ORIGINAL ARTICLE

The effectiveness of nanotechnology toothbrush bristles in maintaining oral hygiene of children aged 9–12 years: a quasi-experimental

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ABSTRACT

Introduction: Dental caries remains a common oral health problem among school-aged children and is associated with oral hygiene practices and plaque control. In Indonesia, its high prevalence highlights the need for effective preventive strategies. Conventional toothbrushes rely mainly on mechanical plaque removal, which may be limited in children due to variations in brushing technique. Recent developments have introduced nanotechnology in toothbrush bristles, where nanosilver is incorporated into the bristle material and has been reported to exhibit antibacterial and anti-biofilm properties that may support plaque control during brushing. However, evidence of its effectiveness in children remains limited. This study aimed to analyze the effectiveness of nanotechnology toothbrush bristles in maintaining oral hygiene among children aged 9–12 years. **Methods:** This study employed a quasi-experimental design with a control group pre-test and post-test approach. A total of 62 children aged 9–12 years were included: the experimental group using nanosilver-bristled toothbrushes (n=31) and the control group using conventional toothbrushes (n=31). All participants received the same toothbrushing instruction at baseline. Oral hygiene was assessed using the Patient Hygiene Performance (PHP) index on selected index teeth representing anterior and posterior sextants, measured at baseline and after a 21-day intervention. As the data were not normally distributed, the Wilcoxon signed-rank test and Mann–Whitney U test were used. **Results:** Baseline PHP scores were comparable between groups ($p>0.05$). After the intervention, the mean PHP score in the experimental group decreased from 3.87 ± 1.074 to 1.51 ± 1.040 (61.0% reduction; $p<0.05$). In the control group, the mean PHP score decreased from 3.38 ± 0.734 to 2.88 ± 0.799 (14.8% reduction; $p<0.05$). The reduction in PHP scores was significantly greater in the experimental group ($p<0.05$). **Conclusion:** Toothbrushes with nanosilver bristles were more effective than conventional toothbrushes in improving oral hygiene among children aged 9–12 years.

KEYWORDS

Nanotechnology, nanosilver bristles, oral hygiene, school-aged children

INTRODUCTION

Good oral and dental hygiene is an essential component in supporting the overall health and well-being of children and adolescents.[1] In Asia, dental caries remains one of the most prevalent chronic conditions affecting children, with a reported prevalence of 52.6% in primary teeth and 58.8% in permanent teeth based on a large-scale meta-analysis. These findings indicate a substantial burden of dental caries among children in the Asian region.[2] In Indonesia, the situation is even more concerning.[3] The 2023 Indonesia Health Survey (SKI) reported a caries prevalence of 84.8% among children aged 5–9 years and 63.8% among

those aged 10–14 years.[4] Although 67% of children in West Java brush their teeth twice daily, only 5.8% do so correctly, indicating that effective brushing technique remains low despite adequate frequency.[5] This reflects inadequate oral hygiene behavior and a lack of understanding of proper toothbrushing methods from an early age, particularly among school children in Indonesia. This pattern aligns with global findings emphasizing that brushing technique, rather than frequency alone, determines effective plaque control.[6]

Dental plaque is a structured biofilm primarily composed of *Streptococcus mutans* and is the main factor contributing to caries and gingival inflammation in children.[7] Poor brushing techniques often leave residual plaque on tooth surfaces, leading to enamel demineralization and caries.[8] Therefore, improving brushing effectiveness through innovations in toothbrush design and materials is essential to prevent plaque buildup, especially among children who are still developing consistent brushing habits. Recent microbiological evidence shows that dental biofilm can mature rapidly and become more pathogenic when not effectively disrupted, making children particularly vulnerable due to their limited brushing skills.[9] Children aged 9–12 years are in a transitional developmental stage in which manual dexterity improves but still varies widely, making this group an important target for plaque-control interventions.[10]

