Original Article

A Novel Classification System of Smart Mechanical Plaque Control: A Cross-Sectional Survey with Cluster Analysis

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Abstract

Background: Recurring advances in the field of mechanical plaque control (MPC) devices have shown promise in improving the oral hygiene status of the community. However, little is known about the association between the knowledge of healthcare professionals regarding these advances, the manufacturers in understanding the demand of the community, and the community's willingness to switch to these "smarter" advances in MPC. This article puts forth a novel classification system of smart MPC to bridge this research gap. **Materials and Methods:** After a Delphi consensus and a sample pretesting, a customized questionnaire survey based on the knowledge, attitude, and practice model was filled by 618 participants. The participants were divided into two groups: Group I from the healthcare profession (n = 236) and Group II from other professions (n = 382). A Chi-square test was used to determine the significant variables. These variables went through K-means and cluster silhouette scoring for cluster analysis. A correlation coefficient using regression line was used to analyze the relation between related variables. **Results:** The Chi-square test revealed nine components with statistically significant associations ($P < 0.05$). K-means clustering of the nine parameters revealed six clusters (silhouette score >0.5) that guided in drawing a classification of smart MPC. **Conclusion:** This study reveals the dearth of knowledge among the participants regarding advanced MPC and their negligence in following basic oral hygiene routines. The classification system derived through cluster analysis provides a basis for understanding the upgraded modes of MPC.

Keywords: Community dentistry, dental devices, dental plaque, home care, toothbrushing

Introduction

The first line of defense for the oral cavity against pathogenic microbes is performed by mechanical modes of plaque control. The first recorded written reference of a toothbrush dates back to 1651, although miswaks are presumed to be in use in the 7th century. The modern prototype of the manual toothbrush took its roots in 1780 but got patented in 1857. Three decades later, the dental floss was patented by Johnson and Johnson. The need for efficient cleaning of the proximal teeth surfaces was recognized in the 1980s after which interdental brushes were invented.[1]

Harold Loe's landmark study in 1965 demonstrated how gingivitis caused by accumulated plaque can be reversed through mechanical plaque control (MPC). Fourteen years later, another landmark study showcased a 40% decrease in plaque accumulation after one session of toothbrushing.[2] Hence, it becomes all the more important that a routine such as toothbrushing needs to be both qualitative (apt brushing technique) and quantitative (twice a day).

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The invention of the first electric toothbrush (Broxodent) by Dr. Philippe-Guy Woog made the foundation for dividing the toothbrush into two variants: manual and powered.

The manual toothbrush improved its cleansing efficacy by making changes in the brushing planes, bristle arrangements, material of bristles, design of the brush head, angle of the brush neck, and the gripping patterns of the handle.[3] Powered toothbrushes on the other hand have now gone wireless compared with their maiden prototypes. The modes of action range from piezoelectricity generation to the sonic and ultrasonic action of the bristles.[4] Factors such as age, systemic condition, motor abilities, oral health, ongoing oral treatment, and socioeconomic status are taken into

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consideration when devising modifications of the manual and powered toothbrushes.

Based on these user characteristics and the growing need for improving oral health, manufacturers of MPC have developed a plethora of toothbrushes in the past decade. The added moderations in these toothbrushes are not restricted to individual traits. Thus, to clarify the various key specifications of advanced MPC methods, it is necessary to know beforehand how the current scenario of MPC holds with the people. Moreover, it is important to know whether or not they would be willing to accept the changes that have hit the market recently and are bound to advance soon.

To provide a basis for the understanding of these advances of MPC for healthcare professionals, manufacturers, and the community, a systematic categorization of these dental devices is needed. To explore this subject, the study design involved a cross-sectional survey, followed by cluster analysis of significant attributes to draw a valid classification. The reporting of this survey study was performed using the Checklist for Reporting of Survey Studies (CROSS) guidelines as per the recommendations of the EQUATOR Network.

Materials and Methods

Ethical clearance was obtained from the institutional ethics committee to conduct the survey study. A Delphi consensus consisting of three periodontists, two public health dentists, and three pediatric dentists formed the panel of subject experts who helped in the formulation of a customized cross-sectional survey questionnaire. After a trial survey among 20 participants, any ambiguities in the questionnaire survey were rectified before sending it to the actual sample.

A knowledge, attitude, and practice (KAP) model was used to make the questionnaire.[5] The questionnaire survey consisted of 22 questions. The survey form was structured into four categories: personal data, current oral health behaviors, awareness regarding advanced MPC techniques, and acceptance of advanced MPC techniques.

