

# Long-term Effectiveness of Integrated Caries Preventive Programs in Thailand Among Preschool Children Using a System Dynamics Model

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**Objective:** To compare the effect of three caries preventive interventions provided by Thailand’s Ministry of Public Health (MOPH): supervised toothbrushing (STB), fluoride varnish (FV), and combined STB+FV from 0 to 5 years old to the base case using the System Dynamics Model (SDM). **Methods:** The SDM was developed to compare the intervention scenarios: STB, FV, and combined STB+FV with the base case scenario. Meta-analyses determined the effective rates of the interventions included in the model. **Results:** The model indicated that the population with no caries in deciduous teeth increased by 7.5%, 5.7%, and 4.2% at three years of age, and 12.8%, 9.9%, and 5.9% at five years of age, under STB+FV, STB, and FV respectively when compared to the base case. At three years old, the population with untreated caries in deciduous teeth decreased by 12.9% in STB+FV, 9.8% in STB, and 7.3% in FV, and by 10.9% in STB+FV, 8.5% in STB, and 4.9% in FV, at five years old. The increase in the population without caries is considered clinically significant compared to baseline. **Conclusion:** The model determined that an effective combination of STB and FV should be administered between 0 and 5 years of age to reduce caries in the primary dentition. The SDM could be applied as a “what-if” analysis in order to determine the most beneficial intervention or policy by comparing them.

**Keywords:** Fluoride varnish, Caries, Toothbrushing, System Dynamics Model

## Introduction

Dental caries is the most common oral illness, with a global disease burden of 514 million primary teeth and 2 billion permanent teeth (World Health Organization, 2023). According to the 8th National Oral Health Survey (Bureau of Dental Health, 2018), the prevalence of dental caries in Thailand’s primary dentition at three and five years old was 52.9% and 75.6%, respectively, and in the permanent dentition at 12 years old was 52.0%. Children who had caries in their primary teeth were more likely to develop caries in their permanent teeth (Motohashi *et al.*, 2006). Furthermore, dental caries was the leading cause of extraction (Al-Shammari *et al.*, 2006). Loss of primary teeth before the permanent teeth erupt, may result in delayed eruption and malocclusion with functional or aesthetic difficulties (Olatosi *et al.*, 2012). Furthermore, there is an impact on children’s growth and development. Therefore, limiting caries in primary teeth is crucial for the health of children.

Poor awareness of oral hygiene and caries, as well as limited access to preventive oral health programs contribute to high caries prevalence (Petersen *et al.*, 2005). Oral hygiene practices, consumption of sugary foods, snacking, access to fluoride varnish service, mother’s education, and socioeconomic position are significant risk factors for developing caries in Thai children (Wongkongkathep,

2012; Boonyawong *et al.*, 2022). Thailand’s Ministry of Public Health (MOPH) implements oral health preventive programs for specific age groups. Applications of supervised toothbrushing (STB) and fluoride varnish (FV) are planned for the primary dentition from the ages of 0 to 5 years old (Bureau of Dental Health, 2021). Alternative policies or initiatives, on the other hand, had to be considered. The System Dynamics Model (SDM) can be used as a simulation model to assist decision-makers in program process planning by examining “what-if” analysis (Mielczarek, 2016).

Because the SDM can help with policy design, it was applied to the caries preventive interventions, STB and FV, suggested by the MOPH for children aged 0 to 5 years old. The SDM focuses on the dynamic study of phenomena (Mielczarek, 2016). The feedback loops (reinforcing and balancing loops) regulate the system’s dynamics, and the stocks and flows quantify the dynamic objects that move through the system, altering over time by collecting them (Mielczarek, 2016; Forrester, 1987). To estimate the results quantitatively, the SDM has to simulate the targeted treatments both individually and in combination.

Therefore, the goal of this study was to examine the effect of existing caries preventive interventions by the MOPH for children aged 0 to 5 years old (STB, FV, and combined STB+FV) to the base condition using the SDM.

