inhibition. The study found that electric toothbrushes were significantly better than manual toothbrushes at removing plaque. Both are effective in reducing gingivitis, but the difference is not significant. Based on this article, in daily life to clean the mouth, the best choice of rotary vibration electric toothbrush is to clean dental plaque.

Keywords: Human factors, industrial design, toothbrush, dental plaque, gingivitis.

1. Introduction

1.1. Background

With the popularization of knowledge about dental health, the design and use of toothbrushes have become an important issue of concern. According to the results of the fourth national oral health epidemiological survey released by the national health and Family Planning Commission of China in 2015, the level of oral health knowledge of Chinese residents has gradually improved. The rate of brushing teeth twice a day for 5-year-old and 12-year-old children in China was 24.1% and 31.9% respectively, an increase of 9.5% and 13.9% compared with 10 years ago. The rate of adults brushing twice a day was 36.1%. As a common product in people's daily routine, the appearance, function, and material of toothbrushes have been constantly optimized and innovated.

Dental plaque is a complex biomembrane that collects on the oral hard tissues (teeth). Although composed of more than 500 bacteria, colonization follows an orderly type. The primary colonizers adhered to the enamel salivary membrane, followed by secondary colonization through bacterial adhesion. A variety of adhesins and molecular interactions promote these adhesive interactions and conduce to the development of plaque, ultimately leading to diseases such as caries and periodontal disease [1].

1.2. Importance

In the whole process of product design, from design to product promotion, users, as the core, must be regarded as an integral part of the process. And the product design is directed or restricted by users and human factors. Therefore, human factors and industrial design are closely linked and inseparable.

Generally, the form of the toothbrush, wearing of the toothbrush, techniques and time of toothbrushing, and the use of floss or mouthwash determine the efficiency of toothbrushing [2]. In self-made oral hygiene, the primary attention is the elimination of biomembrane in interdental regions

such as supragingival and subgingival biofilm. Although there are various methods for preventing dental plaque constitution, the use of toothbrushes had be supported as the most effective [3].

1.3. Objective

By studying the existing data on toothbrush design and their effectiveness in protecting tooth surfaces from mediators that may cause plaque, gingivitis, or other dental diseases; Using human factors technology to find the advantages and problems of the existing toothbrush design; Put forward some new ideas.

2. Related work

2.1. Prototype design

2.1.1 Examples



Figure 1. Sample of product orientation with the final prototype by REACH [4]

This prototype has experimented with other advanced toothbrushes in numerous, comprehensive clinical assessments and market tests. The result shows that this design exceeds the other toothbrush in the aspect of plaque removal, especially in the area that is hard to reach [4]. Combined with Kreifeldt's User-Tool-Task paradigm analysis framework, the REACH design team directed a range of studies focusing on the specific brushing behavior. After human-factors analysis and time-motion studies, the project design team acquired a lot of results about the interrelationship between toothbrushes, hands, and brushing methods [5-6].



Figure 2. The first electric toothbrush—Broxodent®

In 1954, Dr. Philippe-Guy Woog manufactured the first electric toothbrush Broxodent® (Figure 2) in Switzerland [7].

2.2. Toothbrush with human factors

Ergonomics research is extremely important in modern product design [8]. Based on ergonomics, the innovative toothbrush design analyzes the shape of the toothbrush, redesigns and develops the existing use mode, and improves its function [9].

The user–tool–task paradigm framework proposed by Kreifeldt (Figure 3) is beneficial to analyze brushing actions with human factors.

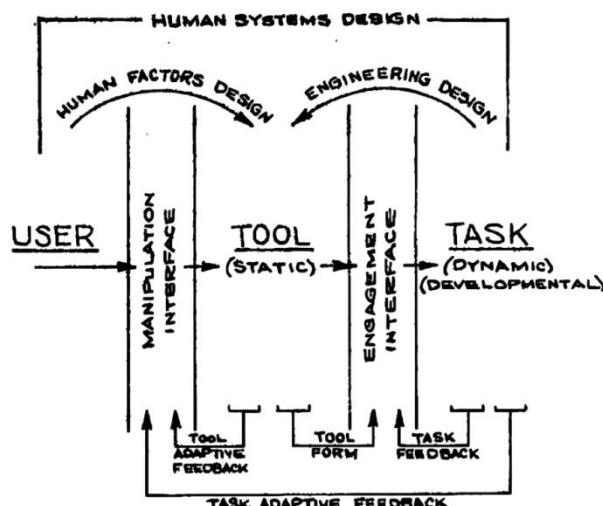


Figure 3. User-tool-task paradigm [4]

