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MORALITY BEFORE KNOWLEDGE

# Smart candy as a salivary pH indicator for early detection of dental caries risk in children with family-based preventive approach: A literature review

**Zelka Dapala[1],* Yana Nitya Safira[1], Videli Elvaretta[1], Muhammad Dwivo Doprecia[2], Inez Shafa Damhudi[2]**

[1] *Department of Dentistry, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia;*
[2] *Department of Medicine, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia.*

*Correspondence: azelkadapala@gmail.com

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## ABSTRACT

**Background:** Dental caries is a multifactorial pathological condition and highly prevalent non-communicable disease, particularly in children, with significant impacts on health and quality of life. Early detection remains challenging due to invasive, clinic-based methods that are often inaccessible to children. This literature review aims to explore the potential of smart candy as a salivary pH indicator combined with a family-based preventive, offering a child-friendly and community-based strategy to support early caries prevention in alignment with national and global oral health goals. **Methods**: This study utilized a literature review method with the keywords "dental caries in children", "family-based preventive", and "smart candy [MeSH]" to explore databases such as Google Scholar, ScienceDirect, ResearchGate, and NCBI. Inclusion criteria included in vitro and in vivo experimental studies, cohort studies, comparative analysis studies, and reviews published in the last 10 years. Exclusion criteria included incomplete studies, inaccessible papers, and non-English or Indonesian texts. Based on these criteria, 50 references were selected including journals and books for review. **Findings:** Smart candy has shown the effectiveness as salivary pH-indicator tool that facilitates early detection of dental caries risk by providing real-time visual cues based on salivary pH changes. When integrated with a family-based approach, it helps overcome psychosocial barriers and improves adherence to preventive oral health behaviors in children. **Conclusion**: Smart candy is a child-friendly innovation that detects early dental caries through salivary pH-based visual cues, supporting preventive care and empowering families, especially in underserved areas. Despite challenges like regulation and supervision, government-backed community integration could boost its impact and support national and global oral health goals. **Novelty/Originality of this article:** This study explores smart candy as a child-friendly innovation for early caries detection. Combined with family-based prevention, it offers a new approach to reduce dental caries in children.

**KEYWORDS**: dental caries in children; family-based preventive; smart candy [MeSH].

## 1. Introduction

Dental caries is a pathological condition that affects the hard tissues of the teeth, caused by a multifactorial process involving cariogenic bacteria, the host (tooth structure and saliva), dietary substrates (especially fermentable carbohydrates), and time. This prolonged interaction leads to progressive demineralization and breakdown of the tooth's organic

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matrix, eventually resulting in visible cavities and functional impairment (Abadi et al., 2023). Globally, the prevalence of dental caries remains alarmingly high. According to the World Health Organization (WHO), around 60–90% of school-aged children suffer from caries, affecting over 350 million individuals worldwide. In Indonesia, the situation is even more severe. Data from the 2018 National Basic Health Research/*Riset Kesehatan Dasar (Riskesdas)* shows a national dental caries prevalence of 88.8%, with children being the most affected demographic (Ministry of Health of the Republic of Indonesia, 2023). This positions dental caries not only as the most widespread non-communicable disease globally but also as a critical public health concern. In fact, in 2015, WHO identified dental caries as the top condition contributing to the Global Burden of Disease Study.

Despite this overwhelming prevalence, efforts to control and reduce dental caries are hindered by significant limitations in early detection and intervention strategies. Traditional methods such as visual-tactile inspection and radiography are not only dependent on the availability of dental professionals but are often invasive or intimidating, especially for children. This fear factor contributes to low participation in routine oral health checks. A recent study emphasized that delays in dental caries detection are often associated with the lack of accessible and child-friendly diagnostic tools, leading to the progression of untreated lesions and negative psychosocial effects on children’s daily activities (Ruff et al., 2022). Beyond the physical consequences like tooth pain and infection, caries can also disrupt a child’s concentration at school, sleep patterns, and nutritional intake, resulting in decreased quality of life (Fernandez et al., 2024). Studies have shown that children with untreated caries report significantly poorer physical, emotional, and social functioning than the one who has caries-free peers (Susilawati et al., 2023), illustrating that dental health is closely tied to overall child well-being and development.

To address this pressing issue, Indonesia has embraced the global health agenda, particularly the third goal of the 2030 Sustainable Development Goals (SDGs), which aims to ensure healthy lives and promote well-being for all. One of the nation’s responses is the “Caries-Free Indonesia 2030” campaign, a visionary initiative to eliminate dental caries in children through a combination of prevention, early detection, and health promotion. Realizing this goal requires not only systemic support and innovation in dental care but also the development of practical, child-friendly tools that encourage early screening in non-clinical environments such as homes and schools. Studies have shown that early caries intervention significantly improves children's oral health-related quality of life and reduces long-term treatment burdens (Fernandez et al., 2024; Zhang et al., 2022). Additionally, empowering young people to actively participate in health innovation is crucial, as youth play a vital role as agents of change. Through involvement in community-based and sustainable programs, such as smart candy innovations, youth can help bridge the gap between modern dental science and accessible oral health solutions (Huang et al., 2021).

Therefore, this literature review aims to explore the potential of smart candy as a salivary pH indicator in detecting early dental caries risk in children. This review also presents the integration of smart candy and family-based prevention strategies that can improve community-level of oral health as the outcomes. This review is structured as follows: Section 2 outlines the methods of literature selection, Section 3 discusses findings on current diagnostic tools of dental caries, including the concept and efficacy of smart candy, and Section 4 concludes with clinical implications and future directions of the implementation of smart candy.

## 2. Methods

The methodology employed in this literature review involved a literature review using the keywords “dental caries in children,” “family-based preventive,” and “smart candy [MeSH].” The literature search was conducted across multiple scientific databases and search engines, including Google Scholar, ScienceDirect, ResearchGate, and the National Center for Biotechnology Information (NCBI). Inclusion criteria for selected articles encompassed in vitro and in vivo experimental studies, cohort studies, comparative analyses, and review articles, all published within the last ten years.

The exclusion criteria applied in this review included studies that were incomplete at the time of the literature search, studies that were not available in full-text format, and publications written in languages other than English or Indonesian. The selection process began with an initial screening of titles and abstracts to evaluate relevance based on the inclusion and exclusion criteria. Subsequently, full-text articles were reviewed to determine the alignment of the content with the specified keywords and the overall objectives of this literature review. Based on this systematic search and evaluation process, a total of 50 references were selected including journals and book as sources in this study. The following steps are shown in Figure 1.