## Method

The method was divided into two parts: (i) a systematic review and meta-analysis defined the effects of each intervention, which were (ii) subsequently input as parameters in the SDM.

Systematic reviews and meta-analyses of the effects of STB and FV on caries in 0–5-year-olds were performed by the researchers (Oo, 2023). The studies were searched from the databases; PubMed, Cochrane, Scopus and Web of Science and identified as included studies according to inclusion criteria based on PICO (Participants, Intervention, Comparison and Outcome). The PICO is shown in the appendix, Supplementary Table I (Available at <https://kb.psu.ac.th/psukb/handle/2016/18189>). Meta-analyses used the random-effects model in RevMan 5.3 software. The estimated effect size of the meta-analysis was risk ratio (RR) and the effective rates were retrieved by the formula  $([1-RR]*100\%)$ . All detailed processes were followed according to the systematic-review and meta-analysis guidelines of the Cochrane Handbook version 5.1.0.19 (Higgins, 2011). The protocols of the STB and FV were registered at PROSPERO: STB (CRD42022376887) and FV (CRD42023415218).

The SDM focused mainly on the primary dentition age. To determine the final SDM, Group Model Building (GMB) sessions, including experts and researchers, were conducted three times. The experts were dentists

with good experience in relevant fields. In the sessions, the participants consulted to identify the time horizon, the variables, and their behaviors, and developed causal loop (CLD) and stocks and flow diagrams for the model. The CLD showed the relationship between caries and related events and feedback loops among them, and was then converted to the stocks and flow diagram to quantify the outcomes (Figure 1). The square blocks in the diagram represent stocks, which are defined as states of the variables (Mielczarek, 2016; Forrestors, 1987). The flows determine the variation in the stocks and are denoted as in and out arrows (Mielczarek, 2016; Forrestors, 1987). The fractions influence the rates of flow, as the fraction of caries development affects the rate of developing caries. When interventions are set with the purpose of reducing the rate of developing caries by decreasing the fraction of caries development. The Vensim DSS version 6.4 software was used for the model run. The model includes a population of 678,243 Thais born in 2021, obtained from Thailand's National Statistical Office. The model began at birth and was simulated until the age of five. The simulated outcome results are shown at three and five years old since the interventions' coverage and effectiveness rates differ between the ages of 0–3 and 3–5 years.

The effective rates of the interventions used in the model were appraised from systematic reviews and meta-analyses (Oo, 2023). The other parameters required in the