Researchers used this framework to determine the toothbrush material and structure design and show the interaction and feedback among user, tool and task. In this new framework, the user represents people using a toothbrush, the tool represents a toothbrush and the task means dental cleaning. And it indicated the processing elements in the operation boundary surface (such as comfort, safety, and feasibility) and the engagement interface (such as toothbrush shape, brush material, handle curve or angle, etc.) (Figure 4) [10].

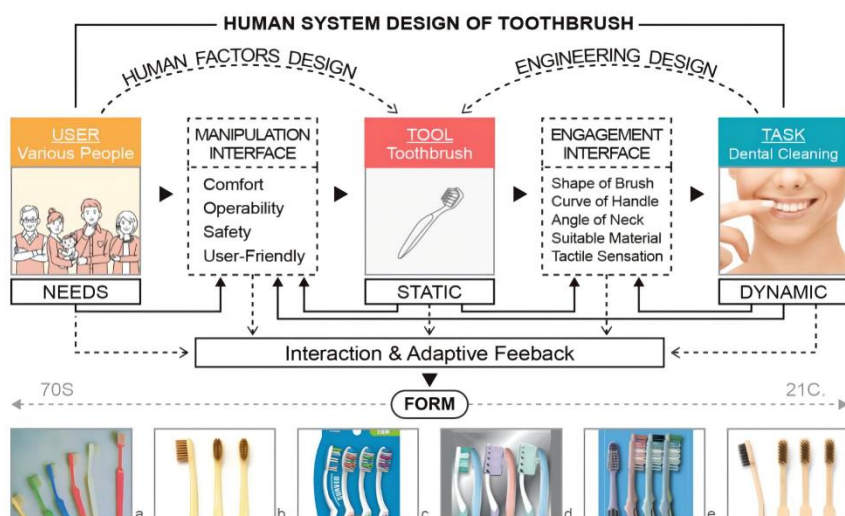


Figure 4. User-tool-task frame with the design of toothbrush [10]

According to the study mentioned above, the structure of a toothbrush can be roughly divided into four parts: brush head, brush bristles, brush neck, and brush handle. And the effectiveness of the toothbrush after use will be directly affected by the ergonomics of each part [11].

Brush head: As the main part of the toothbrush, the brush head needs to be operated in the mouth. In general, it is designed in a circular arc shape [12]. The toothbrushes must be able to clean the teeth in the oral cavity. Therefore, the toothbrush should be designed to move up and down flexibly in a narrow space. Relevant body size data show that 11-15mm is the size range of the adult brush head, with a length of 18-35mm. On the basis of ensuring safety, the width of the brush head should be designed relatively thin, lower than 5mm [13]. Different brush head designs will also affect the cleaning effects after vibration or sonic brushing.

Brush bristles: As the most delicate part of the toothbrush, the scale range of the bristles should follow the corresponding national standards [14]. The size of a child's toothbrush should be smaller than that of an adult's. Generally, the height of the brush should be designed lower than 13 mm, the length of the brush surface needs to be lower than 42 mm, and the diameter of the bristles ranges from

0.2 to 0.3 mm [13]. In addition, when brushing, the brush hair directly contacts the tooth surface and interior of the oral cavity. Therefore, the selection of materials is important, because it will seriously impact the comfort and cleaning effect during brushing. At present, the most commonly used bristle materials in the market are mainly Nylon filament, natural bristle, silica gel and bristle material involving bamboo charcoal C active ions [13].

Brush neck: The smooth arc-shaped brush neck is the connection between the brush handle with the brush head. The brush neck could have a certain elasticity to cope with different motions during brushing. And the neck length is about 50 mm [13].