One innovation that has gained attention in preventive dentistry is the application of nanotechnology to toothbrush bristles. Nanotechnology involves the manipulation of materials at the nanometer scale (1–100 nm) to enhance their physical, chemical, and biological properties.[11] In oral hygiene, nanosilver (AgNPs) is one of the most widely used nanoparticles due to its strong antibacterial and anti-biofilm effects. When integrated into toothbrush bristles, nanosilver can inhibit bacterial growth, reduce plaque formation, and maintain oral cleanliness for longer periods than conventional bristles. In addition, nanosilver is biocompatible, safe for daily use, and suitable for children. Studies report that nanosilver can disrupt bacterial cell membranes, interfere with metabolic pathways, and prevent microbial adherence to tooth surfaces—mechanisms thought to contribute to plaque reduction in pediatric populations.[12,13]

Despite the increasing commercial availability of nanotechnology-based toothbrushes, scientific evidence regarding their effectiveness among school children in Indonesia remains limited, particularly under real-life conditions. Previous international studies have shown promising results; however, most have been conducted in controlled settings or among adult populations.[14] There remains a clear research gap regarding whether these toothbrushes provide meaningful clinical benefits for school-aged children in natural school environments, especially within the Indonesian context. Therefore, school-based research is essential to evaluate their actual effectiveness.[15]

This study employs a quasi-experimental pretest and posttest design over a 21-day period at Cireundeu Elementary School and Baros 5 Elementary School, using the Patient Hygiene Performance (PHP) index, a reliable tool for assessing plaque accumulation across multiple tooth surfaces in pediatric oral health research.

The novelty of this study lies in evaluating the effectiveness of nanotechnology toothbrush bristles in a real-life school setting among Indonesian children aged 9–12 years. Therefore, this study aims to evaluate the effectiveness of nanotechnology toothbrush bristles in improving oral hygiene, as measured by the Patient Hygiene Performance (PHP) index.

METHODS

This quasi-experimental study used a pretest and posttest control group design to evaluate changes in oral hygiene before and after the use of a nanotechnology-based (nanosilver) toothbrush. The study was conducted at two elementary schools in Cimahi City, West Java, namely Cireundeu Elementary

School (intervention group) and Baros 5 Elementary School (control group), over a period of 21 consecutive days. The study population consisted of elementary school children aged 9–12 years, as children in this age group are generally capable of understanding tooth brushing instructions, maintaining a daily brushing routine, and cooperating during oral examinations.

Participants were selected using a cluster-based sampling approach, with schools assigned as intervention and control groups, followed by random selection of eligible students within each school. Participants were required to meet the following inclusion criteria: (1) children aged 9–12 years; (2) actively enrolled as students at Cireundeu Elementary School and Baros 5 Elementary School; (3) willing to participate in all stages of the study (pretest, intervention, and posttest); and (4) having parental consent through a signed informed consent form. The exclusion criteria were as follows: (1) children undergoing orthodontic treatment or using removable orthodontic appliances; (2) children absent during data collection; and (3) participants who did not complete the full 21-day intervention period.

The sample size for this study was calculated based on a comparative pretest and posttest design involving two groups. The estimation was informed by a previous study entitled "Microbial Contamination and Plaque Scores of Nanogold-Coated Toothbrush," which compared nanotechnology-based toothbrushes with conventional toothbrushes and reported differences in plaque-related outcomes.[17] The mean plaque score values reported in that study were used to estimate the expected effect size in the present study.

The PHP index was treated as an ordinal clinical outcome and summarized using numerical scores. Sample size estimation was performed using a standard normal deviation for a two-sided significance level of 5% ($Z\alpha = 1.96$) and a statistical power of 80% ($Z\beta = 0.84$). Based on these parameters, the minimum required sample size was 28 participants per group. To account for potential dropouts, an additional 10% was added, resulting in a final sample size of 31 participants in each group.

Thus, a total of 62 children were included in this study, with 31 participants assigned to the intervention group from Cireundeu Elementary School and 31 participants assigned to the control group from Baros 5 Elementary School.