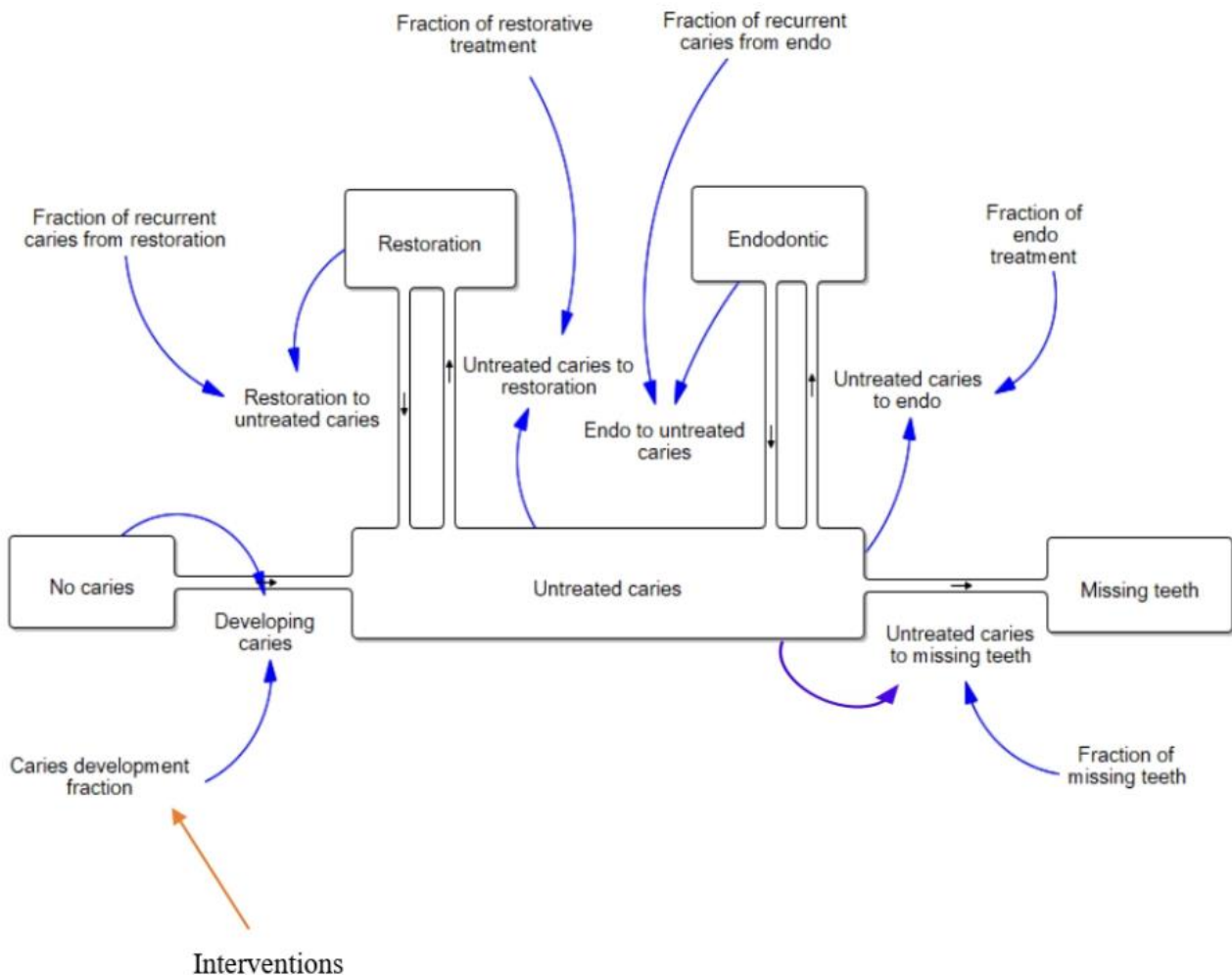


Figure 1. Stocks and flows diagram.

model were obtained from published literature, Thailand's 8<sup>th</sup> National Oral Health Survey (NOHS), the National Statistical Office of Thailand and Thailand's Health Data Center (HDC) which is a national database consisting of the 50 standard files of MOPH medical and health information and the dental file is one of the standard files collected for dental service (Srithong *et al.*, 2019).

The structural validity of the model was determined by evaluating the suitability of the model boundaries, the model's structures and parameters, and the dimensional consistency of the model's equations with 30 participants in three GMB sessions (Qudrat-Ullah *et al.*, 2010). Participants included Thai dental public health specialists from the Bureau of Dental Public Health, Provincial Health Authorities (PHA), Faculty of Dentistry, central hospitals, and community hospitals, as well as the PHA association and SDM experts. For the model's boundary adequacy, dental caries and related concerns and interventions were examined to ensure that they were congruent with the study's conceptual framework and purpose. As part of structure verification, the progression of dental caries states or variables in the model was reviewed to see if they were related to the natural history of the illness. The model's parameters were checked to see if they were relevant to the information in the existing system. The dimensional consistency of the model's equations was examined to determine whether each equation matched dimensionally to the natural system. The experts agreed that the model's structure accurately reflected the current reality.

We evaluated the model's behavior using the behavior replication test (Shreckengost, 1985). It was examined to ascertain the simulated behavior of the variables (dental with caries-related events), which was compared to historical reference data in which the interventions were applied. According to the simulation results, there are comparable numbers of Thai children who do not have caries.