Brush handle: The unique portion in contact with the human hand during tooth brushing is the handle [13]. Thus, it should be designed to fit the shape of the human hand to facilitate grasping. Considering the possibility of contacting water and suitability when brushing teeth, the material of the brush handle should be non-slip and healthy. Because it is common to touch water during brushing, and in view of fitness, the material of the brush handle should be skidproof and healthy. And the length of the brush handle is generally about 120 mm [13].

2.3. Classification of the electric toothbrush and some examples

There are two main classification methods for electric toothbrushes.

According to its motion type, it can be divided into vibrational (Figure 5a) and rotation-oscillation (Figure 5b) powered toothbrushes. The bristles of the vibrational powered toothbrush can vibrate side-to-side, but the toothbrush should still be moved actively like a manual one. The rotation-oscillation-powered toothbrush has a small and round brush head and Candida yeast on the denture. Gently move the brush head back and forth in a circular motion to clean the teeth.

With regard to its movement speed, it can be divided into sonic and ultrasonic electric toothbrushes. The sonic toothbrush is a toothbrush that emits a droning sound in the range of 20 Hz to 20,000 Hz that can be heard by humans and can generate a sufficient and fast motion. The ultrasonic toothbrush refers to any electric toothbrush whose movement speed is higher than these limits. These two can not only clean the accessible area of the tooth surface with mechanical polishing but also dislodge the surface stains and bacteria by the high-frequency vibration of the bristles with fluid pressure and shear force [15].

This part will give some examples of these different powered toothbrush designs from the perspective of human factors.

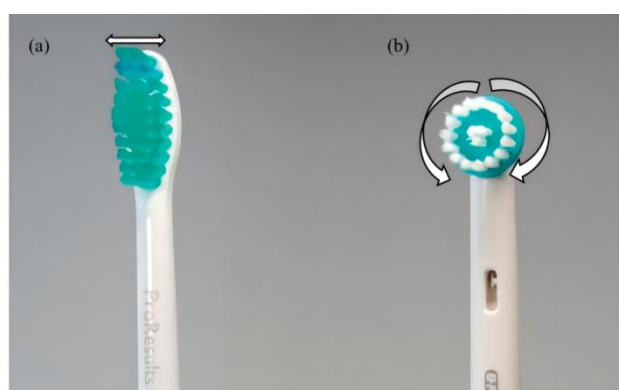


Figure 5. (a) A vibrating electric toothbrush; (b) a rotary oscillating electric toothbrush [15]

2.3.1 Oral-B iO (Figure 6(a))

The toothbrush is the latest innovative product in the Oral-B O-R powered toothbrush series and has three main features. The first is linear magnetic drive. Controlled energy is directed to the bristle tips to create micro-vibrations. On the one hand, it provides users with a quieter brushing experience, and on the other hand, it creates a special attraction for some consumers. The second is a redesigned round brush head. On the basis of the original round brush head, the bristle density has increased and the newly developed 'Tuft-in-Tuft' technology (Figure 6(b)) is adopted. The bristles are arranged at a particular Angle ($16^{\circ}41'$) to create thinner and longer tufts that maximize tooth surface area tuft

regions and cleaning. The third is a smart pressure sensor. The smart pressure sensor and variable-speed smart driver pilot the user to brush within an optimum pressure range of 0.8-2.5N (as tested in clinical trials) (Figure 6(c)). In addition, it has a menu of functions to promote compliance by coaching brushing time, position, and pressure. Users can also use artificial intelligence to interact through the compatible Oral-B iO app [16].

