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Authors	Hu, Shijia;Hong, Catherine Hsu Ling;Gao, Xiaoli;Wee, Hwee-Lin;Wang, Yi;Lai, Bien Wen Pui;Ho, Shenna Yu-En;Allen, Patrick Finbarr;Tan, Sharon Hui Xuan
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Managing root caries with silver diamine fluoride, sodium fluoride and direct restorations: A cost-effectiveness analysis

Shijia Hu[1], Catherine Hsu Ling Hong[1], Xiaoli Gao[1,2], Hwee-Lin Wee[2], Yi Wang[2], Bien Wen Pui Lai[3], Shenna Yu-En Ho[3], Patrick Finbarr Allen[1,4], Sharon Hui Xuan Tan[1,2]

[1] Faculty of Dentistry, National University of Singapore, Singapore

[2] Saw Swee Hock School of Public Health, National University of Singapore, Singapore

[3] National Dental Centre Singapore, Singapore

[4] Restorative Dentistry, University College Cork, Ireland

Corresponding Author	Hu Shijia, BDS, PhD Associate Professor Discipline of Orthodontics and Paediatric Dentistry Faculty of Dentistry, National University of Singapore 9 Lower Kent Ridge Road, Singapore 119085, Singapore Tel: +65 6772 7757 Email: denhus@nus.edu.sg

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ABSTRACT

Objective: To assess the cost-effectiveness of silver diamine fluoride (SDF) relative to sodium fluoride (NaF) and traditional resin-modified glass ionomer cements (RMGIC) restorations for the management of root caries in older adults aged 60 and above.

Methods: A Markov model design was chosen and two models were constructed: 1) Clinic-based model - with access to dental facility that allows for placement of traditional restorations, 2) Community-based model - without access to dental facility due to mobility, lack of executive function, or financial barriers. Modelling was done over a 10-year time horizon with a cycle length of one year. Data on transition probabilities and relative risks were obtained from published literature for the base case. Outcomes of interest were incremental cost per incremental caries-controlled year and incremental cost per incremental extraction-free year. Probabilistic sensitivity analyses were conducted to account for uncertainty in the base case.

Results: In the clinic-based model, both SDF and NaF were dominated by traditional RMGIC restorations, which had lower cost, and higher number of caries-controlled and extraction-free years, with a 90% probability of being cost-effective. In the community-based model, NaF was dominated by SDF, which incurred lower cost and resulted in a higher number of caries-controlled and extraction-free years, with almost 100% probability of being cost-effective.

Conclusions: Traditional RMGIC restoration was the most cost-effective option for managing root caries when full dental facility is available. In situations where treatment is provided in a community setting, SDF was more cost-effective than NaF.

CLINICAL SIGNIFICANCE

Based on limited clinical studies and within the Singapore oral health system, traditional RMGIC restoration was most cost-effective in clinical settings for managing root caries, while SDF was most cost-effective in community settings.

INTRODUCTION

By 2030, one in six people globally will be aged 60 and above and this is expected to double by 2050[1] [1]. Root caries is prevalent among older adults (≥ 60 years of age) affecting nearly half of these individuals [2], with an 18% increment every year [3]. Singapore is one of the most rapidly aging societies in the world, where one in four citizens will be aged 65 and above by 2030 [4]. A recent local study reported a mean number of decayed and filled root surface of 3, with 30% scoring greater than 3 in older adults aged 60 and above [5].

Restoration of root caries affected teeth is challenging, due to difficulty of access and moisture control. With regard to success of different restorative materials for root caries, resin-modified glass ionomer cements (RMGIC) and etch-and-rinse composite resins tend to demonstrate higher success rates [6]. While most studies report strong short-term success, moderate-term outcomes are less favourable, with failure rates of approximately 20% within two years [7]. This contrasts sharply with the average annual failure rate of 4.2% for coronal restorations [8]. Other than the difficulties faced with restoring root caries, frail and functionally-dependent elderly may face additional barriers in accessing dental care such as the inability to provide consent or cooperate for traditional dental restorations because of declining physical and executive functions [9]. Furthermore, mobility difficulties in some patients necessitate the need for specialised medical transportation to access care in a dental clinic and when unavailable, require care to be delivered *in situ* without access to dental facility [10]. The challenges associated with root caries management in this vulnerable population highlight the importance of preventive and minimally invasive measures, fuelling the search for alternative root caries management options.