The questionnaire was sent to the participants through electronic means such as email and social media where the link to the Google Form was shared. The form consisted of an opening body detailing the reason behind the survey and assurance of confidentiality of participants' data.

The total time of the survey was between February 2022 and June 2022. During this period, participants were asked to further share the link to the survey questionnaire, thereby executing a snowball sampling technique.

Sample size was calculated using the formula $n = Z^2 x\ px\ (1-p)/E^2$ where the Z-score for a confidence interval of 95% was 1.96 and a margin of error of 4.08% at an estimated proportion of 0.5 for maximum variability. Based on this, the approximate sample size was approximately 577.56.

Incomplete forms and multiple entries were excluded during data synthesis. A test of significance using the Chi-square test for independence was performed using SPSS 20.0. The results were later tabulated based on the analysis of the significance of the outcome variables.

The significant attributes were transferred to Orange Data Mining software (version 3.36.2) wherein they were charted through K-means clustering algorithm with silhouette-based quality estimation. A silhouette width scoring of over 0.5 was considered as a reasonable classification, whereas the ones below 0.2 indicated a lack of substantial cluster structure.

Results

The questionnaire form was sent to 700 participants, of which 82 were excluded. The reasons for exclusion included lack of response of the participants and incomplete form filling. Thus, statistical analysis was performed for 618 unique visitors who were considered for the final sample [Table 1].

Demographic data

The majority of the survey participants belonged to the Asia-Pacific region (45%), followed by Europe (23%), Africa (14%), North America (9%), and South America (9%).

Of the 618 responses, 45.1% of the respondents were aged between 20 and 40 years, 33.7% fell in the 0- to 20-year age group, whereas 16.3% of the respondents were between 40 and 60 years of age. Approximately 38.2% of the total sample size belonged to the healthcare profession.

Current oral hygiene behaviors

Of the 618 participants, 52.3% brushed once a day, whereas 41.1% brushed twice a day. Approximately 87.4% of all participants are currently using a manual toothbrush. Among the 236 respondents who are in the healthcare profession, 223 use a manual toothbrush.

Approximately 82.2% of healthcare professionals and 62.8% of the participants from other professions brushed for 1-3 minutes in their single brushing session, which was a highly significant difference according to the intergroup comparison ($P < 0.001$). Approximately 170 of the 618 participants did not floss (27.5%).

Awareness and acceptance of advanced MPC

No statistical significance was observed among respondents from either group who were aware of using an eco-friendly toothbrush irrespective of their profession ($P = 0.108$). However, 366 of the 618 participants were willing to switch to an eco-friendly toothbrush, which drew statistical significance from both groups. ($P < 0.05$).

Questions on hands-free toothbrushing revealed that 24.5% of participants from the healthcare group and 23.5% of participants from other professions were not aware of any such advances ($P = 0.848$).

Participants from the healthcare profession were better aware of toothbrushes that work through laser therapy and solar energy ($P < 0.001$).

When asked if they would recommend powered toothbrushes for children younger than 6 years, 41.5% of healthcare professionals responded in the affirmative ($P < 0.001$).

Only 128 of the 618 participants would want a toothbrush with Bluetooth connectivity. This implies a low acceptance rate ($P < 0.001$).

Music incorporation in toothbrushes was met with a higher acceptance among healthcare professionals ($P < 0.001$). Of the 208 participants from the age group of 0-20 years, 48.5% of them wanted music to be a mandatory feature in their toothbrushes.

Participants from the healthcare professional (50.84%) showed a greater preference for toothbrushes operating under solar power and a higher willingness to switch to toothbrushes that work based on laser therapy ($P < 0.001$).

Cluster analysis

After ten reruns in the K-means cluster algorithm, six centroids were identified [Figure 1]. Each of the six clusters depicted a structured category as a part of the classification of smart MPC. These were chosen based on the standardized value wherein the silhouette width was ≥0.5.

Three of the six clusters, each containing a pair of significant parameters were plotted for correlation coefficient using a regression line. Each of them had a R-value between 0.39 and 1.00, indicating a positive discernible trend between the related parameters [Figure 2].

Discussion

Healthcare professionals consist of individuals belonging to medical and allied sciences. An aspect of being a healthcare professional involves being updated with the latest advances related to devices and equipment that can have a vital impact on the community as a whole. Dental devices such as smart or advanced MPC are a group of such aids that can directly influence the oral health status of a community.