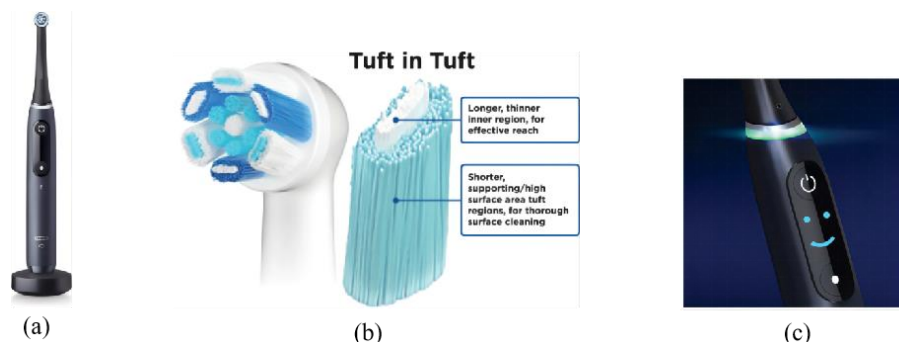


Figure 6. (a)The Oral-B iO oscillating-rotating powered rechargeable toothbrush; (b) The Oral-B Ultimate Clean toothbrush head applies 'tuft in tuft' technology; (c) An intelligent pressure sensor provides positive information and lights green when optimum pressure (0.8–2.5 N) is used [16]

2.3.2 Hybrid toothbrush (Elgydium Clinic/Inava Hybrid– Pierre Fabre Oral Care)



Figure 7. Hybrid toothbrush (Elgydium Clinic/Inava Hybrid– Pierre Fabre Oral Care) [17]

This toothbrush (Figure 7) has the appearance of a manual toothbrush, using a conventional oval head related to sonic technology. The bristles are conical (18/100 at the basis and 1/100 at the top), and these are formed by the round Tinex® fibers. It provides 3 mode choices, manual, sonic, or combination (manual and sonic). The side-by-side movable brush head can produce up to 28000 strokes per minute, which can effectively remove dental plaque [17].

2.4. Dental plaque and gingivitis

2.4.1 Relevant knowledge

Dental plaque is a kind of biofilm, also called dental biofilm. For one thing, researchers regarded the biofilm as a symbiotic component of the natural immune system. And for another, the uncontrolled movements of pathogens may lead to health issues, such as gingival inflammation, whose characteristics are redness of the gums, bleeding, and swelling. [18]. Periodontitis is a multifactorial disease with high epidemiological meaning. As a result, the elimination of supragingival and subgingival biofilms is primarily beneficial for long-term periodontal health and is correlated to the efficiency of tooth cleaning directly [19]. At present, there is no method to guarantee the definitive elimination of dental plateejanbiofilms from the oral cavity. However, using traditional

toothpaste, cleansers, and various toothbrushes can greatly decrease its pathogenicity by destroying the integrity of the structure and regenerating the normal microbiome. Especially, ultrasonic toothbrushes are able to improve oral health and clean dental plaque effectively.

2.4.2 Plaque Removal Studies

A developed methodology investigated and indicated how the bristle diameter and brushing duration affect the plaque removal for the Meso-distal surface of teeth. Subjects were required to brush tooth for a total of 130 seconds, scoring for plaque before the first brush and after each consecutive brushing for 32.5 seconds [5].

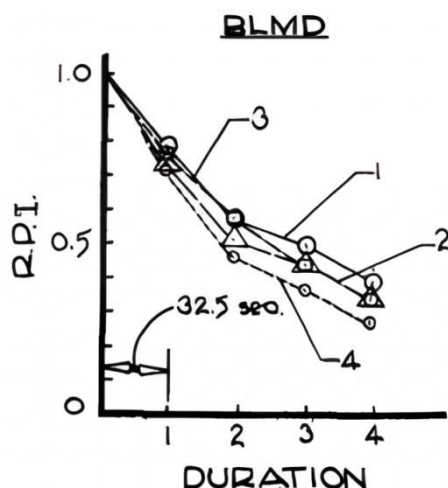


Figure 8. Shows the reduction of plaque with increasing brushing duration [5]

Figure 8 indicates that brush 4 (.011") had the best plaque cleaning effect, whereas brush 1 (.006") had the worst plaque cleaning effect. (BLMD is an average value over the three major surfaces) In spite of bristles being arranged differently in bristles 2 and 3, bristles 2 and 3 had the same quantity of bristles in the same space and were not different significantly in their ability to reduce relative plaque.