The study began with a pretest examination using a disclosing solution to visualize plaque distribution on the tooth surfaces. Subsequently, oral hygiene status was assessed using the PHP Index. Before the intervention, participants received education on proper toothbrushing techniques using the Fones method, accompanied by a live demonstration conducted by co-assistant dentists under the supervision of a dentist, with the sessions conducted in a classroom setting.[18,19]

After the educational session, each participant was provided with a toothbrush according to group allocation. The intervention group used a nanosilver-bristled toothbrush (Smoca; Jiangsu Xingsheng Brush Co., Ltd., Jiangsu, China), a commercial product registered with the Indonesian Ministry of Health, while the control group used a conventional toothbrush (Pepsodent Brilliant Soft; Unilever Indonesia, Jakarta, Indonesia). The toothpaste used for both groups was Pepsodent Anti-Cavity Toothpaste (Unilever Indonesia, Jakarta, Indonesia) to ensure consistency in fluoride content and abrasive composition throughout the study. Participants were instructed to brush their teeth twice daily, in the morning and evening, for 21 consecutive days. Brushing activities were periodically supervised by co-assistant dentists and teachers under the supervision of a dentist to ensure adherence to proper brushing techniques and the designated brushing schedule. [20,21]

Prior to the distribution of toothbrushes, all participants received educational training on the Fones brushing technique to ensure that every child understood and consistently applied the correct brushing movements during the study period.[22] This step aimed to minimize variations in plaque removal due to

differences in the brushing technique. The demonstration was conducted directly by the researcher using a plastic dental model, followed by practice sessions until the participants could correctly replicate the technique.[23]

Figure 1. Toothbrushing education using the Fones technique

Figure 2. Nanosilver toothbrush and standard toothbrush

Figure 3. Disclosing Solution

After the toothbrushes were distributed, the participants underwent an initial examination to assess their PHP Index as a pretest measurement. Following the examination, the participants were supervised to ensure that they brushed their teeth according to the technique taught during the educational session. All participants were instructed to brush their teeth twice daily (morning and evening) for 21 consecutive days.

The 21-day intervention period used in this study aligns with the FDI World Dental Federation's *Brush Day & Night* program, which recommends consistent twice-daily brushing for 21 consecutive days to develop proper oral hygiene habits in children.[23] Brushing activities were periodically supervised by the researcher and teachers to ensure that brushing was performed correctly and to monitor participants' compliance with the prescribed brushing schedule.[24]

On the 21st day, a posttest examination was conducted using the same PHP Index, a plaque index that assesses debris and plaque accumulation on selected tooth surfaces. The PHP Index categorizes oral hygiene into four levels: Very Good, Good, Moderate, and Poor, where lower scores indicate better oral hygiene

and higher scores indicate poorer oral hygiene. The assessment was performed on six index teeth in the maxillary and mandibular arches. Both pretest and posttest examinations were conducted in the morning before breakfast and before school activities began. All examinations were carried out in the school environment, while tooth brushing took place in the schoolyard under the supervision of the researcher and teachers. All examinations were performed by the same examiner to ensure consistency and minimize bias.

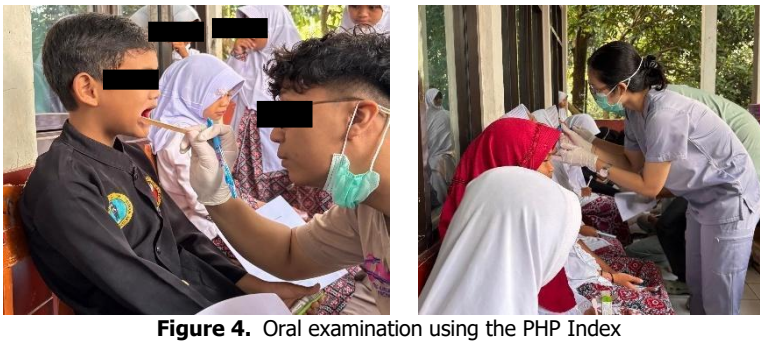

Figure 4. Oral examination using the PHP Index

Data were analyzed using IBM SPSS Statistics version 25. Descriptive analysis was used to summarize participants' characteristics and PHP scores. The Kolmogorov–Smirnov test was applied to assess data normality. Because the PHP index scores were not normally distributed, the Wilcoxon signed-rank test was used to compare pretest and posttest PHP scores. Statistical significance was set at $p < 0.05$.

This study was reviewed and discussed in a Full Board (plenary) meeting of the Health Research Ethics Committee, Faculty of Medicine, Universitas Padjadjaran. The committee determined that the study involved minimal risk and granted ethical approval.