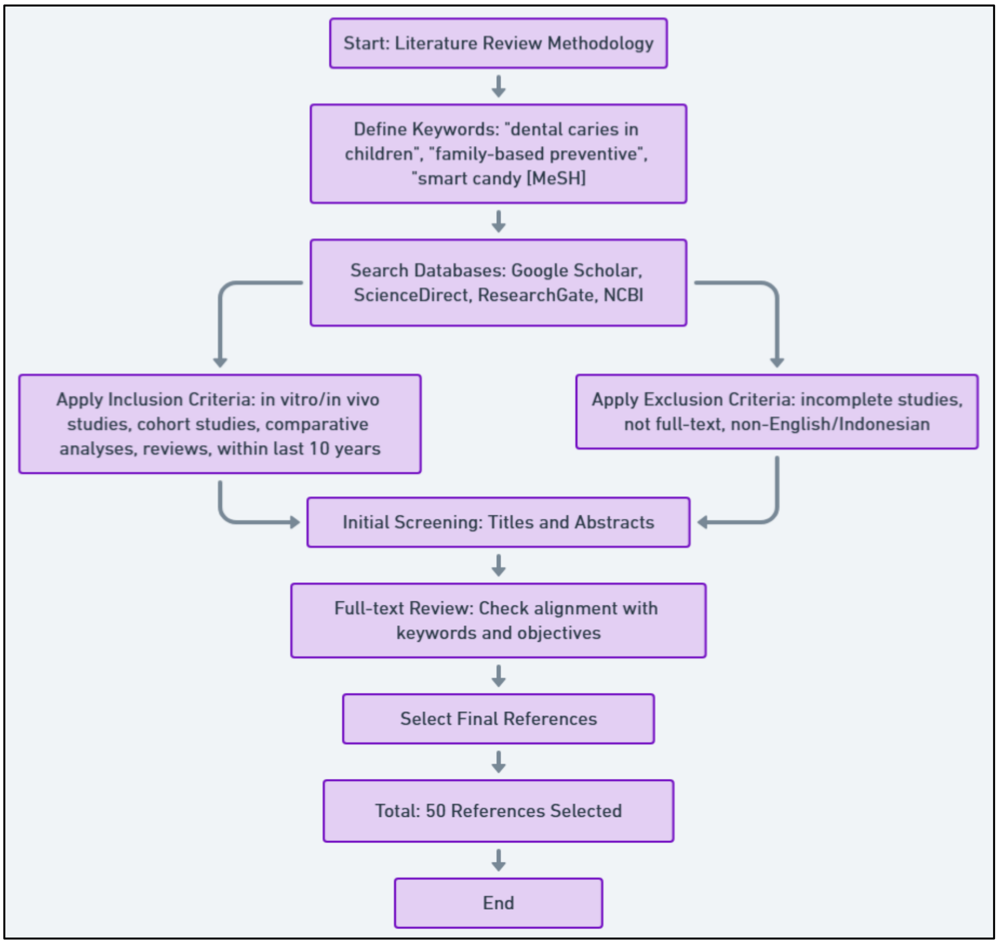

Fig. 1. Flowchart of literature review methodology

## 3. Results and Discussion

### *3.1 Epidemiology and health impact of dental caries in children*

#### *3.1.1 Prevalence and incidence of dental caries in children*

According to the World Health Organization (WHO) survey**,** about 60-90% of children worldwide have dental caries. To be precise, more than 350 million children have caries in primary teeth. According to a report by He et al. (2024), the highest prevalence of caries or cavities in children under 3 years of age was found in the upper central incisor (29.1%) and lower second molar (28.5%). This report also states that dental caries tends to be found more on the occlusal surface of the lower second molar teeth and followed by the deciduous lower first molar.

The situation in Indonesia also shows a very high prevalence. Based on the Basic Health Research/*Riset Kesehatan Dasar (Riskesdas)* in 2018, the national dental caries prevalence reached 88.8% (Ministry of Health of the Republic of Indonesia, 2023). In the early age group, children aged 3-4 years have a DMFT index value of 6.2, while children aged 5 years show a value of 8.1. However, based on the results of the Indonesian Health Survey (IHS) in 2023, there was a slight decrease with a DMFT value of 4.9 for 3-4 year olds and 6.7 for 5 year olds. However, both age groups are still categorized as high to very high DMFT index (Ministry of Health of the Republic of Indonesia, 2023). This shows that caries is still a major health problem among Indonesian young children.

In children aged 12 years and 15 years, based on the 2018 Basic Health Research/*Riset Kesehatan Dasar (Riskesdas)*, the DMFT scores were 1.9 and 2.4, respectively. Based on the results of the Indonesian Health Survey (IHS) in 2023, there was a slight decrease with a DMFT score of 1.3 for 12-year-olds and 2.0 for 15-year-olds. So, it can be concluded that the DMFT index score in 12-year-old and 15-year-old children is smaller than that of children with early age, which means that caries in 12-year-old and 15-year-old children is less than that of 3-4-year-old and 5-year-old children.

### *3.1.2 Impact of dental caries on children's quality of life and public health burden*

Dental caries not only cause cavities and pain but can also interfere with a child's daily activities. Children with caries tend to have a lower quality of life compared to those without dental problems. This condition can affect various aspects of a child's life, ranging from physical activities to psychosocial well-being.

Susilawati et al. (2023) found a significant relationship ($p<0.5$) between caries status and quality of life of elementary school students in Bandung using the chi-square method. The significant relationship between caries status and quality of life indicates that the higher the level of caries, the lower the quality of life in children. Where 50 students had an average def-t score of 4.9 with chi-square test obtained $p=0.019$; 67 students had an average DMF-T score of 2.43 with chi-square test obtained $p=0.037$; pufa score had an average of 4 with chi-square test obtained $p=0.037$; and PUFA score >0 in 63 students with an average score of 2 with chi suare test obtained 0.049.

Apro et al. (2023) analyzed the use of PUFA/pufa index, DMF-T and assessment using CPQ (Child Perception Questionnaire) scores. CPQ describes the impact of caries on a person's psyche (psychometric). The results stated that children with dental caries experience interference in daily activities such as chewing, not wanting to eat so malnutrition, difficulty sleeping, missing school, and disrupting learning concentration. On the emotional side, children look easily upset, embarrassed, and worried about the appearance. Children who experience active caries, will experience disrupting their social life, such as rarely smiling, difficult to talk to, and not wanting to play with their friends so that children become more closed to the surroundings.

Similar findings can be seen from the study of Pan et al. (2025) in Shanghai which examined 1591 of 12-year-old children who collected data on caries, gingival bleeding, and dental calculus. It was found that the main direct impact of caries was to cause pain, decreased masticatory ability, and discomfort while eating so as to avoid eating or chewing using one side. In addition, oral health problems in children are not limited to direct, children tend to miss school more often and not concentrate on learning so that achievement can decrease.

Pakkhesal et al. (2021) using 350 children aged 3-6 years in Iran, evaluated the dmft index so that the average result was $3.94 \pm 4.17$. After that, the child's parents were given a questionnaire using the Early Childhood Oral Health Impact Scale (ECHOIS) regarding the quality of life of children and parents. The mean score of both was $11.88 \pm 6.9$, where $9.36 \pm 5.02$ affected the quality of life of children and $2.52 \pm 3.20$ affected parents. Where the p-value on children is $p=0.05$ and the effect on parents is $p=0.000$. So, it can be concluded that children's oral health has more influence on the quality of life of parents than the children themselves because parents are usually very sensitive to children's health. Quality of life scores increased as the dmft index increased, indicating a positive correlation between caries severity and decreased quality of life for children and parents.

*3.2 About dental caries*

*3.2.1 Definition of dental caries*

Dental caries is a disease characterized by changes in the form of demineralization of hard tissues such as enamel, dentin, and cementum, both in baby teeth and permanent teeth (Warreth, 2023). Fermentation of sugar, especially lactose and sucrose by oral cariogenic bacteria such as *Streptococcus* mutans and *Lactobacilli* causes an increase in lactic acid and other types of acids in the mouth, so that the pH of the oral cavity becomes acidic and at a certain pH range (pH<5.5), enamel is demineralized (Durá-Travé & Gallinas-Victoriano, 2023). Demineralization causes damage and over time can develop into cavities (Rathee & Sapra, 2025). Dental caries is classified as a complex multifactorial disease influenced by the ecosystem in the oral cavity. This condition is the result of interactions between diet, host factors, and oral microbial biofilm activity that over time increase demineralization of the tooth structure (Garg & Garg, 2025; Durá-Travé & Gallinas-Victoriano, 2023).

*3.2.2 Pathogenesis of dental caries*

Dental caries is a chronic, multifactorial, and biofilm-mediated disease that arises from the complex interplay between pathogenic oral microorganisms, frequent consumption of fermentable carbohydrates, particularly dietary sugars, the quantity and quality of saliva, and individual host susceptibility factors such as enamel composition, oral hygiene habits, and systemic health conditions. This disease does not develop instantly but follows a prolonged and cumulative process involving repeated cycles of acid challenge and mineral loss. The progression of dental caries is typically categorized into three primary stages: the initial formation of dental plaque and biofilm on the tooth surface, subsequent demineralization of the enamel structure, and the eventual formation of irreversible carious lesions or cavities.