2.4.3 Effects of the electric toothbrush and manual toothbrush on dental plaque and gingivitis

No matter what type of toothbrush, electric toothbrush, or manual toothbrush is used, the teeth are cleaned by friction. In essence, the electric toothbrush is designed and modified on the basis of the manual toothbrush. Therefore, the electric toothbrush should have the basic features and functions of the manual toothbrush and be upgraded on this basis. However, in terms of the effect on plaque and gingivitis, whether the electric toothbrush is better than the manual toothbrush, and whether it is better to a large extent, some researchers have conducted some research and experiments. Based on the existing literature, this section compares the effectiveness of commercially available electric toothbrushes and manual toothbrushes in suppressing dental plaque and alleviating gingivitis.

Baab et al. [20] designed the experiment. This experiment recruited 40 adults (18 to 59 years old) with gingivitis and randomly assigned them to the "manual" or "electric" group. At 1, 2, and 4 weeks, they were given oral hygiene instruction, and an examiner assessed plaque scores and gingivitis symptoms before and after brushing. The O-R electric toothbrush model for the "electric" group is the Interplak electric toothbrush. The manual toothbrush model for the "manual" group is Butler 411 toothbrush.

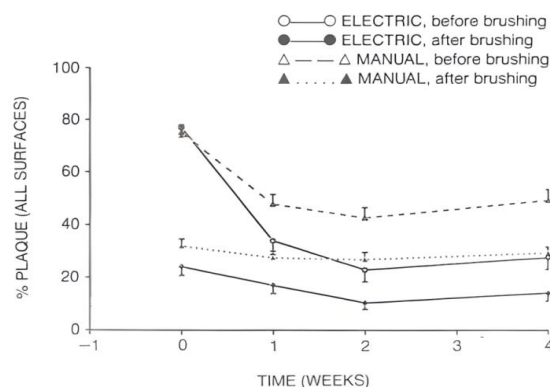


Figure 9. The efficiency of rotational-powered toothbrushes and manual toothbrushes in inhibiting dental plaque was compared [20]

Both groups started the experiment with an equally 80% plaque infection on the interdental surface (Figure. 9). After brushing, electric and manual brushes scored 24% and 32%, respectively, for plaque. Before and after brushing, the motor group's scores dropped to 23 percent and 10 percent by the second week, respectively, while the scores of the manual group dropped to 43 percent and 27 percent, respectively. The plaque scores of both groups were slightly higher at week 4, but the motor group had significantly less plaque at week 4 than the manual group. In subjects who used a rotary electric toothbrush for three months, the plaque was significantly reduced and gingivitis symptoms were controlled. Manual toothbrushes don't have the same dramatic effect as electric toothbrushes.

3. Discussion

Different types of electric toothbrushes may have different effects on plaque control and gingivitis. Tritten et al. [21] used ultrasonic toothbrushes with soft nylon bristles compared with manual toothbrushes for plaque removal and used gingival index (GI) and gingival bleeding propensity score to evaluate gingivitis symptoms.

Table 1. Average plaque degree across all teeth [21]

Visit		All interproximal			All posterior		
		Manual ^{a)}	Sonicare ^{a)}	p-value ^{b)}	Manual ^{a)}	Sonicare ^{a)}	p-value ^{b)}
baseline	Pre-brushing	2.99(0.80)	2.95(0.77)		2.78(0.54)	2.76(0.55)	
	Post-brushing	2.63(0.75)	2.26(0.72)		2.31(0.54)	2.00(0.60)	
	% reduction	11.78(9.36)	22.38(16.23)		16.65(11.55)	27.70(16.22)	
4 weeks	Pre-brushing	2.42(0.26)*	2.40(0.36)*	0.740	2.38(0.36)*	2.35(0.45)*	0.519
	Post-brushing	2.23(0.29)	2.07(0.29)	0.047	2.09(0.36)	1.94(0.40)	0.043
	% reduction	7.90(7.71)	13.49(8.68)	0.004	12.09(7.83)	17.35(9.34)	0.003
12 weeks	Pre-brushing	2.38(0.25)*	2.31(0.33)*		2.36(0.34)*	2.29(0.48)	
	Post-brushing	2.20(0.30)	2.00(0.38)		2.10(0.35)	1.91(0.51)	
	% reduction	7.45(6.57)	13.53(9.16)		11.06(7.27)	16.75(11.00)	

^{a)} Manual: N=27 subjects; Sonicare: N=29 subjects.