A base case scenario, assuming that no intervention was provided was used as a reference to compare the intervention scenarios and all parameters were unchanged throughout the model's run.

The interventions: supervised toothbrushing (STB), fluoride varnish (FV) and combination of STB+FV were examined as intervention scenarios. The effective rates of the interventions in Thailand were adjusted and entered into the model. The intervention coverage rate (STB, FV, and combined STB+FV) refers to the proportion of the Thai population that received the interventions.

STB is proposed to provide for children 0–5 years old by the Ministry of Public Health, Thailand, according to dental public health implementation guidelines (Bureau of Dental Health, 2021). It is planned to start from birth until 5 years old to prevent dental caries by supervising the correct toothbrushing method twice a day with fluoride toothpaste and appropriately designed toothbrush (Bureau of Dental Health, 2021). Parents, caregivers or teachers are trained in the brushing method by dental health personnel and advised to supervise their child's oral cleaning (Bureau of Dental Health, 2021). The coverage of the STB at 0–3 years old was 60% and at 3–5 years old was 78% (Health Data Center (HDC), 2022; Chomphon: Provincial Health Office, 2022).

The estimated effect sizes in the meta-analyses (19% for 0–3 years and 15% for 3–5 years old) were adjusted with coverage rates and put into the model, 11.4 % for 0–3 years old and 12.0 % for 3–5 years old (Oo, 2023). Details of retrieving the effective rates are shown in Supplementary Table II (Available at <https://kb.psu.ac.th/psukb/handle/2016/18189>).

The Ministry of Public Health, Thailand, planned to implement FV for children 0–5 years old (Bureau of Dental Health, 2021). It is intended that dental professionals apply fluoride to all surfaces of primary teeth biannually to reduce caries progression. The coverage of FV was 50% at 0–3 years old and 60% at 3–5 years old (Health Data Center (HDC), 2022). The effective rates were 17% and 8% for 0–3 and 3–5 years old, respectively (Oo, 2023). After adjusting the coverage rates, effective rates were only 8.5% in children 0–3 years old and 4.8% in children 3–5 years old (Oo, 2023). These values were set in the model to slow caries development. (Details of retrieving the effective rates are available at <https://kb.psu.ac.th/psukb/handle/2016/18189>).

The combined STB and FV intervention aimed to diminish caries' development and also starts from birth until 5 years old. The coverage of the combined intervention was 42.7% (Ungchusak *et al.*, 2009). Subgroup analysis for the combined STB+FV was explored in the meta-analysis of FV (Oo, 2023). The effective rate was 34% in children 0–3 years old. Depending on the coverage rate, the effective rate of the combined intervention was regarded as 15% for both 0–3 and 3–5 years old (Oo, 2023). It was established in the model to reduce the rate of caries development (Available at <https://kb.psu.ac.th/psukb/handle/2016/18189>).

Multivariate sensitivity analysis with a random uniform distribution was conducted in Vensim DSS version 6.4 software to investigate how varying the model parameters could affect the outcome (Figure 1). The initial values of parameters for the stocks and fractions that control the rate of flows were input. The parameter values of the fractions varied by  $\pm 10\%$ . This value was used as the criterion, which came from these two sources. The caries development fraction varied depending on the  $\pm 10\%$  confidence interval (CI) of the estimated effect size in the meta-analysis (Oo, 2023). And the 10% change in coverage compared between with and without the national policy of comprehensive care among children (Bureau of Dental Health, 2013). The mean values with a 95% confidence interval of the population with untreated caries at five years of age under the base case and interventions are presented in Table 1.

The stocks from the model representing no caries, caries, treated cases due to caries (restoration and endodontic treatment), and missing teeth due to caries were considered the study outcomes.

The Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University, EC6503-011, reviewed and approved this study on March 7, 2022.

## Results

At the age of 3 years, the population with no caries in the combined STB+FV intervention scenario is higher than in the other scenarios and the base case (Table 2).