The first stage begins with the formation of the acquired pellicle, a thin proteinaceous film that forms on the clean enamel surface within minutes of tooth cleaning. Tooth enamel contains negatively charged hydroxyapatite crystals, while the outermost enamel surface holds a slight positive charge. This allows for electrostatic attraction between the enamel and negatively charged salivary glycoproteins. Additionally, hydrophobic interactions contribute to the stabilization of the pellicle layer, which then serves as a substrate for bacterial adhesion. Not all oral bacteria can bind directly to the pellicle; some require bridging molecules, such as calcium ions ($Ca^{2+}$), to facilitate attachment. The initial attachment between bacteria and the pellicle is reversible, as it is governed by weak van der Waals forces and is sensitive to environmental conditions such as pH, temperature, saliva flow, and mechanical force (Fejerskov & Nyvad, 2025; Li et al., 2023).

As bacterial adhesion becomes stronger, the process transitions into irreversible attachment, where specific interactions occur between microbial adhesins and pellicle receptors. Early colonizers, such as *Streptococcus sanguinis* and *Actinomyces* spp., initiate biofilm formation through coaggregation, where other bacterial species adhere to the existing microbial community. This results in a multi-species biofilm, or dental plaque, which can be visibly observed if not removed. Over time, the biofilm matures and produces an extracellular polymeric matrix composed of glucans and fructans, making it more resilient and difficult to remove through mechanical means alone.

The second stage involves demineralization, which begins when acidogenic bacteria ferment dietary sugars and produce organic acids, such as lactic acid. In healthy conditions, saliva plays a buffering role, balancing the cycles of demineralization and remineralization. However, frequent sugar consumption lowers the pH below 5.5, disrupting this balance and causing sustained mineral loss from the enamel. As a result, early carious lesions form, typically seen as white spot lesions on the enamel surface.

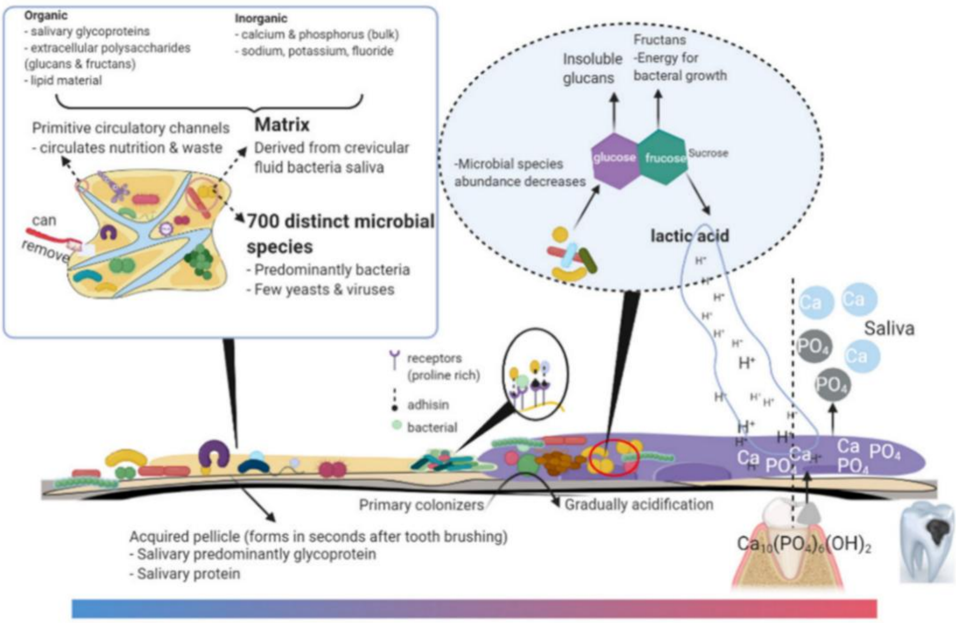


Fig. 2. Pathogenesis of dental caries by cariogenic microbes
(Chen et al., 2021)

If the demineralization process continues without effective remineralization or preventive action, the lesion advances to a stage where the enamel becomes porous, leading to cavitation. Once this occurs, the enamel's protective barrier is compromised, allowing bacteria to infiltrate the underlying dentin. Dentin is softer and contains microscopic tubules that facilitate bacterial progression toward the pulp. This can result in pulpitis and, if left untreated, may lead to pulp necrosis, periapical abscesses, and even systemic infection. Early identification and timely intervention are therefore essential to prevent irreversible structural damage and to preserve long-term oral health and functionality (Rathee & Sapra, 2025; Fejerskov & Nyvad, 2025). The pathogenesis scheme of dental caries can be seen in Figure 2 and Figure 3.

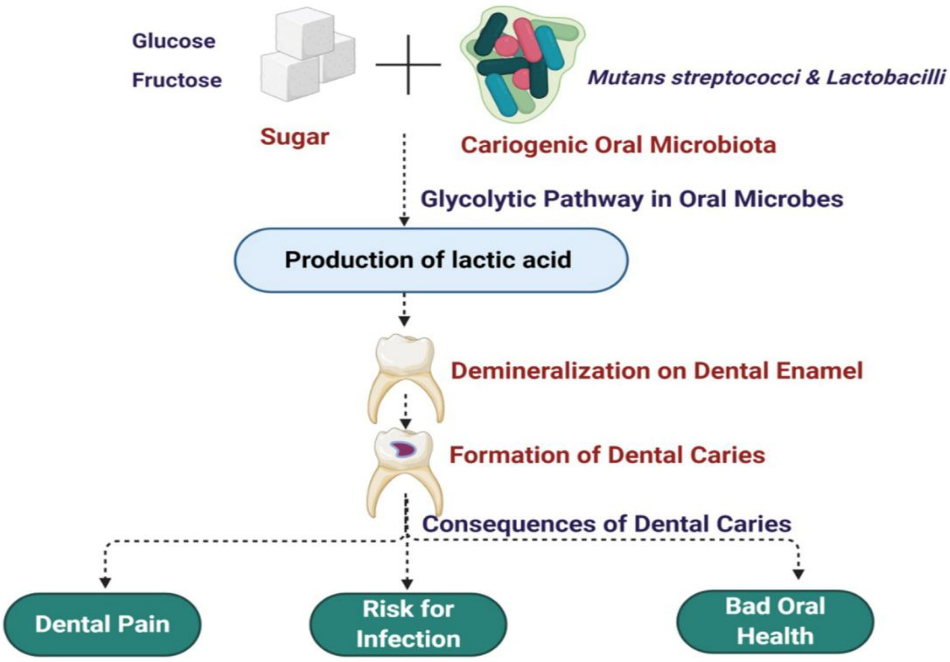


Fig. 3. Pathogenesis of dental caries workflow

(Gasmi Benahmed et al., 2021)

### *3.2.3 The role of salivary pH in dental caries*

At the pathogenesis stage, demineralization does not necessarily cause harm if it is balanced by remineralization. This balance can be maintained when the pH remains at a normal level (around pH 7.4), allowing saliva and oral fluids to remain supersaturated with hydroxyapatite and fluorapatite (Fejerskov & Nyvad, 2025). The pH level plays a crucial role in regulating this equilibrium. As pH decreases, oral fluids lose the supersaturation with hydroxyapatite, and once the critical pH level (pH <5.5) is reached, it will become only saturated. In low-pH environments, the solubility of apatite minerals rises significantly, compromising the stability. Consequently, increased acidity can lead to the initiation of mineral loss, lesion development, and dental erosion (Fejerskov & Nyvad, 2025).