^{b)} Repeated measures ANOVA of both devices across all time intervals (device by time interaction, 2x5).

p-values are for pre-brushing, post-brushing, and % reduction, respectively.

* Significant difference from baseline; p<0.001 (Wilcoxon signed ranks test).

Table 2. The degree of gingivitis symptoms [21]

Index	Device ^{a)}	Baseline	4 weeks	12 weeks	p-value ^{b)}
GI	Manual	1.41(0.16)	1.20(0.17)*	1.19(0.21)*	0.211
	Sonicare	1.40(0.10)	1.16(0.19)*	1.12(0.24)*	
BT	Manual	1.64(0.28)	1.27(0.22)*	1.24(0.24)*	0.366
	Sonicare	1.64(0.20)	1.22(0.23)*	1.20(0.29)*	
BOP	Manual	41.98% (15.47)	27.74% (13.53)*	24.30% (12.81)*	0.804
	Sonicare	41.19% (10.21)	27.97% (12.29)*	29.89% (12.63)*	

GI, gingival index; BT, bleeding tendency; BOP, bleeding on probing.

a) Manual: $N=27$ subjects; Sonicare: $N=29$ subjects.

b) Repeated measures ANOVA of both devices across all time intervals (device by time interaction, 2×5).

p -values are for pre-brushing, post-brushing, and % reduction, respectively.

* Significant difference from baseline; $p < 0.001$ (Wilcoxon signed ranks test).

A total of 56 mild-to-moderate participants took part in the 12-month trial, starting with approximately the same amount of plaque on all teeth before brushing. After baseline brushing, the percentage of plaque reduction decreased to a low of 17.42% in the manual group and 27.16% in the ultrasound group. At week 4 and week 12, the percentage reduction of dental plaque in the manual group was 13.13% and 11.77%, and the reduction in the ultrasound group was 18.03% and 16.53%. Overall, compared with the manual group, the ultrasound group had a significant advantage in plaque elimination, especially after baseline brushing, the percentage of plaque reduction reached the highest reduction of 27.16%. Over the next few weeks, there was almost no difference in plaque reduction between both groups, but the ultrasound group still had an advantage over the manual group.

In the study population, the degree of gingivitis was assessed on three dimensions: gingival index (GI), degree of bleeding (BT), and percentage of bleeding sites at the inspection (BOP). As shown in Table 2, GI, BT, and BOP all showed a downward trend after baseline. In particular, the percentage of bleeding sites during probing showed a significant decrease between baseline and week 4. It was demonstrated that gingivitis symptoms were effectively relieved after using a manual or ultrasonic toothbrush. However, there was no obvious divergence in the reduction of gum inflammation among the manual group and the ultrasound group. In particular, the study also proposed that the gingival wear rate in the manual group was largely greater than that in the acoustic group, possibly because the acoustic brush was cleaned by hydrodynamic activities and mechanical scrubbing [21], so the force of the acoustic brush used by the subjects was less than that of the manual brush.

In addition, different types of the electronic toothbrush also have advantages and disadvantages in removing plaque. Aaron et al. [22] compared the rotating vibrating toothbrush with the acoustic toothbrush. The study demonstrated that rotary vibration toothbrushes are better at removing dental plaque than acoustic ones. This experiment mainly tested the effect of two kinds of toothbrushes on plaque removal after brushing for two minutes. The toothbrushes used in the two groups were Oral-B Triumph and Sonicare FlexCare. In this experiment, the dental plaque score was divided into three areas: the whole tooth, the edge area of the tooth, and the adjacent surface of the tooth. The edge area of the tooth was located at the bottom of the tooth near the gum, while the adjacent surface area was mainly near the intertooth.