Prior to participation, written informed consent was obtained from the parents or legal guardians of all participating children, and verbal assent was obtained from the children to confirm their voluntary participation. All participants were informed about the purpose, procedures, potential risks, and benefits of the study. To ensure confidentiality and privacy, all personal data were anonymized and securely maintained throughout the research process.

RESULTS

This study collected observational data on toothbrushing from 62 respondents, consisting of children aged 9–12 years at Cireundeu Elementary School and Baros 5 Elementary School. The study was conducted in September to October 2025, during which participants in the intervention group used nanosilver-bristled toothbrushes, while the control group used conventional toothbrushes.

Table 1. Respondent characteristics among school children at Cirendeu and Baros 5 Elementary School

Respondent Characteristics	Number	Percentage
Gender		
Male	30	48.3
Female	32	51.6
Age		
10 years old	14	22.5
11 years old	37	59.6
12 years old	11	17.7
School area		
Cireundeu Elementary School	31	50
Baros 5 Elementary School	31	50

The results showed that the majority of respondents were female (51.6%) and aged 11 years (59.6%). The distribution of participants between Cirendeu and Baros 5 elementary school was equal (50% each), ensuring balanced representation between schools. These findings indicate that the respondent characteristics were evenly distributed across age and gender, representing a homogenous sample of school children aged 9–12 years in Cimahi City. (Table 1).

Table 2. Plaque hygiene performance categories before using nanosilver toothbrush at Cireundeu elementary school

Categories of Plaque and Hygiene Performance Index	Number	Percentage
Very Good	0	0
Good	1	3.2
Moderate	9	29.0
Poor	21	67.7

Based on Table 2, before using the nanosilver toothbrush, most respondents were in the poor category (21 respondents; 67.7%). Meanwhile, 9 respondents (29.0%) were in the moderate category, and only 1 respondent (3.2%) was in the good category. No respondents were classified as very good (0%). These findings indicate that prior to the intervention, the respondents' oral hygiene status was predominantly poor.

Table 3. Plaque hygiene performance categories before using conventional toothbrush at children aged 9-12 Years at Baros 5 elementary school

Categories of Plaque and Hygiene Performance Index	Number	Percentage
Very Good	0	0
Good	0	0
Moderate	15	48.3
Poor	16	51.6

Based on Table 3, before using the conventional toothbrush, most respondents were classified in the poor category (16 respondents; 51.6%), while 15 respondents (48.3%) were in the moderate category. No respondents were categorized as good or very good (0%). These findings indicate that prior to the intervention, the respondents' oral hygiene status was generally predominantly poor.

Table 4. Plaque hygiene performance categories after using nanosilver toothbrush at Cireundeu elementary school

Plaque and Hygiene Performance Index Categories	Number	Percentage
Very Good	0	0
Good	21	64.5
Moderate	8	3.2
Poor	2	32.3

Based on Table 4, after using the nanosilver toothbrush, most respondents were in the good category (64.5%), followed by moderate (32.3%), and only 3.2% remained in the poor category. These results indicate an improvement in oral hygiene after the intervention.

Table 5. Plaque hygiene performance categories after using conventional toothbrush at Cireundeu elementary school

Plaque and Hygiene Performance Index Categories	Number	Percentage
Very Good	0	0
Good	2	6.5
Moderate	20	64.5
Poor	9	29.0

Based on Table 5, the majority of respondents were classified in the moderate category, accounting for 20 respondents (64.5%). The poor category included 9 respondents (29.0%), while only 2 respondents (6.5%) were classified as good. No respondents were categorized as very good (0%). These results indicate that plaque and oral hygiene performance after using a conventional toothbrush was predominantly at a moderate level.

Table 6. Comparison of Mean PHP Scores Between Intervention and Control Groups Before and After Toothbrushing Intervention at Children Aged 9-12 Years in Elementary School

Variabel	(Mean ± SD)	
	Pretest	Posttest
Intervention group	3.87 ± 1.074	1.51 ± 1.040
Control group	3.38 ± 0.734	2.88 ± 0.799

The mean PHP score in the intervention group showed a marked decrease from (3.87 ± 1.074) at pretest to (1.51 ± 1.040) at posttest. In the control group, the mean score also decreased from (3.38 ± 0.734) at pretest to (2.88 ± 0.799) at posttest. However, the reduction in the intervention group was greater than that in the control group, suggesting that the nanosilver toothbrush was more effective in reducing plaque accumulation and improving oral hygiene compared to the conventional toothbrush.