**Table 1.** Sensitivity analysis of the population with untreated caries in the primary dentition at 5 years of age.

Scenarios	Population with untreated caries		
	Mean	Lower bound (95% CI)	Upper bound (95%CI)
Base-case	291,148	268,783	308,481
STB	265,571	244,773	281,879
FV	273,334	251,401	290,523
STB+FV	260,816	239,778	277,387

As the percentage changed from base-case, it increased by 7.5% in STB+FV, 5.7% in STB, and 4.2% in FV. The population with untreated caries is the highest in the base case scenario, 32.81%, compared to other intervention scenarios of 30.40% in FV, 29.59% in STB, and 28.55% in combined STB+FV. It changed from base case to decrease by 12.9% in STB+FV, 9.8% in STB, and 7.3% in FV. The restoration population decreased by 14.3%, 10.9%, and 8.2%, while the population with endodontics decreased by 14.4%, 10.9%, and 8.3% in STB+FV, STB, and FV, compared to base-case. The population with missing teeth also decreased by 14.4% in STB+FV, 10.9% in STB, and 8.2% in FV from base-case.

At the age of 5 years, the combined STB+FV still yields the highest population with no caries, 53.07%, followed by 51.70% in STB, 49.84% in FV, and 47.04% in the base case (Table 2). Compared to the base case, the no caries population increased by 12.8%, 9.9%, and 5.9% in STB+FV, STB, and FV, respectively. The population with untreated caries is still higher in the base case scenario than in other intervention scenarios: 42.88% vs. 40.79% in FV, 39.23% in STB, and 38.17% in the combined STB+FV.

It decreased by 10.9% in STB+FV, 8.5% in STB, and 4.9% in FV compared to the base case. The population with restoration and missing teeth decreased by 13.1%, 9.9%, and 7.1%, while the population with endodontics decreased by 13.1%, 10.0%, and 7.1% in STB+FV, STB and FV, respectively, compared to the base case.

Figure 2 shows that the population with no caries falls slowly as the population ages. Compared to the base case scenario, it remains highest under the combined STB+FV, followed by the STB and FV throughout the years.

## Discussion

In this SDM simulation, the combined supervised toothbrushing and fluoride varnish intervention is more effective in preventing caries than each provided separately. All interventions increased the proportion with no caries among 5-year-old children compared to the change in practice-based national programs between the 7th and 8th National Oral Health Surveys (Bureau of Dental Health, 2018). When comparing these surveys, the caries-free population at 5 years old shows a 3% difference between them. Whereas the results from this study found 5.9%, 9.9% and 12.8% in FV, STB and STB+FV, respectively.

The effective rates of STB were not high (11.4% at 0–3 years and 12.0% at 3–5 years), although the coverage rates were high. A better approach to STB should be considered. Twice daily STB with fluoride toothpaste for preschool children has been found effective in caries prevention (Andruškevičienė *et al.*, 2008). STB was carried out by kindergarten personnel in the morning and by parents in the evening at home, both of whom received an oral hygiene demonstration to help them supervise the children. Following this study, proper STB with fluoride

**Table 2.** Simulation results of primary dentition at the age of 3 and 5 years among 678,243 Thai population born in 2021.