Saliva does not only play a role in tooth remineralization. Saliva consists of various types of minerals, proteins, and other materials. The main substance of saliva is water. Because it is composed of large amounts of water, saliva also plays a role in maintaining dental health by cleaning the mouth from various types of food residue, sugar, acid, and microorganisms. Saliva contains mucin proteins that act as antimicrobials and nutritional source. Saliva also functions as a buffer fluid. This function exists in saliva because saliva contains bicarbonate ions, phosphates, and various types of buffer proteins. Each function of saliva aims to maintain homeostasis of the oral environment (Fejerskov & Nyvad, 2025).

The acid-base balance in oral fluids is influenced by various types of ions, one of which is hydrogen. Hydrogen in the oral cavity can be a derivative of organic and inorganic acids in oral fluids, acids resulting from bacterial fermentation of carbohydrates, and acids obtained directly from the diet. Acids that appear in the oral environment will be cleaned and balanced by salivary buffer fluids. The ability of saliva to maintain this acid-base balance is called the salivary buffer capacity (Fejerskov & Nyvad, 2025).

Primarily, salivary pH is influenced by three types of buffer systems. First, the bicarbonate buffer system. The bicarbonate buffer is the system that makes up the largest buffer capacity of saliva. At pH 6, 90% of the stimulated salivary buffer capacity and 50% of the unstimulated salivary buffer capacity come from the bicarbonate buffer system. Bicarbonate ions play a role in binding hydrogen ions, this reaction will produce carbonic acid which will then be broken down by carbonic anhydrase in saliva into water and carbon dioxide (Fejerskov & Nyvad, 2025).

The second buffer system is phosphate. The phosphate buffer capacity is at its maximum in the pH range of 6-8. The phosphate buffer system has different reactions under certain pH conditions. At pH 6-7.5, phosphate appears as $H_2PO_4^-$, $H_3PO_4$ at acidic pH (pH 0-4), and $HPO_4$ and $PO_4$ at pH above 8. Finally, the protein buffer system. Protein buffers contribute when the pH is below the critical value or below pH 5. At acidic pH, various types of proteins increase the viscosity of saliva and become a blanket that protects teeth from the acidic environment. Protein also plays a role in increasing salivary pH. In this function, sialin synthesized by the salivary glands will stimulate oral bacteria to produce bases such as ammonia and carbon dioxide, which have the effect of increasing salivary pH (Fejerskov & Nyvad, 2025).

The acid-base balance of salivary pH is key to maintaining dental health. Caries can occur when the pH of saliva and oral fluids is in an acidic or low pH condition. If this condition persists for a prolonged period without sufficient compensation from the buffer system or salivary clearance, the mineral balance will shift toward demineralization, leading to structural damage of the tooth and, ultimately, the formation of irreversible caries lesions. Therefore, stabilizing salivary pH is essential in preventing early enamel breakdown and halting the progression of carious lesions. Incorporating routine pH monitoring and preventive strategies into oral health practices can significantly contribute to long-term dental preservation. The detail related the role of salivary will be seen in Figure 4.

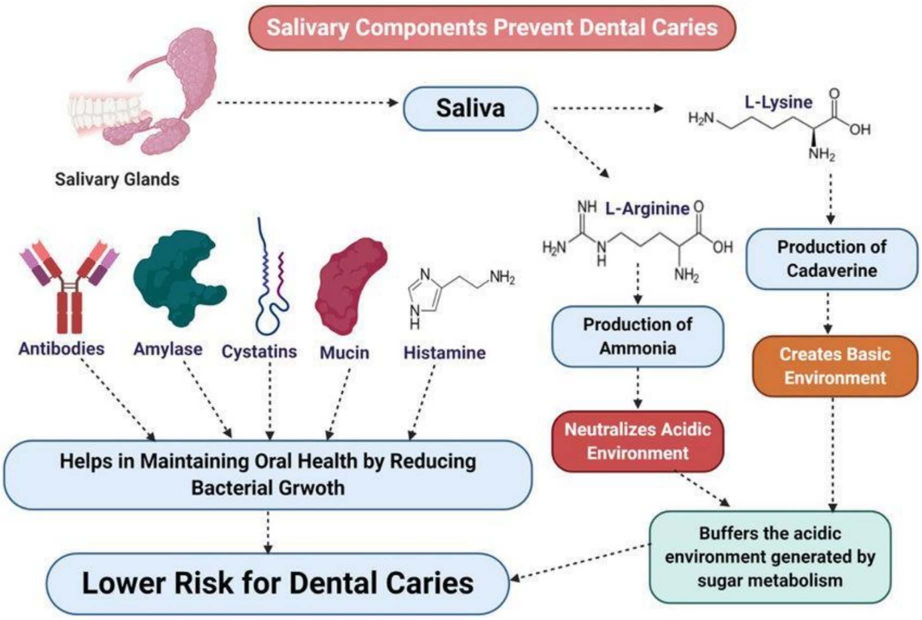


Fig. 4. The role of salivary components and salivary buffer system in dental caries prevention (Gasmi Benahmed et al., 2021)

### *3.3 Detection methods of dental caries*

To better understand the positioning of smart candy within the broader diagnostic landscape, a comparative overview of existing early caries detection tools is presented. This includes visual inspection, radiographic examination, fluorescence and laser-based technologies, and saliva pH sensor technolgy. Each method offers distinct advantages and limitations in terms of accuracy, invasiveness, cost, and feasibility for community-based or pediatric use. The following table summarizes key features of these diagnostic approaches.

Table 1. Number of receptors in each container

| Detection methods | Advantages | Limitations |
|---|---|---|
| Visual inspection | • Simple, low-cost, and non-invasive method;<br>• Lab accuracy equals for early-stage caries detection;<br>• Highest sensitivity and lowest specificity shown. | • Inconsistent interpretation of carious lesion features;<br>• No meta-analysis on early lesion visual diagnosis;<br>• Limited reach on subgingival proximal surfaces. |
| Radiographic examination | • Assesses progression and interproximal or occlusal surfaces;<br>• Shows characteristic patterns of specific caries types;<br>• High accuracy for interproximal caries in primary and permanent teeth. | • Cannot distinguish cavitated and non-cavitated lesions;<br>• Fails to detect early caries or remineralization changes;<br>• Low sensitivity for detecting dentin caries. |
| Fluorescence and laser-based technologies | • Detects subtle changes in tooth structure from early demineralization;<br>• Higher sensitivity and accuracy in early-stage caries detection;<br>• Useful in preventive dentistry for children. | • High rate of false positives Influenced by external factors;<br>• No universal threshold standard. |
| Saliva pH sensor technology | • Practical, non-invasive, and low-cost, and suitable for home use; | • The results may fluctuate due to factors such as diet, hormonal changes, and time of day; |

| | | |
|---|---|---|
| | • The results are immediately observable through a color change;<br>• It enables early detection of caries risk before significant damage occurs by monitoring salivary pH levels. | • Sensitivity and specificity of this method are lower compared to standard laboratory tests. |

(Thanh et al., 2021; Blumer et. al, 2023; Ghodasra et al., 2022; Tashkandi et al., 2025; Zhang et al., 2024; Mahajan et al., 2023; Matzeu et al., 2021; Choudhary et al., 2022)

### *3.3.1 Visual inspection*

Initial examination is the most common and frequently used method, especially due to its convenience, low cost, and non-intrusiveness. This method is carried out by using direct observation of the tooth surface with the unaided eye or using aids such as a dental mirror and lighting. Previous studies have shown that visual examination is quite good at detecting caries that have formed cavities, especially on the occlusal surface of posterior teeth. It has a sensitivity of about 80% and a specificity of 75% (Thanh et al., 2021). The method will be seen in Figure 5.