Table 7. Effect of toothbrush type usage on patient hygiene performance (PHP) scores among Children at Cireundeu Elementary School and Baros 5 elementary School

Variabel	z	P Value
Nanosilver toothbrush	-4.214	0.001
Standard toothbrush	-2.858	0.004

The Wilcoxon test results showed significant differences before and after brushing in both groups ($p<0.05$), with a stronger effect observed in the nanosilver toothbrush group ($Z=–4.214$; $p=0.001$) compared to the standard toothbrush group ($Z=–2.858$; $p=0.004$). These findings confirm that the nanosilver toothbrush significantly improved oral hygiene performance compared to the conventional toothbrush.

DISCUSSION

The findings of this study indicate that children who used toothbrushes with nanosilver bristles achieved significantly greater improvements in plaque removal compared to those using conventional toothbrushes. Based on Table 6, the nanosilver group showed a substantial decrease in PHP scores from 3.87 to 1.51, whereas the control group decreased only from 3.38 to 2.88. These results suggest that nanosilver bristles provide a superior clinical plaque-removal effect, potentially associated with the antibacterial properties reported in previous studies.

The effectiveness observed in this study aligns with earlier findings by Durgesh et al., which demonstrated significantly lower plaque scores when using nanogold-coated toothbrushes,[24] and Ozgul Baygin et al., who reported superior antibacterial activity from silver-nanoparticle–infused brushes.[25] The consistency

between these studies and the present findings supports the growing consensus that nanotechnology-based oral hygiene devices offer improved antibacterial performance beyond traditional bristle materials.

The distribution of oral and dental hygiene categories in Tables 4 and 5 further supports these findings. After 21 days of intervention, the majority of participants in the nanosilver group moved into the "good" PHP category (64.5%). In contrast, only 6.5% of participants in the control group achieved the "good" category, while most remained in the "moderate" category (64.5%). The clinically observed advantages further support and extend the microbiological findings reported by Tuzuner et al., which demonstrated that toothbrushes incorporating silver nanoparticles (AgNPs) possess effective antibacterial activity and self-sanitizing properties. The release of active silver ions from the bristles is known to inhibit the proliferation and colonization of residual pathogenic bacteria following toothbrushing. By maintaining the intrinsic cleanliness of the toothbrush bristles, nanosilver technology may reduce microbial reservoirs and minimize the risk of re-inoculation (re-infection) into the oral cavity. This mechanism enables more effective mechanical plaque control, which is subsequently reflected clinically in improved oral hygiene status compared to the use of conventional toothbrushes.[25]

These results indicate that the effectiveness of nanosilver toothbrushes is not solely dependent on the mechanical action of brushing. Nanosilver bristles are reported to release Ag^+ ions with antibacterial activity, including disruption of bacterial cell membrane integrity and inhibition of metabolic processes of plaque microorganisms. However, it should be emphasized that these antibacterial mechanisms were not directly assessed in the present study and are inferred from previous studies. The observed improvement should therefore be interpreted as enhanced clinical plaque control rather than direct evidence of antimicrobial activity.[26]

Tables 2 and 3, which show the initial PHP score classification, reveal that most participants in both groups had poor oral hygiene prior to the intervention (67.7% in the nanosilver group; 51.6% in the control group). This is consistent with national surveys indicating that Indonesian children often brush daily but exhibit ineffective brushing techniques.[4] Because both groups began at comparable hygiene levels, the greater improvement in the nanosilver group is unlikely to be influenced by baseline differences. Instead, it may reflect the added value of the nanosilver bristle material.[27]

The significant findings in Table 7, where the nanosilver group displayed a stronger Wilcoxon Z-score ($Z=-4.214$; $p=0.001$), provide statistical confirmation that the plaque reduction was not due to random variation. In contrast, although the control group also improved, the statistical strength was weaker ($Z=-2.858$; $p=0.004$). This suggests that nanosilver toothbrushes may provide a more consistent and measurable improvement. Similar outcomes were observed in studies evaluating nanomaterials in dental composites and coatings, where antibacterial nanoparticle incorporation has been associated with reduced biofilm formation.[28]