Several agents have been suggested for the primary prevention of root caries, including chlorhexidine varnish, sodium fluoride varnish (NaF), silver diamine fluoride (SDF), high fluoride dentifrices, and triclosan [11]. Of these, 38% SDF was found to be the most effective in preventing root caries [12]. A cost-effectiveness analysis (CEA) found that while SDF was costlier in low-risk populations, it was more effective than no treatment [13]. In high-risk populations, SDF was the

most effective and most cost-effective option when compared to no treatment, NaF, and chlorhexidine varnish [13]. Another CEA found that while NaF was costlier, it was more effective than no treatment [14]. Several recent systematic reviews have recommended the use of 38% SDF as an alternative management option to traditional restorations for the arrest of root caries in older adults [15-17]. However, this recommendation is based on only two clinical studies [18, 19], with no information on cost-effectiveness of SDF. Currently, there are limited CEAs to assess whether traditional restorative and non-restorative options are cost-effective for arresting root caries in both clinical settings with full dental facilities and community settings without access to restorative treatment options. As such, the strength of clinical recommendations for the management of root caries remain uncertain.

This study sought to assess the cost-effectiveness of SDF relative to NaF and traditional RMGIC restorations for the management of root caries in older adults in care settings with and without access to restorative treatment options.

MATERIALS AND METHODS

Target population and setting

The study adopted a healthcare system perspective, in line with recommendations from the Agency for Care Effectiveness in Singapore [20]. Dental care services are primarily financed through a fee-for-service model including out-of-pocket payments, government subsidies, and insurance coverage. The target population was older adults aged 60 and above; grouped into those with access to dental facility and those without access to dental facility due to mobility, lack of executive function, or financial barriers. Data on transition probabilities and relative risks were obtained from systematic reviews and published literature (Table 1). Ethics approval was granted by the National Healthcare Group Domain Specific Review Board (Singapore) (study reference 2021/00986). The study was reported according to the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) guidelines.

Markov model design

A Markov model design was chosen to reflect discrete time state transitions. SDF was applied annually [19] and NaF was applied four times a year [21], in accordance with previous studies. Two models for the management of root caries were adopted.

Clinic-based model: with access to dental facility that allows for placement of traditional restorations (Figure 1):

(1) Annual application of 38% SDF on teeth with root caries only

(2) Four times a year application of 5% NaF on teeth with root caries only

(3) Traditional RMGIC restoration of teeth with root caries

Community-based model: without access to dental facility that does not allow for placement of traditional restorations (Figure 2):

(1) Annual application of 38% SDF on teeth with root caries only

(2) Four times a year application of 5% NaF on teeth with root caries only

Modelling was conducted over a 10-year time horizon at the tooth level for a single older adult starting from the age of 60, with an average of 19 remaining teeth [22]. The time horizon was selected in line with other studies for comparability [13, 14]. The initial untreated root caries prevalence (defined by cavitated lesions using the World Health Organization criteria) was set at 38.0% [23]. The cycle length was set at one year to account for annual failure rates available in literature [13]. After a literature search based on the study parameters, published literature on the effectiveness of the various treatment options (i.e., SDF, NaF, RMGIC) was used for the base case (Table 1). Following treatment, the teeth would either become root caries controlled or develop treatment failure (due to failure to arrest primary caries, restoration failure or recurrent caries). In the clinic-based model, SDF and NaF were applied only on teeth with active root caries for the initial treatment, and as maintenance for teeth that did not fail after the initial treatment in these arms. After the first round of SDF and NaF application, teeth with treatment failure were either restored with a traditional RMGIC restoration or extracted. In the community-based model, teeth with

treatment failure were either retreated with the same fluoride treatment (i.e., SDF or NaF) or extracted.

Health outcome of interest

SDF, NaF and traditional RMGIC restorations were compared using incremental cost effectiveness ratios (ICERS). The key outcomes of interest were the incremental cost per incremental caries-controlled year, and the incremental cost per incremental extraction-free year.

Costs and currency

In this study, cost was framed as financial cost based on institutional charges in line with the healthcare system perspective. Data on charges were obtained from two national oral healthcare centres (National Dental Centre Singapore (NDCS), National University Centre for Oral Health (NUCOHS)) in Singapore. Out-of-pocket charges for a review visit, SDF application, NaF application and single surface traditional RMGIC restoration were obtained in a single year for the base year of 2019 (Table 1). All treatment was assumed to have been performed chairside. For the base case scenario, CEA was carried out using cost data from NDCS. Costs were estimated in Singapore dollars (S$1.00 = USD$0.74). Across all treatment arms and for both models, a dental review was conducted at least once annually if the patient still had teeth that were not lost to extraction. Only one standard review visit was costed for each patient annually, with no review cost charged for additional treatment visits. Discounting was conducted for both costs and effectiveness at 3%. Half cycle correction was applied for both costs and effectiveness.