Fig. 5. Visual study of an 8-year-old child with several carious lesions (Schulz-Weidner et al., 2024)

The reliability of this method is highly dependent on the skill and experience of the clinician, so subjective interpretation is possible. Besides, there are significant limitations in detecting non-cavitated lesions, secondary caries hidden under restorations, and lesions in areas that are difficult to reach visually, such as proximal surfaces and subgingival areas. Limited access and lighting make caries detection in these locations suboptimal. Blumer et al. (2023) stated that these limitations may result in many cases of early caries being inadequately identified.

The accuracy of visual inspection in children can be affected by several additional variables. Enamel hypomineralization, food stains, and poor oral hygiene habits, for example, can mask early carious lesions, leading to a misdiagnosis. Enamel hypomineralization, such as molar-incisor hypomineralization (MIH), can make it difficult to identify early caries. Typically, this disorder is characterized by discoloration of the tooth enamel, ranging from opaque white to brownish-yellow spots. These changes resemble carious lesions, which can lead to a misdiagnosis. This is in line with previous studies that have suggested an association between MIH and increased caries susceptibility in children, especially due to the complexity of the early identification process and its clinical management (Pacheco Jiménez et al., 2023). In addition, the child's level of cooperation is also an important factor. Preschool children or those with special needs often have difficulty cooperating when asked to open the mouths for a long time or to remain still during the examination, which can result in decreased accuracy in observation. Therefore, although this method is still widely used, visual examination is considered not effective enough as a single screening tool to detect caries early in children.

*3.3.2 Radiographic examination*

Intraoral radiographic examinations, such as bitewing and periapical, play an important role in evaluating the internal structure of the teeth and detecting caries that are not clinically visible, especially in the interproximal and subgingival areas. Compared to visual methods, radiography offers advantages in documentation and longitudinal evaluation because the images can be stored and analyzed by different assessors at different times. The method will be seen in Figure 6.

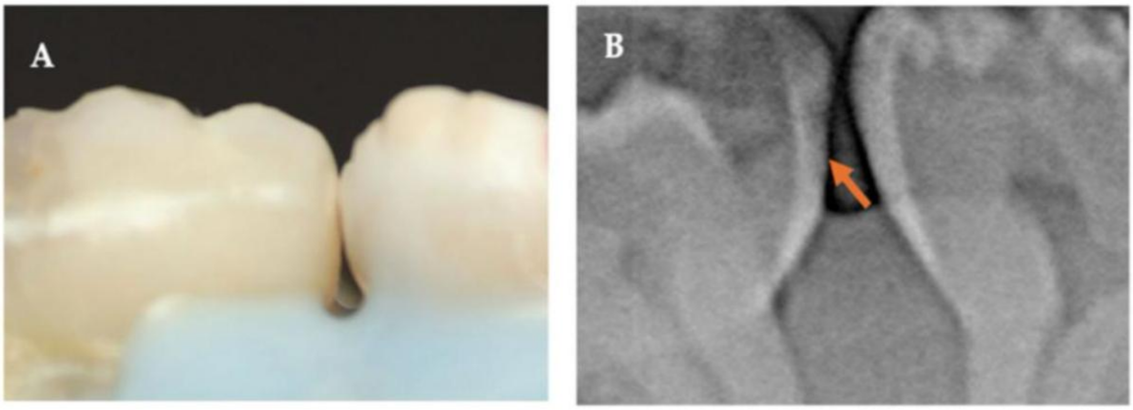


Fig. 6. Bitewing radiography revealed an artificial caries lesion
(Tashkandi et al., 2025)

The effectiveness of this method in the context of community screening, especially in children, is still limited. The USPSTF report shows that anterior teeth, especially maxillary central incisors, are often not optimally recorded, making it difficult to detect caries in this area. In addition, lesions that are still limited to enamel are often not visible on radiographic images (Barry et al., 2023). This is supported by the StatPearls report (Ghodasra et al., 2022), which notes that the sensitivity of radiography in detecting early enamel caries is even less than 50%, depending on the depth and location of the lesion. Radiography has low sensitivity in detecting early caries lesions limited to enamel. Lesions must reach a minimum depth of about 500 µm to be detected radiographically or when penetrate the depth of dentin. Coupled with the risk of X-ray exposure in children, as well as the need for high cooperation when taking images, it adds to the challenges. Hence, although radiography is useful in clinical practice, its technical and diagnostic limitations make it less than ideal for use as a mass screening tool at the community level.

*3.3.3 Fluorescence and laser technologies*

Technological advancements in the field of dental diagnostics have introduced a range of innovative tools designed to enhance the early detection and monitoring of dental caries. Among these, devices such as DIAGNOdent which utilizes laser fluorescence with Quantitative Light-Induced Fluorescence (QLF), and LED-based intraoral cameras like VistaCam represent significant breakthroughs. These diagnostic instruments are specifically developed to improve the sensitivity and accuracy of caries detection, particularly in the initial stages where lesions are not yet visible through traditional clinical examination. By employing fluorescence-based detection techniques, these tools are capable of identifying subtle changes in tooth structure caused by early demineralization. The underlying principle involves detecting alterations in fluorescence that occur as a result of mineral loss in the enamel or dentin, which are indicative of the early stages of caries development. Compared to conventional diagnostic approaches such as tactile probing and radiographic imaging. These advanced technologies provide superior visualization, allowing clinicians to identify and monitor caries progression with greater precision and less invasiveness. Moreover, children's ability to support real-time, non-destructive evaluation makes children particularly valuable in preventive and minimally invasive dentistry, where early intervention is key. Overall, these diagnostic innovations contribute significantly to the advancement of personalized and proactive dental care, offering enhanced outcomes for both patients and practitioners. The example will be seen in Figure 7.

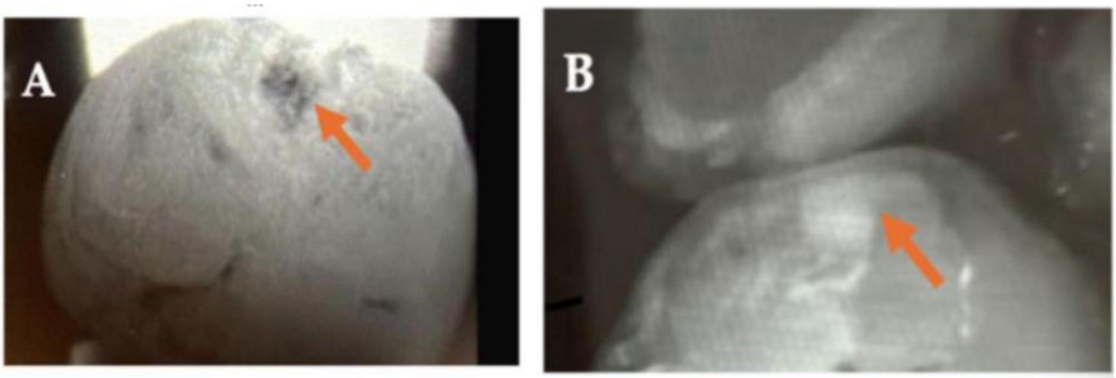


Fig. 7. (a) DIAGNOdent; (b) iTero element 5D
(Tashkandi et al., 2025)

On the other hand, the effectiveness of this technology still faces several obstacles. One of the main limitations of the use of fluorescence-based caries detection tools is the high rate of false-positive results. This is due to the system's inability to accurately distinguish between active lesions and lesions that have undergone remineralization or other structural changes that do not require clinical intervention (Zhang et al., 2024). Lesions that do not require invasive treatment are often detected as pathological, risking over-treatment or unnecessary restorative actions. Interference from external factors such as plaque, food coloring, and inactive caries lesions can also interfere with the accuracy of the reading, increasing the risk of overdiagnosis.