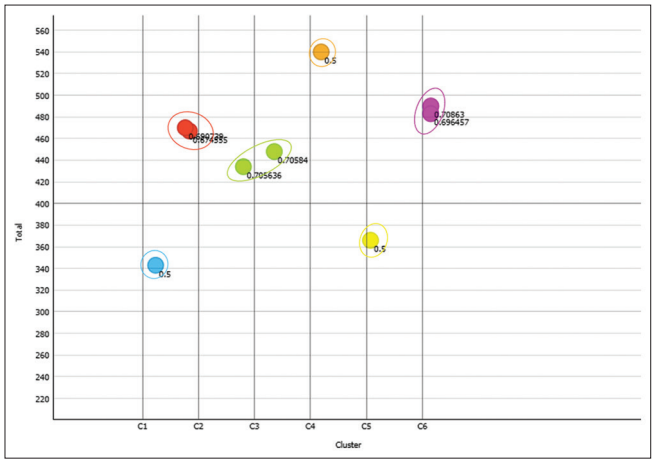

Figure 1: K-means cluster analysis with labeled silhouette width scores

The reason behind grouping the participants of our study based on their profession was to analyze whether healthcare professionals are themselves aware and have an acceptance of the advanced MPC methods. The KAP of healthcare professionals toward these advances is directly proportional to the awareness of these devices among the masses and the manufacturers in understanding the acceptance of their MPC devices [Figure 3].

Powered toothbrushes have been previously classified based on three generations according to their mode of action electricity (Gen 1), vibrating and rotational movements with pressure-sensor brush heads (Gen 2), and rechargeable brushes with sonic waves (Gen 3).[6] However, MPC devices have advanced much beyond, and simply classifying them as powered toothbrushes dose not suffice.

The Delphi consensus decided on the following "smart" features for incorporation in the questionnaire: eco-friendliness, dimensional uniqueness, the pace of toothbrushing, other modes for toothbrushing, digital advancements, and advances in interproximal cleaning.

This study showed that powered toothbrushes were used by only 12.6% of the participants, which indicates that the conventional manual methods are still preferred despite the better cleaning efficacy of powered toothbrushes.[7] Approximately 41.1% of participants stated that they brush only once daily which puts into question what needs to be prioritized, creating awareness of routine toothbrushing or coming up with advanced strategies irrespective of ignorant oral hygiene behaviors.

Flossing was not a part of the oral hygiene routine of 44% of the participants from the healthcare profession and 40% of the participants from the other professions, which yet again indicates that a lacuna exists concerning the awareness of the importance of flossing.

Although manufacturers continue to come up with advanced MPC, the results of our study showcase that even healthcare

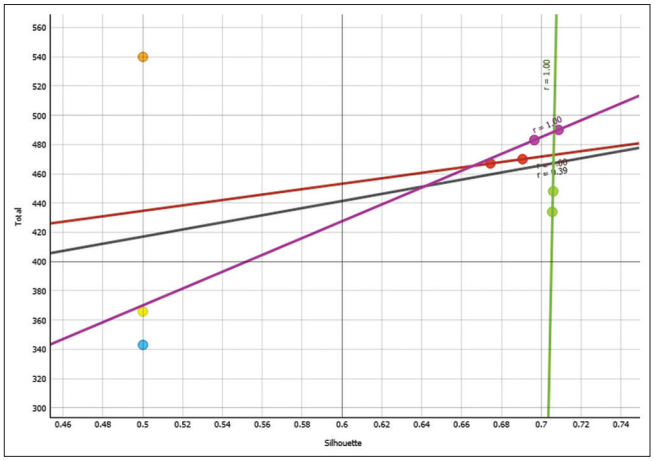

Figure 2: Regression line for determining the trend between relatable parameters in clusters with multiple attributes

Table 1: Statistical Analysis of the survey

Profession	Brushing 1-3 min	Certain that they use an eco-friendly toothbrush	Willing to switch to an eco-friendly toothbrush	Can imagine brushing without hands	Would recommend a powered toothbrush to children below 6 years of age	Would prefer a toothbrush with a Bluetooth connection	Would want music to be a mandatory feature in their toothbrush
Healthcare (*n*=236)	194	66	149	58	98	69	140
Other (*n*=382)	240	85	217	90	69	59	135
Chi-square value	26.193	2.58	2.419	0.082	40.72	16.89	33.97
P	<0.001*	0.108	<0.05	0.848	<0.001*	<0.001*	<0.001*