Sensitivity analyses

To account for uncertainty in the base case scenario, probabilistic sensitivity analyses were carried out by varying the effectiveness parameters based on published data, and setting the upper and lower bounds as 95% confidence intervals where available, or the 99% confidence intervals if only ranges were available. Cost parameters were varied based on data from NUCOHS. Beta distributions were set for transition probabilities, and gamma distributions were set for costs. Monte Carlo microsimulations were carried out with 1,000 samples drawn from the probabilistic

distributions. Cost-effectiveness acceptability curves were plotted to depict the probability of each intervention being cost-effective at various willingness to pay (WTP) thresholds.

Value of information analyses

Given the limited information in the literature, a value of information analysis was conducted to determine the value of further assessments/research on the input variables. Value of information analysis was carried out for the models to quantify the uncertainty over the estimates. Expected value of perfect information (EVPI) captures the impact of incorrect decisions arising as a result of uncertainty [24, 25], and the cost that decision makers are willing to pay to eliminate the uncertainty. The WTP threshold for each incremental caries-free year was set at S$0, in line with prior studies [13]. Net monetary benefit (NMB) was tabulated as the net difference after subtracting the incremental cost from the incremental effectiveness multiplied by the WTP threshold. The EVPI was tabulated by calculating the difference in the average of the highest NMB if perfect information was available for each simulation, and the highest mean NMB of the treatment with the highest overall NMB when averaged across all simulations. Population EVPI was tabulated by multiplying the NMB by the total population of older adults aged 60 and above in Singapore, discounted over 10 years.

To determine the cost of uncertainty of individual parameters, expected value of partially perfect information (EVPPI) analysis was carried out using a nested Monte Carlo simulation with 1000 inner and 500 outer simulations [26]. EVPPI enables the evaluation and assessment of the factors that have a greatest impact on the outcome, and the value of collecting additional information for individual parameters. EVPPI analysis was carried out for the cost and effectiveness (caries-free years) of SDF, NaF and traditional RMGIC arms.

Data analyses were carried out in Microsoft Excel and TreeAge Pro 2024 (TreeAge Software, Williamstown, MA, USA).

RESULTS

Clinic-based model

The total cost for SDF, NaF and traditional RMGIC restoration were S$2886, S$3782 and S$2474 per older adult respectively. The total number of caries-controlled years for SDF, NaF and traditional RMGIC restoration were 119, 106, and 120 respectively, and the total number of extraction-free years were 137, 132, and 138. Both SDF and NaF were dominated by traditional RMGIC restorations which had lower cost, and higher number of caries-controlled and extraction-free years compared to SDF and NaF (Table 2).

Community-based model

In the base case, SDF and NaF incurred a total cost of S$682 and S$1075 per patient respectively. The total number of caries-controlled years for SDF and NaF were 117 and 62 respectively and the total number of extraction-free years were 136 and 122. NaF was dominated by SDF which incurred lower cost and resulted in a higher number of caries-controlled and extraction-free years (Table 2).

Sensitivity analysis

In the clinic-based model, traditional RMGIC restorations had above 90% probability of being cost-effective for caries-controlled years at a WTP threshold of S$0, which declined with higher WTP thresholds. The probability of SDF being cost-effective ranged from 7 – 29% at WTP thresholds within S$200 (Supplementary Figure S1). For extraction-free years across all WTP thresholds, the probability of traditional RMGIC restoration being cost-effective was similarly over 90% and decreased with higher WTP thresholds (Supplementary Figure S2). In the community-based model, the probability of SDF being cost-effective over NaF was above 65% and increased to almost 100% with increasing WTP (Supplementary Figures S3 and S4).

In the deterministic sensitivity analysis, baseline prevalence of root caries had the greatest impact on ICER values in the clinic-based model (Figure 3). Higher caries arrest rates for SDF led to traditional restorations being dominated by SDF. The SDF option dominated NaF in all scenarios for the clinic-based and community-based models (Supplementary Table S1).

Results from the microsimulations for the clinic-based model were distributed in all four quadrants in the scatterplot, depicting uncertainty in the estimates (Supplementary Figures S5 and S6). For the community-based model, the NaF option was less effective but there was greater uncertainty if it was more or less expensive than SDF (Supplementary Figures S7 and S8).