States	Scenarios at 3 years of age				Scenarios at 5 years of age			
	Base-case n (%)	STB n (%)	FV n (%)	Combined STB+FV n (%)	Base-case n (%)	STB n (%)	FV n (%)	Combined STB+FV n (%)
No caries	431,400 (63.60)	455,929 (67.22)	449,712 (66.31)	463,781 (68.38)	319,064 (47.04)	350,669 (51.70)	338,044 (49.84)	359,969 (53.07)
% change from base-case	-	+5.7	+4.2	+7.5	-	+9.9	+5.9	+12.8
Untreated caries	222,546 (32.81)	200,669 (29.59)	206,220 (30.40)	193,653 (28.55)	290,829 (42.88)	266,049 (39.23)	276,703 (40.79)	258,876 (38.17)
% change from base-case	-	-9.8	-7.3	-12.9	-	-8.5	-4.9	-10.9
Restoration	10,373 (1.53)	9,241 (1.36)	9,526 (1.40)	8,884 (1.31)	28,726 (4.24)	25,862 (3.81)	26,692 (3.94)	24,970 (3.68)
% change from base-case	-	-10.9	-8.2	-14.3	-	-9.9	-7.1	-13.1
Endodontic	787 (0.12)	701 (0.10)	722 (0.11)	674 (0.10)	2,229 (0.33)	2,006 (0.30)	2,070 (0.31)	1,936 (0.29)
% change from base-case	-	-10.9	-8.3	-14.4	-	-10.0	-7.1	-13.1
Missing teeth	13,137 (1.94)	11,703 (1.73)	12,063 (1.78)	11,251 (1.66)	37,395 (5.51)	33,657 (4.96)	34,734 (5.12)	32,492 (4.79)
% change from base-case	-	-10.9	-8.2	-14.4	-	-9.9	-7.1	-13.1

## No caries

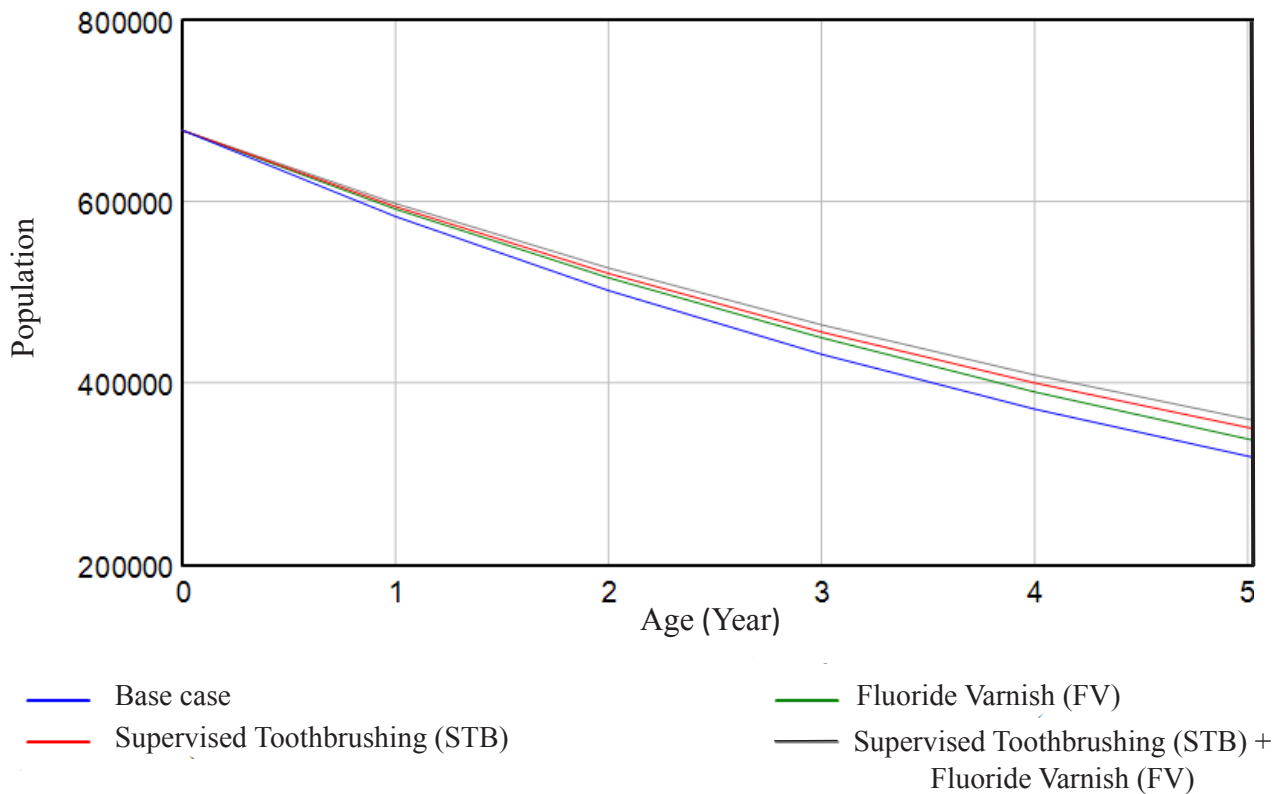


Figure 2. Population with no caries.

toothpaste by well-trained personnel may enhance STB for preschoolers.