Another major challenge in the use of fluorescence technology is the absence of a universally applicable threshold value standard in clinical practice. Interpretation of test results varies widely across populations, patient age, and caries location, making it difficult to develop evidence-based clinical decision-making guidelines. Previous studies have shown that the threshold values recommended by the DIAGNOdent manufacturer are not always consistent and need to be re-evaluated based on specific conditions, such as caries location and tooth surface type (Mahajan et al., 2023). For example, the optimal threshold value for caries detection on the occlusal surface of permanent teeth will differ from that required for root surfaces or primary teeth. This emphasizes the need to adjust the threshold value according to the specific clinical context.

In addition to technical aspects, limitations also arise in practical aspects, especially in its application to the pediatric population. Exposure to bright light, unfamiliar-looking tools, and quite intense instrument sounds can cause fear or discomfort, which ultimately interferes with cooperation during the examination. Several methods have been developed to reduce fear in patients, especially children, but some side effects have also been seen. This is supported by findings highlighting that the use of virtual reality in the management of dental phobia in children can cause side effects such as nausea and discomfort, which can hinder the acceptance of this technology by young patients (Gilboa Pras et al., 2024). Furthermore, the relatively high cost and the need for operator training make this high-tech caries detection technology less suitable as a screening tool at the community or household level.

*3.3.4 Saliva pH sensor technology*

Tracking salivary pH is an important non-invasive method for determining the possible emergence of caries teeth. The observation was done on 100 children aged between 6 and 12 years in Shahpura Tehsil, Jaipur, to evaluate the connection between the prevalence of carious teeth and salivary pH. pH is measured electrochemically with a portable pH meter. The results indicated that children with lower salivary pH (around 6.0–6.4) had higher caries rates compared to those with closer to neutral pH (Choudhary et al., 2022). These findings underline that salivary pH monitoring, although simple and non-invasive, has clinical value as an indicator of caries risk, especially in children, and can be utilized in screening and prevention efforts. The scheme will be seen in Figure 8.

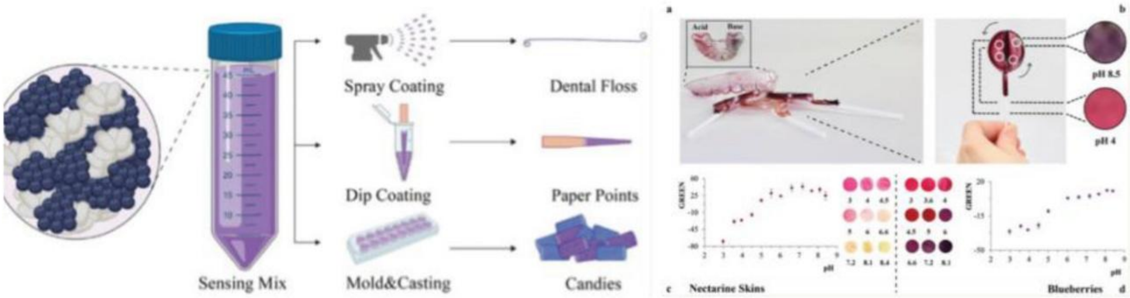


Fig. 8. Schematic of the manufacture of a silk fibroin-based pH sensor device (Matzeu et al., 2021)

The development of a shape-adaptable oral interface to assess oral pH is one of the latest innovations in this technology. Matzeu et al. (2021) created a device that combines bioactive materials and colorimetric chemical sensors into commonly used oral devices, such as dental floss and lollipops. This device has the ability to visually detect changes in pH by changing its color by sending visual signals. This low-cost and easy-to-use device allows early detection of caries and provides an immediate response to changes in the pH of biological fluids.

*3.4 Smart candy*

*3.4.1 Concept of smart candy*

Smart candy is an innovative confectionery product specifically designed to monitor salivary pH levels using natural pigments that undergo visible color changes in response to varying degrees of acidity. As a pH-sensitive detector, this product provides a simple and practical approach to the early detection and prevention of dental caries, especially in children (Latiff et al., 2025). The mechanism is based on detecting the acidity of saliva and reflecting it through an observable color shift. Normal unstimulated salivary pH typically ranges between 6.2 and 7.6, with an average of 6.8. When the pH drops below 6.5, it may signal a heightened risk of enamel demineralization, an early indicator of tooth decay (Bhattacharya et al., 2023). This immediate visual feedback offers a valuable opportunity to identify and respond to harmful oral health conditions before it become severe.

To optimize safety and functionality, smart candy is formulated with non-cariogenic sweeteners such as xylitol and sorbitol, which are known not to contribute to the development of cavities. It also incorporates elastic structural components like gelatin and starch, which help the candy maintain its form and function during consumption. By combining the appeal of a sweet treat with the utility of a diagnostic device, smart candy presents a dual-purpose solution that is both engaging and educational. The candy's enjoyable and familiar format encourages greater participation among children, helping to reduce resistance to oral health monitoring. Moreover, it serves as a gateway for educating children and caregivers about the importance of maintaining oral hygiene from an early age.

Smart candy's interactive and child-friendly design makes it well-suited for a variety of settings, including home routines, school health initiatives, and broader community dental programs. Its affordability and ease of use allow it to be integrated into low-resource settings where access to clinical dental tools may be limited. As a result, smart candy not only serves as a preventive tool but also supports health education and awareness-building efforts. By turning oral health monitoring into a fun, sensory experience, it encourages proactive behavior and empowers families to take part in the children's dental care. Look Figure 9 to understand the specification.

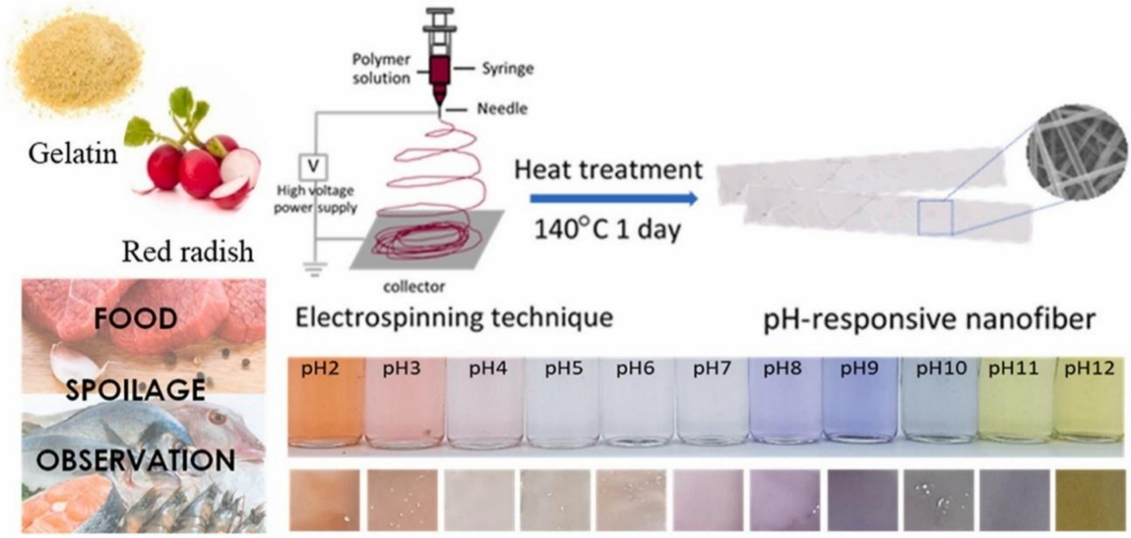


Fig. 9. Smart candy specification
(Chayavanich et al., 2023)

The most essential component enabling pH detection in smart candy is the natural pigment anthocyanin. As described by Solmali Dhal (2023), anthocyanins are organic compounds that exhibit a broad range of colors, typically shifting from red to purple depending on the pH of the environment. These pigments are inherently pH-sensitive, making it particularly effective for monitoring the acidity or alkalinity of human saliva. In acidic conditions, anthocyanins exhibit a red coloration, whereas under alkaline conditions, pigments transition to blue or may even appear colorless. This responsiveness makes anthocyanins ideal for real-time pH monitoring through visual cues, which is especially valuable for child-focused health applications that prioritize simplicity, safety, and engagement.