Profession	Aware of solar-powered toothbrushes	Willing to switch to solar-powered toothbrushes	Aware of toothbrushes using laser therapy	Willing to switch to laser therapy toothbrushes	Do not Floss	Use powered toothbrush
Healthcare (*n*=236)	66	120	70	80	31	13
Other (*n*=382)	57	112	65	73	139	65
Chi-square value	15.57	28.83	13.662	17.12	39.55	17.51
P	<0.001*	<0.001*	0.001*	<0.001*	<0.001*	<0.001*

*Indicates statistical significance at *P*<0.05

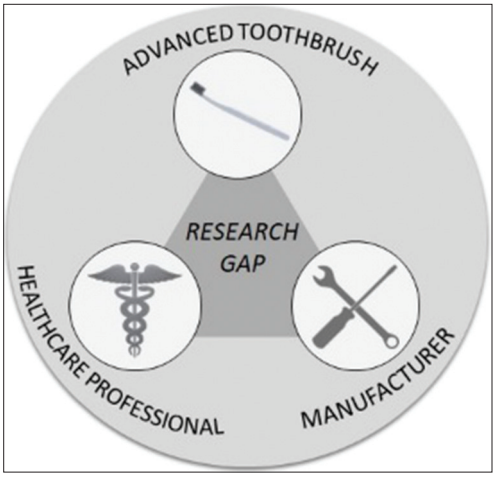

Figure 3: The communicative gap between manufacturers, healthcare professionals, and the advances in mechanical plaque control, which influences their acceptance and awareness in the community

professionals struggle to keep up with these advances. Furthermore, irrespective of their profession, a majority of the population continues to rely on conventional techniques of MPC with a concurrent shortcoming in following standardized oral hygiene behaviors.

Deriving a classification based on cluster analysis is a well-established technique. It helps group data sets of similar attributes (K-means clustering) while simultaneously evaluating the quality of the clusters (silhouette scoring). Furthermore, in clusters drawn from more than one parameter, a regression line helped in confirming that the parameters are related and of similar character.[8] Based on the cluster analysis, six categories made up our proposed classification: ecologically smart, effortlessly smart, dimensionally smart, radiantly smart, digitally smart, and interdentally smart.

Considering the growing awareness of plastic pollution, manufacturers have developed toothbrushes that do not use electricity or batteries for their functioning and are rather made with biodegradable materials using plant livestock and bioplastics (Beyond Electric).[9] Eco-friendly toothbrushes also include ones that reduce the usage of toothpaste by incorporating premedicated bristles. Most companies use the synthetic polymer Nylon-4 when manufacturing eco-friendly toothbrushes.[10]

A clad of advanced toothbrushes takes the shape of the arches of the upper and lower jaw. Bristles are embedded within these arch forms which work through sonic waves that are delivered after powering on the toothbrush. Some companies fabricate such brushes that are customizable to each patient by 3D printing technology (Blizzident).[11] Despite the available prospect of achieving plaque control with minimal effort, such toothbrushes have not been promoted enough as per the results of our survey. Only 23.9% of the participants believed that it was possible to brush teeth without the use of hands.

Some other smarter toothbrushes contribute to eco-friendliness by housing multiple components of oral hygiene maintenance in a single tool (Ultibrush) or by reusing the same components of an existing toothbrush to develop a brand-new toothbrush (Reswirl).[12,13] Despite such impressive advances, the current survey shows that 41% of participants were still not ready to switch to an eco-friendly toothbrush.

Influenced by digital advances, toothbrushes now come up with a range of features such as gyroscope, Bluetooth connectivity, quad pacer, color-coded bristles, artificial intelligence, in-built timers, different brushing modes, and software applications. Light-induced fluorescence digital visualization systems can aid the user in knowing about the areas of the tooth with more plaque retention by viewing these areas on the associated software installed on a phone with a Bluetooth connection.[4,14–16] In contempt of such promising, technologically advanced systems in the market, only 25% of the participants from the healthcare profession and 15%

Table 2: Proposed classification system of smart mechanical plaque control

Cluster designation	Class	Characteristics
C1	Effortlessly smart	Arch-shaped brushes that clean every tooth surface without the use of hands
C2	Ecologically smart	Made of recyclable compostable materials with minimal use of heavy metals
C3	Digitally smart	Digital components such as Bluetooth, quad pacer, gyroscope, timer, artificial intelligence, and plaque detection embedded in the toothbrush
C4	Dimensionally smart	Multiheaded brush heads with customizable grips for faster oral hygiene maintenance
C5	Interdentally Smart	Flosses made of biocompatible materials or ones with high water pressure and built-in timer
C6	Radiantly smart	Toothbrushes using radiations of solar energy or different wavelengths of lasers for oral hygiene maintenance

of participants from other professions preferred to have a Bluetooth-embedded toothbrush. Notably, merely 22.7% of the respondents under the age of 40 years wanted a toothbrush with Bluetooth connectivity. This infers the repulsion of the younger generation toward technological headways.