The improved plaque control observed in the nanosilver group may be associated with the antibacterial properties of nanosilver bristles, as reported in previous studies. The release of Ag^+ ions has been shown to inhibit *Streptococcus mutans*, a key bacterium involved in plaque formation and caries development, and may also suppress bacterial replication within dental biofilms.[30]

This mechanism is particularly relevant in children, whose motor skills and toothbrushing techniques are still developing. Consistent with findings reported by dos Santos, children often fail to adequately reach all tooth surfaces during brushing, thereby increasing the risk of plaque retention.[29] In this context, nanosilver bristle material may function as an adjunctive factor that helps compensate for limitations in children's brushing techniques and contributes to more sustained plaque control. However, it should be emphasized that these

antibacterial mechanisms were not directly evaluated in the present study and are inferred from previous research. Therefore, the findings should be interpreted as evidence of clinical plaque reduction rather than direct proof of antibacterial activity or microbiological changes in dental plaque.

In terms of practical application, these findings may have implications for school-based oral health programs. The greater improvement observed in the nanosilver group suggests that nanosilver toothbrushes may be considered as a complementary strategy within UKGS (Usaha Kesehatan Gigi Sekolah/School Dental Health Program), a school-based program in Indonesia that aims to improve and maintain students' oral health through promotive, preventive, and basic curative activities, particularly in communities with limited access to regular dental check-ups. Given that plaque microbiology is influenced by multiple environmental and behavioral factors, the availability of toothbrushes with reported antibacterial properties may provide an additional supportive measure for children who are more vulnerable to plaque-related oral health conditions.[31]

Although the findings support the effectiveness of nanosilver toothbrushes, several limitations must be acknowledged. The intervention period of 21 days may not fully capture long-term changes in plaque accumulation or caries development. Previous studies suggest that longer observation periods are required to evaluate changes in gingival inflammation and enamel demineralization. Additionally, factors such as brushing pressure, dietary habits, and saliva characteristics were not controlled and may have influenced the observed plaque levels.

In addition, this study did not assess microbiological parameters, including bacterial colony counts, salivary pH, and plaque composition. These biological parameters may provide more objective and direct evidence of antibacterial effects. Accordingly, future studies should incorporate microbiological analyses to further substantiate the antimicrobial properties of nanosilver bristles beyond visual plaque index assessments.

Overall, nanosilver toothbrushes demonstrated superior performance in reducing plaque accumulation among school-aged children compared to conventional toothbrushes. These findings indicate a greater clinical reduction in plaque accumulation and suggest that nanotechnology-based toothbrushes may be considered as a supportive preventive tool for oral hygiene maintenance in school-aged children, However, the observed effects are based on clinical plaque assessment, and the antibacterial mechanisms are inferred from existing literature rather than directly measured in this study. Further research with longer follow-up periods and inclusion of microbiological parameters is recommended to strengthen the evidence on long-term effectiveness and underlying mechanisms.

Another limitation is the dependency on children's cooperation during brushing education and supervision. As observed in similar school-based studies, children may vary in their compliance, attention, and brushing rhythm. Although both groups received the same instruction, individual behavioral differences may have influenced plaque removal effectiveness. Nevertheless, the significantly greater improvement in the nanosilver group suggests that bristle material differences overshadow minor inconsistencies in brushing behavior.

Despite these limitations, the study adds valuable insight into the role of toothbrush material innovation in improving children's oral hygiene. The consistent improvements across all measured outcomes suggest that nanosilver toothbrushes may serve as an effective preventive strategy, complementing oral health education and routine brushing practices. Their integration into community and school-based programs may help reduce plaque accumulation and caries risk, particularly among children in areas with limited access to dental services.

CONCLUSION

The findings of this study indicate that the use of nanosilver toothbrushes significantly improves plaque reduction in school-aged children compared with conventional toothbrushes. Supported by evidence from previous studies and consistent clinical plaque reduction outcomes, nanosilver toothbrushes may serve as a complementary approach to routine oral hygiene practices aimed at improving children's oral health. The implication of these findings is that nanosilver toothbrushes may be considered an additional preventive strategy to support plaque control among school-aged children, particularly in populations with varying levels of toothbrushing effectiveness.

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