Although the coverage rate of FV was satisfactory, the effective rates adjusted for coverage were only 8.5% in 0–3 and 4.8% in 3–5-year-olds. A more effective FV intervention should be emphasized. Weintraub *et al.* (2006) found that FV applied twice yearly and added parental counselling reduced caries incidence. On the day of the FV application, parents or caregivers were asked to refrain from brushing their children’s teeth with a fluoride dentifrice to minimize total fluoride exposure, and 5% FV was applied with 0.1 mL (1 drop) per arch by a dentist. Although FV application is suggested in clinical settings for all children under 6 years of age, numerous guidelines differ on periodicity and whether or not to consider caries risk (Goff *et al.*, 2022).

Whilst the effective rate of combined STB and FV was better than that for each intervention separately, the coverage rate was lower. After adjusting the coverage rate, the effective rate of the combined STB+FV still only 15%. Attention should therefore be given to increasing the coverage rate, whilst considering the available resources. In Thailand, the unit cost of fluoride varnish is 180 baht, or 5.18 USD (Riewpaiboon, 2011) and 109 baht, or 3.14 USD, for oral hygiene instruction with an oral health examination (Tianviwat *et al.*, 2009). Additional resources would be required to apply fluoride varnish more than establish supervised toothbrushing. Shifting or adding resources has to be considered based on the available resources.

The SDM method followed the recommended approach (Forrestors, 1987) using qualitative (causal loop diagram) and quantitative approaches (stocks and

flows diagram). Three GMB sessions were to finalize and validate the model. The researchers performed the behavior-based validation by simulating the behavior of the variables and determining whether they were familiar with the historical reference data. Scenario analysis estimated the outcome under different scenarios and sensitivity analysis explored how changing the model parameters could affect the outcome.

The present study is consistent with previous SDM studies of interventions to reduce ECC, informing us that combining the interventions could be a valuable in caries reduction (Hirsch *et al.*, 2012; Edelstein *et al.*, 2015). However, the previous studies focused on numerous preventive interventions such as water fluoridation, fluoride varnish, fluoride toothpaste, educational programs, screening, bacterial transmission reduction, motivational interviewing, and secondary prevention. Several of these interventions have not yet been recommended in Thailand. Those studies used multiple national databases for the model. In this study, most of the model was populated with national and provincial data, but some parameters (such as the fractions of recurrent caries from restoration and endodontic treatment) had to be retrieved from the relevant literature as no national data were available. Another limitation is that we could not model every caries risk factor as this would be too complicated. It was assumed that the rate of caries development was reduced by preventing the risk factors affected by the intended interventions in the study. However, strengths of our study include effective rates derived from meta-analysis, and we were able to include coverage rates of the interventions.

This study supports the use of SDM in evaluating dental care strategies by analyzing and comparing scenarios. It could act as a long-term assessment tool for projecting programs, including SMART (Simplified and Modified Atraumatic Restorative Treatment) or SDF (Silver Diamine Fluoride) for carious teeth. Moreover, since the costs of treated cases and interventions were not considered here, the cost-effectiveness or cost savings of the interventions should be appraised using SDM in a further study.

In conclusion, SDM established that all interventions implemented for children 0–5 years old by the MOPH prevent caries. The combined STB+FV was more effective than the interventions administered separately. A more effective combined intervention could further reduce caries in the primary dentition. SDM can be used to analyze and combine interventions to identify optimal policies.

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