Value of information analysis

At a WTP threshold of S$0, the EVPI was 7149460 for the clinic-based model and 24235288 for the community-based model for caries control. The EVPI increased with increasing WTP for the clinic-based model, in line with increasing uncertainty; while the EVPI decreased sharply with increasing WTP for the community-based model (Supplementary Figures S9, S10). EVPPI was S$1158635 for the effectiveness of SDF in arresting root caries.

DISCUSSION

Despite the recommendations from recent systematic reviews that 38% SDF be used for the management of root caries [15-17], this study demonstrated that traditional restorations with RMGIC was more effective and cost-effective compared to SDF in settings with full access to dental facility (clinic-based). When dental facility is available and the patient can cooperate with dental treatment, RMGIC restoration is still likely the preferred choice for root caries management. However, when management with a traditional restoration was not feasible, SDF proved to be more cost-effective than NaF at managing cavitated root caries. While the financial cost based on institutional charges used in the study does not fully reflect economic cost, the findings are still relevant [27]. However, in places where SDF can be applied by a professional whose salary cost is less than a dentist, the CEA may need to be reassessed as the economic cost of the SDF intervention would be less.

A disadvantage of SDF application is the unaesthetic staining of the tooth [28]. However, a recent study found that more than 70% of community dwelling and care-dependant older adults over 65 years were accepting of SDF treatment. This acceptance rate increased to over 80% if SDF treatment was used for the avoidance of pain and infection and reduce the need for treatment

under general anaesthesia [29]. A major advantage of SDF is the ease of its application in a community setting without the need for specialised dental facility, such as in a nursing home [28]. Moreover, SDF application procedure is relatively simple compared to placement of a traditional restoration and non-dental healthcare professionals (e.g., nurses in a nursing home) can be trained to deliver this treatment *in situ*, particularly beneficial for non-ambulant care-dependent older adults. By reducing the number of treatment appointments required at external dental facilities, this alleviates the burden on caregivers to take time off work or the need to arrange for specialised medical transport [10]. As the current study adopted a healthcare system perspective and did not consider non-medical costs, studies that adopt a broader societal perspective may result in a different conclusion about the cost-effectiveness of SDF on managing root caries.

NaF was dominated by SDF and traditional restorations in both community-based and clinic-based settings. While other studies have reported higher rates of root caries arrest for NaF [15], this was generally limited to non-cavitated lesions, rather than the cavitated lesions examined in the current study. Sleibi et al reported 74.0% of cavitated lesions in patients with dry mouth reversed from leathery to hard texture with NaF applied every three months over a year [30]. However, the study utilized a study-specific severity index that differed from standardized measures such as ICDAS [15], limiting the comparability to other studies and thus not used as the base case parameter. Nonetheless, even when the NaF arrest rate was set at this upper limit of 74.0% in the sensitivity analysis [30], SDF was still found to likely be more cost-effective.

A weakness of this study's model is the lack of information on relative effectiveness between the three treatment modalities which limited the generalisability of the parameters used in the base case. The value of information analysis demonstrated that collecting additional information on the effectiveness of SDF on root caries had the greatest impact on reducing uncertainty in the model outcomes. There are only three clinical trials on SDF effectiveness for root caries and all compared SDF to placebos [18, 19, 31]. Ericson's study measured effectiveness using a study-specific composite outcome of change in root caries score which incorporated new caries development and caries

arrest [31]. This meant that its results were not included in prior meta-analyses. Zhang's study assessed mean arrested caries surfaces at 24 months rather than the proportion of carious root surfaces arrested, thus it was unclear whether the assessed surfaces received SDF treatment and whether the arrest was solely attributed to SDF application [18]. While NaF has been evaluated in the literature for the prevention of root caries, there is limited information on its effect on the arrest of cavitated root caries [15]. Most literature on traditional restorations have been on comparisons between different materials and placement techniques [6]. None of the published studies had common comparators with the other two treatment modalities. Thus, the use of a network meta-analysis to elicit relative effectiveness between the three management modalities was not possible due to the limitation in the present literature. This study had to reference individual studies to model the effectiveness of NaF [21] and SDF [19]. While the study modelled the application of NaF four times a year, others have proposed the application of NaF biannually or annually [15]. However, data is lacking on the effectiveness of NaF applied less frequently at arresting root caries. Therefore, well-conducted clinical trials comparing SDF to NaF and traditional restorations are needed to further refine the parameters used in future CEAs. Nonetheless, the study sought to account for this limitation by determining the value of information that could be derived from studies assessing the relative effectiveness of treatments in arresting root caries. As the first CEA study on the SDF management of root caries, the study's findings offer insights for the development of clinical guidelines and public health policies to optimise resource allocation and ensure the most appropriate cost-effective options.