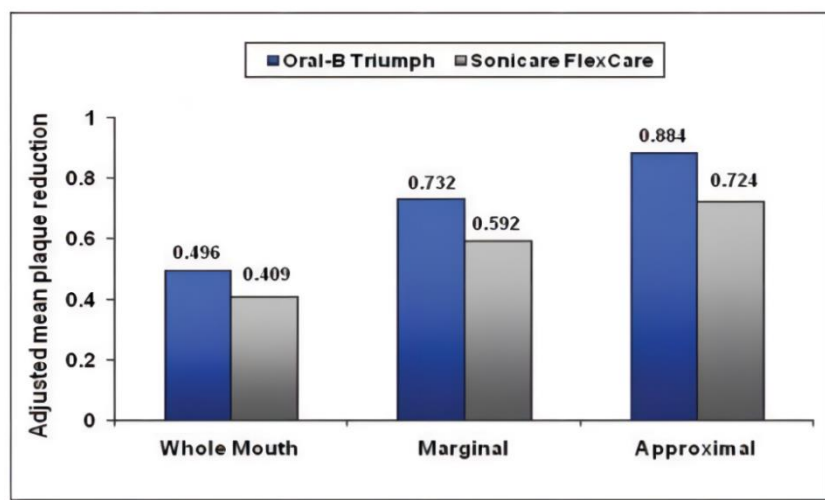


Figure 10. Two kinds of plaque reduction scores [22]

According to Figure 10, the average plaque reduction score of Oral-B Triumph after treatment was 21%, 23%, and 22% higher than Sonicare FlexCare [22] in the whole mouth, marginal region, and

adjacent region, respectively. Oral-b Triumph can better remove dental plaque in difficult-to-clean edge areas and adjacent areas.

From the above review of the comparison of different toothbrushes, it can be concluded that both electric and manual toothbrushes are effective in removing dental plaque. Compared with manual toothbrushes, electric toothbrushes have a more significant effect in removing dental plaque. Especially ultrasonic toothbrushes. Different types of electric toothbrushes also have different effects on treating dental plaque. Toothbrushes that combine rotation and vibration also have an advantage over acoustic toothbrushes in terms of plaque count. But other studies have shown that using a rotating toothbrush for a long time can wear down your gums even more.

A review of the literature shows that both electric and manual toothbrushes can control plaque, relieve gum bleeding and treat gingivitis, but there is no obvious difference between electric and manual toothbrushes in the reduction of gingivitis. Both electric toothbrushes and manual toothbrushes are only one part of daily oral cleaning. Effective cleaning of dental plaque is also inseparable from the use of toothpaste, correct brushing technology, appropriate brushing time, and long-term regular brushing. But there is no denying that the toothbrush does occupy the most important place in daily oral cleaning.

When brushing, the nearer the wrist is to the natural position, the more pleasurable it will be and the less likely it will tire. For example, the inside of molars and the outside of incisors are brushed horizontally, while the outside of molars is brushed vertically. The most difficult and uncomfortable position is when the wrist is lateral to the ulnar and radial joints. Such as in the ipsilateral hand horizontal brush after the inside of the molars and front and back vertical brush inside the front teeth, etc. [22]. According to this, the designer should make the weight, shape, and scale of the toothbrush rational, and it should be fitted to the physiological characteristics of human movement and physics.

4. Conclusion

This study set out to compare the merit and demerit of different toothbrushes or different types of toothbrushes, analyzing how the different structure (with human factors) design of toothbrushes influence the cleaning of dental plaque and gingivitis. This paper contributes to peoples' understanding of how the diverse types or structures of the toothbrush clean our oral cavity and reduce tooth disease, and it extends peoples' knowledge of dental plaque and gingivitis. This work has found that generally both manual and electric toothbrushes play part in cleaning dental plaque, and electric toothbrushes have a greater impact on dental treatment. Besides, different types or structures of the toothbrush have different effects: toothbrushes that combine rotation and vibration also have an advantage over acoustic toothbrushes in terms of plaque count. Based on these conclusions, patients with plaque or gingivitis should consider buying a hybrid electric toothbrush to alleviate dental disease symptoms; practitioners should consider how to reduce the wear of gums caused by using a rotation-vibration hybrid toothbrush for a long time and design better fit human toothbrush structure with human factors, including the man-machine scale, size, material and function realizing, etc.

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