The color transformation of anthocyanins results from structural changes in the molecular configuration at various pH levels. When the pH level drops below 3, anthocyanins assume a flavylium cation form, resulting in a bright red hue. In the pH range of 4 to 6, pigments transition into a hemiketal structure, producing a purple color. When the pH level rises to the typical healthy salivary range of 7 to 8, the pigment forms a quinoidal base, which imparts a blue hue. Beyond a pH of 9, anthocyanins adopt a chalcone structure, resulting in a yellowish-green appearance. These shifts occur without the need for any external chemical reagents or instruments, allowing users to observe changes in salivary pH directly during the consumption of the candy.

This distinct color-changing capability allows smart candy to operate as a visually intuitive and interactive oral health tool, particularly effective for children. As a "candy sensor," it offers an engaging way to help users monitor oral conditions in real time. The immediate color feedback can alert users or caregivers to suboptimal oral pH levels, which may be associated with the early stages of enamel demineralization and cavity formation. This visual cue system not only encourages prompt behavioral responses, such as brushing or reducing sugar intake, but also provides an accessible entry point for introducing concepts of oral health and hygiene to children in both educational and clinical contexts.

Furthermore, the playful and sensory nature of smart candy contributes to higher compliance among pediatric users, who might otherwise resist conventional oral health tools like pH strips or saliva test kits. By combining functionality with familiarity, smart candy enhances participation in preventive health behaviors while also supporting structured oral health education efforts. It is particularly suitable for implementation in school health programs, at-home care routines, and community dental outreach initiatives. With its science-based foundation and user-friendly application, smart candy holds promise as a supportive innovation in public oral health strategies focused on early prevention and education. The detail related to the workflow will be seen in Figure 10.

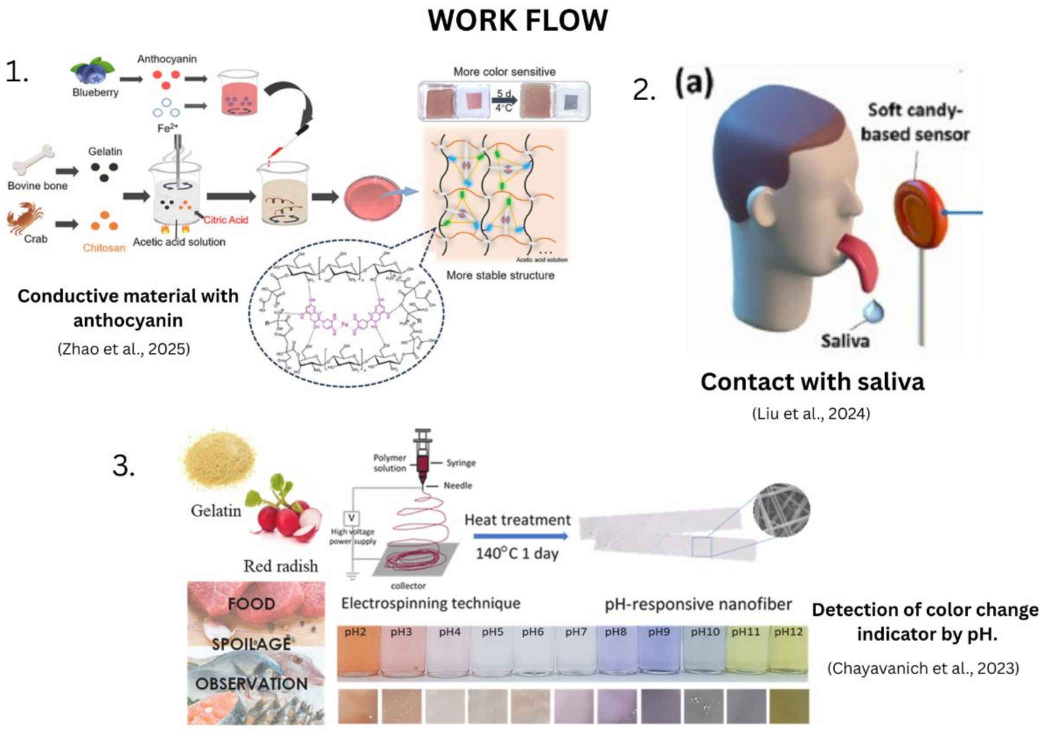


Fig. 10. Smart candy workflow
(Chayavanich et al., 2023; Liu et al., 2024; Zhao et al., 2025)

### *3.4.2 Effectiveness of smart candy*

Smart candy represents a novel innovation in the field of edible sensors, specifically designed for pediatric use in oral health monitoring. It offers a non-invasive, visually engaging method to assess salivary pH levels through noticeable color changes, eliminating the need for complex or potentially hazardous procedures. Its simplicity allows for independent use at home or in schools without the involvement of medical professionals or expensive equipment, making it a cost-effective and accessible solution for early cavity detection. Children are more receptive to familiar and playful forms of examination, such as colorful and flavorful candy, as opposed to traditional methods like saliva strips or electronic devices. This acceptability facilitates early intervention efforts and enhances children's willingness to participate in preventive health measures. Furthermore, smart candy serves as both a monitoring tool and an educational medium, promoting awareness of oral hygiene habits from an early age through a sensory and experiential approach. Its practicality and affordability make it an ideal candidate for integration into community-based dental health initiatives and family-centered care strategies.

The functionality of smart candy is closely linked to the sharpness, clarity, and stability of the color change response, which can be observed with the naked eye during consumption. This visual transformation is driven by anthocyanins, pH-sensitive, water-soluble pigments derived from natural sources such as fruits and vegetables. Anthocyanins exhibit strong thermal and photostability and demonstrate distinct color shifts across various pH levels due to structural modifications of the molecular forms. For instance, at acidic pH levels, pigments appear red due to the flavylium cation structure; at neutral pH, pigments shift to purple or blue due to the formation of hemiketal or quinoidal base structures (Gamage & Choo, 2023). These properties ensure that the candy's effectiveness remains intact during real-time interaction with saliva. The visible color change not only signals the acidity level of the mouth environment but also acts as a visual cue for users, especially children and caregivers to take appropriate preventive measures when low pH is detected, indicating increased risk of enamel demineralization.

The primary ingredient in smart candy, anthocyanin, is typically extracted from berries and other naturally sweet fruits. These ingredients are not only safe and palatable but also rich in nutritional and structural complexity that supports the intended colorimetric function. Structurally, anthocyanins are glycosylated forms of anthocyanidins, belonging to the flavonoid family, and are often conjugated with sugar molecules such as glucose, galactose, or rhamnose. Many anthocyanins are further stabilized by acyl groups or organic acids like malonic, tartaric, and malic acids, enhancing pigment durability and consistency (Serrano et al., 2024). Importantly, the natural sweetness of the fruit-based ingredients may reduce the need for artificial sweeteners, improving product safety and acceptability. By combining health functionality with sensory appeal, smart candy can be a transformative tool in public health, particularly in areas with limited access to conventional dental care. Although it is not intended to replace professional medical interventions, it significantly strengthens the effectiveness of promotive and preventive oral health programs targeted at children, contributing to broader efforts in community health promotion and behavioral change.