This study had several assumptions and limitations. Extractions were assumed to be only due to root caries and no other factors. Given that the Markov models are memory-less [32], the study assumed that the rates of restorative failure and extraction did not change with time of placement of restoration. In addition, the model was simplified and did not model the option of root canal treatment and fixed-prosthesis as an alternative to extractions. Future studies involving more complex discrete event simulations [33], accounting for patient tooth history, can be carried out.

Another limitation was assuming a constant 10 year incidence of recurrent root caries and caries control rates regardless of tooth type [34]. To mitigate this and enhance the robustness of the model, a sensitivity analysis was performed by varying the annual failure rate and number of teeth with treatment failure which yielded similar results to the base case across most scenarios. A strength of using the Markov model is the ability to capture changes in disease states over time, allowing for the long-term evaluation of cost-effectiveness, and accounts for costs and outcomes over time [35].

In conclusion, based on limited clinical studies and within the Singapore oral health system, traditional RMGIC restoration was the most cost-effective option for root caries when full dental facility is available. In situations where treatment is provided in a community setting, or when patients are unable to cooperate for traditional restorations, SDF was more cost-effective than NaF at managing root caries.

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TABLES

Table 1: Model parameters

Parameter	Value	Range	Source[†]
Baseline number of remaining teeth	19	Used 0.5x and 1.5x as lower and upper bound	Fun S 2012
Initial prevalence of untreated root caries	0.38	0.16 – 0.663	Sim C et al, 2024
Annual probability of extraction of teeth with carious root	0.088	0.055 – 0.121	Zhu LW et al, 2024
Annual probability of arrest of root caries with SDF	0.61	Used 0.5x and 1.5x as lower and upper bound	Li R et al, 2016
Annual probability of arrest of root caries with NaF	0.11	[not available] Used 0.5x as lower bound. Upper bound, 0.74	Schaeken JM et al, 1991 Sleibi A et al, 2021
Annual probability of arrest of root caries with RMGIC	0.875	0.773 – 0.977	Wen Y et al, 2024
Annual probability of new root caries (without intervention)	0.1825	0.1322 – 0.2328	Hariyani N et al, 2018
Annual prevented fraction of new root caries with SDF	0.6835	0.542 – 0.8251	Oliveira BH et al, 2018[‡]
Prevented fraction of new root caries with NaF (on teeth with NaF applied)	0.2886	Used 0.5x and 1.5x as upper and lower bound	Chan AKY et al, 2022[‡]
Cost of review (in S$, S$1.00 = USD$0.74)	55	25 - 35	NDCS, NUCOHS (for range)
Cost of RMGIC (in S$, S$1.00 = USD$0.74)	120	60 - 250	NDCS, NUCOHS (for range)
Cost of extraction (in S$, S$1.00 = USD$0.74)	100	40 - 200	NDCS, NUCOHS (for range)
Cost of annual NaF application (4x/year per carious tooth) (in S$, S$1.00 = USD$0.74)	6.4	Upper bound: 52	NDCS, NUCOHS (for range)
Cost of annual SDF application (once/year per carious tooth) (in S$, S$1.00 = USD$0.74)	4.8	Upper bound: 6	NDCS, NUCOHS (for range)

[†]From the literature:

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NUCOHS: National University Centre for Oral Health
NDCS: National Dental Centre
‡ Converted 3 year probability to annual rate

Table 2: League table for the base case scenario						
Intervention	Total cost (in S$, S$1.00 = USD$0.74)	Caries controlled-year	Extraction-free years	Incremental caries controlled-years	Incremental extraction-years avoided	Strategy
Clinic-based setting						
Traditional RMGIC restorations	2474	120	138	[ref]	[ref]	
SDF	2886	119	137	-1	-1	Dominated
NaF	3782	106	132	-14	-6	Dominated
Community-based setting						
SDF	682	117	136	[ref]	[ref]	
NaF	1075	62	122	-55	-14	Dominated

FIGURE LEGEND

Figure 1: Clinical-based Markov model for the management of root caries

Figure 2: Community-based Markov model for the management of root caries

Figure 3: Tornado diagram for deterministic sensitivity analysis and impact of various factors on ICER values in the clinic-based model