Digitally smart toothbrushes also aim at making toothbrushing a pleasant activity for users of all age groups. To engross the child's focus toward toothbrushing, some digital toothbrushes have musical tunes and software-based activities on the phone, which are governed through efficient toothbrushing.[17] Powered toothbrushes are recommended for better oral hygiene measures even in children. Silicon-headed powered toothbrushes are developed to keep them completely safe for use in children younger than six years (Foreo ISSA).[18] Healthcare professionals (41.5%) were better aware in this regard as 18% of participants from the nonhealthcare professionals did not deem powered toothbrushes fit for children younger than six years. This implies that powered toothbrushes for children are not marketed enough or that their safety protocols are not known to the general population.

According to the results of our survey, 160 (25.8%) respondents took over 3 minutes to brush their teeth. Of these, 125 used manual toothbrushes, whereas 35 used powered toothbrushes. Multiheaded toothbrushes have been developed previously for individuals with conditions that hamper their motor skills.[19] However, newer dimensional advances see these toothbrushes with angled heads that cover every surface of teeth and which function through sonic vibrations as well. Such toothbrushes decrease the total time for a single toothbrushing session (less than 45 seconds) while efficiently performing oral hygiene measures.[20,21]

Laser therapy is used in toothbrushes that contain bristles that emit light of different wavelengths to reduce the action of cyclooxygenases and destroy the bacterial cell wall. Solar-powered toothbrushes use solar energy that radiates hydrogen ions from embedded metallic semiconductors, which are involved in the control of plaque.[22–24] Thus, based on the unique mechanism of actions, a "radiantly smart" category was added to the classification.

Although our survey has shown negligence in flossing by the participants, smart advances have been made that efficiently enhance plaque-free environments in the interdental regions. Some of these advances can release water droplets with high air pressure for a timed interval with a capacity of 600 mL. These are highly effective in patients who are undergoing orthodontic treatment or have inflamed periodontal tissues.[25] Some manual upgrades in interdental flossing include the use of flossers made of biocompatible rubber silicon.[26]

Our proposed classification system of smart or advanced MPC methods drawn through cluster analysis is summarized in Table 2. This classification system is registered and copyrighted (Diary No.: 23342/2022-CO/L) by the Copyright Office of the Government of India that falls under the Department of Promotion of Industry and Internal Trade.

This study brings to light the advanced MPC methods that are available in the market for efficient oral hygiene maintenance. The proposed classification system goes a step beyond the conventional categorization of "manual" and "powered" mechanical plaque control agents and highlights the multimodal mechanism of actions of different toothbrushes and flosses in the market. The survey showcases a lack of promotion of these MPC aids and hints at an introspection for the manufacturers to fabricate devices acceptable to the masses. The results of our survey also highlight the lack of awareness of advanced MPC tools irrespective of their profession.

Our study reveals the current oral hygiene preferences but has its limitations. Although responses received saw participants from different countries, 89.6% of the responses came from one particular country (India). A better sampling technique with an increased sample size can help in better understanding the unmet oral hygiene needs at a larger scale.

Conclusion

Given the limitations of this survey study, the following conclusions can be drawn:

- There is a need for better promotion of routine oral hygiene behaviors.
- Manufacturers need to better promote their advanced tools for MPC.
- Healthcare professionals need to be more updated about oral hygiene tools to create or promote awareness related to oral hygiene.

Practice implications

Future research should be implicated in analyzing the efficacy and availability of the advanced MPC techniques and whether or not they are feasible for every population group. Dentists and dental hygienists must remain updated about advanced MPC methods to facilitate better oral hygiene.

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Key messages

This article puts forth a new classification system for MPC that can help dentists in knowing about the current oral hygiene preferences of the patients, the manufacturers in creating newer models of toothbrushes and flosses, and the laymen in knowing about the advanced trends in MPC.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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