*3.4.3 Safety of smart candy*

Smart candy is consistently formulated using edible, child-safe ingredients to ensure both safety and functionality. Its development process involves strict attention to several key factors, such as the product must be non-cariogenic, have a safe oral texture, maintain appropriate glucose levels, and be free from common allergens and toxic compounds. The use of gelatin-based materials helps to provide a soft, elastic texture that dissolves quickly, reducing the risk of choking and making it safe for pediatric use. To ensure its reliability, smart candy must undergo a range of tests, including pH and color stability, shelf life evaluations, and oral toxicology testing either sub-chronic or acute. These tests are essential for confirming the product's safety for long-term use, particularly among children who represent its primary target group (Saini et al., 2024).

The key active ingredient responsible for smart candy's pH-detection ability is anthocyanin, a natural pigment derived from various fruits and vegetables. Common sources include berries, concord grapes, pomegranates, eggplants, red cabbage, black carrots, purple cauliflower, and purple sweet potatoes, along with certain pigmented grains. These anthocyanin-rich sources are known not only for the vivid coloration but also for the antioxidant and anti-inflammatory benefits, which enhance the suitability for use in consumable health products. Anthocyanins change color in response to pH variations, providing a natural, visual indicator of acidity levels in the mouth without the need for artificial colorants or reagents.

To deliver these natural pigments effectively, smart candy typically incorporates carrier substances such as gelatin, chitosan, or cellulose materials proven to be safe and stable for consumption. For example, gelatin-based films infused with anthocyanins from hibiscus (roselle) have demonstrated effective and visible color transitions while preserving ingestion safety (Ke et al., 2024). These formulations ensure that the candy remains both palatable and functional during use.

In combining health education with rigorous safety standards, smart candy stands out as a preventive oral health tool that is both engaging and reliable. Though designed with safety-by-design principles, clinical guidance and parental supervision remain essential in real-world applications to avoid unintended misuse and ensure its proper role in child health monitoring.

*3.4.4 FDA approved smart candy for dental health screening*

Currently, no smart candy product has been officially approved by the Food and Drug Administration (FDA) as a medical device for oral health assessment. However, its concept aligns with the principles of non-invasive oral diagnostic tools like pH indicator strips and intraoral biosensors which have received FDA approval as medical devices.

Although not yet categorized as a medical device, the active components in smart candy, such as natural pigments and non-cariogenic sweeteners have been extensively studied and are considered safe for consumption. One of its main ingredients, anthocyanin, a pigment found in red to purple fruits and vegetables, is classified by the FDA as Generally Recognized As Safe (GRAS). Additionally, pH-modifying substances used in similar applications are recognized as safe when used within toxicological and hygienic limits.

In this regard, using natural indicators like anthocyanins to detect oral pH is considered viable, as long as it does not trigger toxic, allergic, or digestive side effects, especially in children. While smart candy has not yet obtained diagnostic approval, its safe composition and mechanism of action show strong potential for use as a promotive and preventive tool in public health efforts, particularly when based on FDA-recognized ingredients.

*3.5 Smart candy sensor with involving family-based prevention as early detection of dental caries in children*

According to Zahara et al. (2023), enamel demineralization begins at a salivary pH of ≤ 5.5, accelerating the caries process in an acidic oral environment by disrupting calcium and phosphate balance. Early detection of this condition is essential to prevent damage. Zhao et al. (2022) demonstrated that anthocyanins natural pigments found in fruits and vegetables change color with pH levels, making it effective as visual pH indicators (e.g., red in acidic, pink in neutral, and blue in alkaline conditions). This principle can be applied to smart candy by incorporating anthocyanin-rich extracts like purple cabbage or bay flower, allowing the candy to change color when salivary pH drops below the critical level, signaling caries risk.

Marlindayanti et al. (2022) found that senduduk fruit (*Melastoma malabathricum L.*), rich in anthocyanins, can indicate acidic dental plaque, making it suitable for early caries detection. A follow-up study (Marlindayanti et al., 2024) involved mothers in Pipa Putih Village trained to make smart candy from senduduk fruit, which not only detects acidic plaque but may also help inhibit *Streptococcus mutans*, a key caries-causing bacteria.

If smart candy indicates low pH through a color change, it serves as an early warning, prompting timely dental check-ups. This supports the concept of Minimal Intervention Dentistry (MID), emphasizing prevention and early detection. When implemented in family settings, especially through caregiver involvement, smart candy can promote family-based oral health prevention, empowering parents to monitor and respond to early caries risk at home.

*3.6 Clinical implication*

Smart candy can be implemented as a promotive and preventive plan in the family. Smart candy has a shape that is favorable and attractive to children, children will be more interested in trying this smart candy method than using conventional detection methods that use dental tools. Parents have a very important role in supervising and observing the results. In the clinical aspect, smart candy can be used as a screening tool or early detection of caries risk in children. Dentists can recommend the use of this candy during monitoring in children with high caries risk and before visits to the dentist to monitor salivary pH independently. Thus, this approach supports the principles of *Minimal Intervention Dentistry*

(MID), which is prevention and early management without waiting for tooth decay to become severe.

Smart candy can also potentially be used in dental health education programs in schools and posyandu. Color changes provide good education visually to children and parents about maintaining a neutral oral pH so that teeth are not susceptible to caries. Smart candy has the potential as an early detection tool for salivary pH that is acidic and potentially carious. With a family approach, children can be motivated to maintain dental health from an early age and parents can supervise during the process.

## 4. Conclusions

Smart Candy presents a promising, child-friendly innovation for early caries detection through simple visual cues based on salivary pH levels. Its use of anthocyanin-rich natural ingredients offers a safe, engaging, and cost-effective method for monitoring oral acidity for making it highly suitable for family-based preventive care. Seeveral studies reinforce the feasibility of this approach, especially when combined with community training and education. While further clinical validation is needed, smart candy supports the goals of minimal intervention dentistry by enabling early detection and empowering families to take proactive steps in oral health care. As an accessible home-based tool, smart candy has the potential to bridge gaps in preventive dental services, especially for children in underserved communities.

Smart candy faces challenges such as the absence of FDA approval, variability in pH interpretation, and the risk of misuse without adult supervision. To overcome these, cooperation from whole layers of society, especially government, is needed in order to impelement the system into community programs with parental guidance that can enhance its reliability and impact as a safe, accessible, and preventive oral health tool. It's also a step toward a global movement to reach the third point of SDGs and the goal of Caries-Free Indonesia in 2030.

Future research should include pilot studies in school and community-based settings to evaluate the feasibility, user compliance, and diagnostic accuracy of smart candy in real-world contexts. Additionally, regulatory assessment and approval processes will be critical to ensure its safety, efficacy, and standardization prior to widespread implementation. These steps are pivotal for integrating smart candy into structured and evidence-based preventive oral health programs.

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## Author Contribution

Conceptualization, Z.D. and Y.N.S; Methodology, Z.D.; Resources, Y.N.S., V.E., M.D.D., I.S.D.; Writing – Original Draft Preparation, Z.D., Y.N.S., V.E., M.D.D., I.S.D.; Writing – Review & Editing, Z.D., Y.N.S., V.E., M.D.D., I.S.D.; Visualization, Z.D. and Y.N.S.; Project Administration, Z.D.

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Not available.

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The authors declare no conflict of interest.

### Declaration of Generative AI Use
During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

### Open Access


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## Biographies of Authors

**Zelka Dapala,** Department of Dentistry, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia.

- Email: azelkadapala@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

**Yana Nitya Safira,** Department of Dentistry, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia.

- Email: yananitya@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

**Videli Elvaretta,** Department of Dentistry, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia.

- Email: yananitya@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

**Muhammad Dwivo Doprecia,** Department of Medicine, Faculty of Medicine, Universitas Sriwijaya, Palembang, 30114, Indonesia.

- Email: dwivodoprecia@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

**Inez Shafa Damhudi,** Department of Medicine, Faculty of Medicine, Universitas Sriwijaya, Palembang, South Sumatera 30114, Indonesia.

- Email: inezshafadamhudi@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A